

Review

Reflexes and Shared Intentionality in the Origins of Emotions Development: A Scoping Review of Studies on Blinking in Infants

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Abstract

This review aims to explore research on the development of emotions in organisms at the simple reflexes substage of the sensorimotor stage of cognitive development. We review the literature on alterations in spontaneous blinking in children under 6 months of age. Then, we extract the data from the selected studies that allow us to examine whether simple reflexes in infants reveal the emotion signature in the altered reflective responses. The significance of this study is that it is the first review to demonstrate that the affective cues cause altered blinking rates at birth. This study hypothesizes that emotion development begins with the association of affective cues with stimuli responsible for activating the neural pathways of simple reflexes—the mechanism of pre-perceptual multimodal integration. Our analysis posits that pre-perceptual multimodal integration can succeed because of shared intentionality in mother-child dyads. This emotion-reflex stimuli conjunction further develops these simple innate neuronal assemblies, shaping the emotional neuronal patterns in statistical learning that are continuously connected with the neuronal pathways of reflexes. The hypothesis of pre-perceptual multimodal integration converges the presumably opposing naturalist and constructivist viewpoints about emotional development.



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Keywords

Mother-fetus neurocognitive model; emotions; pre-perceptual multimodal integration; shared intentionality

1. Introduction

According to an accepted definition (APA, dictionary), an emotion is a complex reaction pattern involving experiential, behavioral, and physiological elements; this complex reaction pattern is associated with a specific network of coordinated neuronal activity. However, naturalism and constructivism, informed by the perspectives of Charles Darwin and William James, have had opposing viewpoints about the nature of emotions. Naturalists assert that "basic" emotions have evolutionarily based signals; "basic emotions" are innately specified [1-3]. Based on this account, emotions appear owing to the activity of specific innate neuronal networks. Considering the continuing physiological and cognitive development beginning in the prenatal period (see findings in Subsection 1.1), even neuronal patterns of basic emotions can evolve from simpler neuronal assemblies before birth.

Constructivists believe that social learning is dominant in the development of emotions [4, 5]. They account for emotion development through a bond between affective meanings and conceptual emotion categories while rejecting the idea of universal, essential emotion signals [5]. Constructivist theories are based on the concept of valence- and arousal-based categories (conceptual emotion categories), which are thought to gradually narrow down into discrete emotion concepts over the first decade of life [6, 7]. These categories can be explained based on the embodied cognition theory [8-11] and the mathematical apparatus of the dynamical systems theory [12]. The core idea of the embodied cognition theory [8-11] relies on embodied information in neuronal assemblies that launches dynamical system development [9, 12].

Therefore, the critical issue for both approaches is the mechanism to perceive the affective cues and attribute them to specific neuronal assemblies associated with evolutionary innate universal emotion signals (naturalism) or conceptual emotion categories (constructivism) in the initial stage of emotion development before birth. From the perspective of prenatal development, naturalism and constructivism seem to share similar grounds regarding the beginning of emotional development, both relying on a hypothesis of simple innate neuronal assemblies, prototypes of neuronal networks of basic emotions, or emotion concepts. We believe these two opposing viewpoints are based on similar neurophysiological mechanisms that, in the prenatal period, ensure the association of affective cues (beginning from the assimilation of positive/negative valence) with the temporally coordinated activity of specific neuron assemblies.

The remainder of this paper is organized as follows. Subsection 1.1 presents empirical data on the social achievements of organisms in the developmental stage when they only manifest automatic responses to stimuli. Subsection 1.2 summarizes the literature on simple reflexes to present what we know about the bond between reflexes, specific blinking, and emotions. In Subsection 1.3, we show the dichotomy between organisms' achievements and their abilities at the reflexes stage—the primary data entry problem. It also shows the contrary results of two opposing data collection methods for detecting children's intentions: descriptive vs. experimental. The

literature concludes that the intentionality of newborns appears even before it is possible for children's intention to occur. This subsection covers the literature on the potential solution to this problem due to shared intentionality, addressing what helps organisms overcome a noisy barrier to pass from the developmental stage with only automated responses to stimuli to the stage with the holistic mental representation of the environment due to the organization, identification, and interpretation of sensory information. Subsection 1.4 presents evidence from research on brain-heart interplay and shared intentionality. It also cites the literature about the etiology of shared intentionality, which emerges from collaborative mother-fetus neurocognitive processes. This literature shows the essential role of mother-fetus interactions in cognitive function development. Subsection 1.5 poses the research problem. The method used in the current study is described in Section 2. Section 3 presents the results of a literature review of studies on blinking in infants. In the Discussion section, we identify studies and discuss the data about the emotional components of blinking. We also posit the hypothesis of pre-perceptual multimodal integration of affective cues and reflexes stimuli due to shared intentionality.

1.1 When Do Emotions Appear?

What do we know about the beginning of the assimilation of affective or even other meanings? Following Darwin's works, we know that the stability and dissimilation of phenotypic traits in species from different phylogenetic trees and environments may mean this inherited characteristic is common to all animals. It is widely accepted in the study of emotions in animals that they experience negative and positive emotions (see [13-16] for further information).

Face-to-face interaction is one of the mechanisms through which individuals acquire social competence early in their development [17-20]. This sensory interaction allows infant primates, including humans, to learn key information regarding the foundations of early emotional communication [17-19]. Interactions in emotional exchanges enable infants' ecological learning. For instance, research on monkeys (*Macaca mulatta*) has shown that neonatal face-to-face interactions promote social interest and competency in infant rhesus monkeys [17, 18]. Therefore, emotions are associated with the beginning of emotional communication, which leads to cognitive development at the onset of life. It seems plausible that the assimilation of affective cues begins together or even before the assimilation of ecological information.

In humans, recent theoretical studies have shown the origin of the assimilation of meaningful cues by organisms, even when they only manifest automatic responses to stimuli in fetuses by the first trimester of pregnancy [21, 22]. Studies have reported that the intra-pair movements of twins have an even higher degree of accuracy than single fetuses [23, 24]. Further, research has revealed that fetuses show an ability for voice recognition [25-29]; can differentiate a change in the gender of a speaker reading a sentence [29]; can distinguish between sounds (e.g., speech sounds "babi" and "biba") [30]; and can learn frequently heard sounds (e.g., voices and music) and the flavors they experience in the womb [30]. Neuroscience research has revealed the underlying mediation of behavioral responses in response to language and voice stimuli [30]. 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 [30, 31]. At 34 weeks of pregnancy, the lower bank of the temporal lobe was significantly more active during exposure to a maternal voice than to an unfamiliar female voice [30, 31]. Indeed, cognitive development should begin in the womb, as infants show perception

ability in the first hours after birth, such as in reacting to another newborn's crying, early imitation, the other-race effect, recognizing faces by their parts, recognizing faces without their context in schematic pictures, making preferences based on facial attractiveness, distinguishing mother and stranger, and the other-species effect, among others (for more information, see [21, 22, 32, 33]). Empirical evidence has shown that organisms with automatic responses to stimuli demonstrate the ability to comprehend cues and assimilate meaning. These findings may imply the initiation of cognition through or together with emotional exchange, even at the developmental stage, when organisms can independently manifest only simple reflexes, and even before birth.

1.2 Reflexes Neuronal Assemblies Underlying Emotions

Can emotion signatures be observed at physiological and/or neuronal levels during the developmental stage when organisms manifest only simple reflexes? The reflexes provide automated responses to stimuli that are not received and require conscious thought. This is due to the simple neural pathways in the nervous system, namely, "reflex arcs." Blinks are brief, synchronized, conjugate movements consisting of rapid closure followed by the reopening of the upper and lower lids [34] and are distinguished as voluntary, spontaneous, and reflexive blinking [34]. Reflexive blinking is an involuntary, low-level reaction mediated by the brainstem [35]. Each mammalian species has a characteristic blink rate that remains constant under unchanging conditions [36, 37]. The primary function of spontaneous blinking is generally considered similar to that of reflexive blinking, that is, cleansing and irrigation of the eyes [36]. According to Ponder and Kennedy [38], the spontaneous blink rate is remarkably constant for each individual and largely independent of factors such as humidity, light, temperature, and deafferentation of the fifth cranial nerve. They concluded spontaneous blinking is generated centrally in adults and serves functions beyond simple cleansing [38]. Spontaneous blinking is associated with thinking [37-40] and emotion [38, 41, 42]. Eye blinking is thought to be influenced by three factors: (a) the physiological factor of cleansing and irrigation of the eyes, which is remarkably constant for each individual [36-38]. The physiological component of blinking (similar to reflexive blinking) is the baseline for spontaneous blinking, which tends to remain constant under unchanging conditions. (b) The blinking rate decreases with increasing cognitive processing and explicit attention [37-40]. (c) Emotional factors dramatically increase the mean blinking rate, such as sudden emotional excitement [38, 43] and emotional excitement due to deceptive behavior [44].

These findings indicate that in adults, the affective cue (visual stimulus) can join stimuli of other modalities produced by humidity, light, and temperature, altering the blinking rate. Reflective blinking is attributed to low-level reactions mediated by brainstem mechanisms [35], while the modified blinking rate component reflects more complex processing in higher structures [40, 41]. The altered spontaneous blinking rate provides a valuable tool to distinguish the activity due to automatic responses to stimuli from involuntary behavior due to cognitive processes and emotions. If a newborn's blinking rate also increases due to affective cues, such a behavioral response indicates the assimilation of their meanings and the beginning of emotional development.

Therefore, it is plausible that if affective cues can enhance automatic responses to stimuli in newborns, this would show emotion signatures in reflexes and that some reflexes underlie emotions. However, it is unclear how organisms at the simple reflexes substage of the sensorimotor stage of

development perceive affective cues to understand their positive/negative valence and proceed with developing valence- and/or arousal-based categories.

1.3 Shared Intentionality for Affective Cues Perception

To assimilate affective cues, or any cue for that matter, how does an organism at the reflexes substage of the sensorimotor stage of cognitive development extract relevant stimuli from a cacophony of electromagnetic waves, chemical interactions, and pressure fluctuations? This is a complex problem because the blank mind should first select relevant stimuli; only after this does perception function to process the cue (any cue, including the affective cue) to grasp its meaning (a holistic representation of an event or object) through the organization, identification, and interpretation of sensory information. Even the positive/negative valence of stimuli bears meaning. Perception-intentionality cohesion poses a barrier to behavioral shaping stimuli and processes related to response generalization. This is a vicious circle: cognition requires initial knowledge of the environment, which the blank mind cannot ensure or assimilate through sensing [21, 22, 33]. Only after the ninth-month revolution [45] can social learning through communication via sensory cues begin.

The hypothesis of embodied dynamical systems [8, 9, 12] with embodied information [9, 12] is also challenged because even the dynamical system needs intentionality to choose a relevant sensory stimulus from a cacophony of stimuli [21, 22, 33]. Only then can the relevant stimulus achieve related neuronal networks with embodied information, and the dynamical system launches information processing [21, 22, 33]. The embodied dynamical system requires intentionality, which appears due to perception, and vice versa [21, 22, 33]. Perception and intentionality require an initial knowledge of the environment for precise targeting. For instance, in the self-training mechanism—the special case of the embodied dynamical systems theory—no self-training process succeeds in the uncategorized environment. Even observational single-trial learning (introduced by Edwin Ray Guthrie) requires perception and intentionality, which can be problematic for beginners. Self-training mechanisms need feedback whose cue cannot overcome noise in the uncategorized environment without perception and intentionality.

The influential position in Cognitive sciences argues that organisms at the reflexes substage of the sensorimotor stage of cognitive development (Piaget) cannot alone distinguish relevant stimuli in the chaos of irrelevant ones to grasp their meanings through the organization, identification and interpretation of sensory information [45, 46]; relevant sensory stimuli may not overcome the noise threshold, and these organisms cannot solve this problem independently [21, 22, 33]. This so-called binding problem challenges the advent of perception in organisms. According to Treisman [46], three constraints form the threshold a developing organism should overcome at the ecological stage, with only simple reflexes to grasp perception. It is important to note that organisms may not act intentionally at this stage. The three constraints are as follows: (1) Targeting: how are the relevant elements to bind as a single entity distinguished and separated from irrelevant ones? (2) integrating: how is the binding encoded to be signaled to other brain systems and used?; and (3) proportion: how are the correct relations specified between the bound elements within a single object [46]?

An analysis of empirical evidence from the literature on children's development showed the contrary results of two opposing data collection methods for detecting infant intentions: descriptive vs. experimental [33]. Studies within the "descriptive" paradigm observed infants' behavior in daily

routine without introducing special conditions to induce subjects' reactions, i.e., without intervening during observation [33]. Research within this paradigm showed that intention appears in infants no earlier than 2 months of age [33]. In contrast, studies within the "experimental" paradigm systematically intervened by creating specific conditions for the subjects to stimulate their reactions and measure the outcome [33]. Research within the "experimental" paradigm has revealed actions by newborns that appear intentional from birth. The analysis concluded that the intentionality of newborns could appear even before it is possible for children's intention to occur [33].

Shared intentionality is believed to resolve these issues. According to influential opinions, cognition forms at the onset of life because of the gradually increasing social bonds between children and caregivers, beginning with the essential fundamental motive force of shared intentionality [45, 47, 48]. An organism assimilates the first cues in an interaction during shared intentionality, which contributes to the development of perception [21, 22]. The literature shows that organisms can perceive affective cues and assimilate affective meanings simultaneously with or before grasping perception due to shared intentionality.

1.4 Evidence from Research on Brain-Heart Interplay and Shared Intentionality

Numerous research studies demonstrated the influence of heart oscillations on brain activity. Evidence is accumulating that changes in cardiac activity cause changes in brain waves [49-52]. Neuronal activity was observed in response to the heartbeat even after brain damage [53]. Research reported that the periods of signal bursts during temporal coordination of neurons registered by the magnetic resonance imaging (MRI) techniques followed the oscillogram of subjects asked to stay still during brain screening [54]. There is evidence that emotional stimuli first alter heart oscillations in emotional arousal, and only then do the altered heartbeats stimulate a specific cortical response [55]. Numerous studies reported that an altered heartbeat impacts cognitive functions, such as working memory and attention, depending on the nature of the heart's input [56-60].

What do all these facts about the heart's impact on altering cortical processes mean for the mother-fetus interaction from an electromagnetism laws perspective? According to Faraday's law, the electromagnetic field of a time-varying nature can induce internal currents in space wherever it changes, for example, in the brain tissues [61, 62]. Magnetic fields (MF) and electromagnetic (EM) fields might have a similar mechanism, such as generating internal currents [61, 62]. Charged particles exist among proteins and cells [61]. Hence, MF can alter cellular biological processes [61]. In physics, particles with the same physical properties react similarly to the EM field of the same features in a similar environment, independent of the distance between these particles [54]. Waves propagate through tissues depending on their frequency, intensity, and the medium's resistance; low-frequency waves can propagate in tissues at a long distance (about a meter, for example, from the heart to fingers), whereas low-frequency waves (e.g., gamma waves) are limited by a few centimeters (they may support local coordination only).

Then, the heart's magnetic field is the strongest rhythmic field in the human body [54]. Regular human heart rates vary from about 45 to 220 beats/minute (in Hertz, that would be from 0.75 Hz to 3.66 Hz), which is relative to the effective diapason of the frequency ranges for external EM waves to increase cortical excitability as research has already shown [61, 63]. According to Frohlich et al.

[64], a neuroscience review showed that the delta wave amplitude in awake adults is under 15 μV and increases to 50 μV in the rapid-eye-movement sleep period [64]. Meanwhile, the amplitude of a person's electrocardiogram is generally within 5 mV [65], and average heart rates range from 60 to 100 bpm (1-1, 6 Hz, a similar range as the low-frequency brain waves, delta waves). Heartbeats are the body's most potent low-frequency EM oscillator, exceeding brain activity by three orders of magnitude. Finally, there is evidence of maternal-fetal cardiac coupling, which refers to a mutual interaction between maternal and fetal heart rhythms [66]. In physics, two coherent waves are combined, adding their intensities. Given together, the facts of the subsection may mean that the maternal heartbeat may impact the cognitive function appearance in the fetus during gestation.

Founded on these evidence-based data (also the data from 1.1-1.3 sections), the hypothesis of the Mother-fetus neurocognitive model states that physicochemical interactions within the mother-fetus bio-system, especially heart oscillations, sculpt the balanced nervous system and contribute to the development of perception in the fetus during gestation [67]. Research on mother-fetus interaction during pregnancy and its contribution to the child's cognitive development is difficult because of methodological issues. However, shared intentionality can be observed in further stages of the organisms' development since any inborn capacity manifests during the lifespan. Recent research with a large sample size showed interpersonal interactions through shared intentionality in adults [68] and modulation of shared intentionality in children and adults [69-73]. The comprehensive analysis of research data on child development during gestation and after birth [21, 22, 32, 33] and recent findings about neurophysiological processes underlying interpersonal dynamics in neuroscience [31, 74-79] allows us to argue that, in the mother-fetus bio-system, cognitive functions emerge in the naive organism through the mother's heart impact on both nervous systems during gestation [22, 67].

According to the Mother-fetus neurocognitive model, the mother's heart oscillations alter oscillations in both nervous systems, providing synchronization [22, 67]. In short, during the mother's intentional act, her heartbeats (low-frequency oscillation of about 1-1.5 Hz) consolidate locally fired neuronal networks in a choir, shaping harmony only in those networks already involved in local high-frequency oscillations (of about 30-100 Hz) induced by interpersonal dynamics in the particular ecological context [22, 67]. The consolidation of locally fired neuronal networks succeeds due to interference laws where low-frequency oscillation modulates the amplitude of high oscillations, thus transmitting high-frequency oscillations in all nervous system zones, in terms of neuroscience, so-called delta nested gamma oscillations. Thus, the mother's intentional act shapes relevant neuronal activity in the fetus [22, 67]. The mirror neuron phenomenon observed in hyperscanning studies likely represents inter-brain synchronization of the aforementioned origin. Then, the fetus gains the first positive/negative valence of stimuli that the fetus can hear with the mother from outside the womb (see more in [22, 67]). After this achievement, a child's perception can grasp a holistic representation of an object in shared intentional acts by capturing statistical information from cascading successful/failed interactions [22, 67]. This simplified explanation of the collaborative mother-fetus neurocognitive processes shows the essential role of mother-fetus interactions in cognitive function development and how affective cues can enhance automatic responses to stimuli in fetuses and newborns. More sophisticated neurophysiological processes underly nervous systems coupling in coordinated cognitive activity during training of the naive organism that further in-depth research may study more.

1.5 Research Problem and Study Scope

Humans develop their expertise in recognizing others' emotions from childhood to adulthood. However, little is known about the underlying mechanisms of information processing about one's and others' emotions. This review aims to study the development of emotions in organisms, beginning from simple reflexes. Therefore, the first research goal is to catalog studies on a specific simple reflex in infants, namely blinking.

We believe the further review-based analysis would allow us to derive a possible relationship between affective cues and stimuli responsible for activating neuronal assemblies of simple reflexes to propose an underlying hypothesis. Because we are interested in whether the data on simple reflexes reveal the emotional signature in altered reflective responses in the second stage, this article aims to identify empirical data from literature on spontaneous blinking in neonates (children up to 30 days old in the simple reflex substage of the sensorimotor stage of cognitive development) stimulated by affective cues. We believe that, by observing the responses of neonates, we can identify the mental and emotional components that distinguish them from the physiological components of blinking. Because the ecological impact on very young children should also be considered (as noted in the Limitations subsection), the analysis only considers the experimental data obtained from children stimulated by unfamiliar stimuli if the outcome can be compared with a baseline of the physiological component of blinking. In sum, the second research goal is to identify studies (selected determine the first goal) that allow us to determine the emotional components of blinking in neonates. We analyze these data in the Discussion section. The current review is the first attempt to identify and analyze knowledge about emotional signatures in altered reflective responses of blinking.

2. Materials and Methods

The current review explores existing studies on blinking in infants to identify knowledge gaps and speculate on possible causality that can deepen the understanding of emotions' origin. The literature review search followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 method. In accordance with the first research goal, we defined only one criterion for including studies in the article: if they reported blinking in infants under 6 months of age.

The spontaneous blinking rate is remarkably constant for each individual under stable conditions and is mainly independent of factors such as humidity, light, and temperature [36-38]. However, endogenous (e.g., hormone concentration levels [80]) and exogenous (e.g., smoke, dust, wind) factors can influence this rate [81, 82]. Therefore, a comparative analysis of the emotional and physiological components of the blinking rate requires the simultaneous measurement of blinks in the same subjects and environment.

According to Brennan et al. [83], 3-week-olds can keep attention to unfamiliar stimuli for up to 80 s (1 min and 20 s). We assume that newborns' emotional arousal due to unfamiliar stimuli does not last much longer than their attention to them. Unfamiliar tasks cannot enable cognitive processes in either caregivers (because of the simple functions prepared for young children) or children. In contrast, emotional arousal due to unfamiliar tasks can briefly appear in both parties. We expect to observe the emotional and physiological components of blinking together (without the cognitive component) from the data obtained in the two conditions: new stimuli and no change

(baseline) without a preference for which condition is first. Because newborns can keep their attention on unfamiliar stimuli for no longer than 80 seconds [83], we also consider experiments where stimuli were not changing for at least 3 min, and blinks were counted each minute separately. In this case, we expect to estimate the emotional and physiological components of blinking in the first part (at least 1–2 min long) and only one physiological component in the second part (beginning from the 3rd min). Therefore, to be included in the review, the studies needed to satisfy the following measuring conditions: (a) either the blinks were counted twice under two conditions: new stimuli and no change (baseline), or (b) the blinks were counted each minute for at least 3 min to measure the blinking rate when young children were exposed to the unfamiliar stimuli. We believe that this measurement condition would allow us to compare the children's results with a baseline for distinguishing the emotional and physiological components of blinking.

Therefore, in accordance with the second goal, the Discussion section analyzes the data on the blinking rate in children due to emotional excitement, distinguishing the studies (from those cataloged ones) that satisfy three criteria:

1. Children's age up to 30 days (the simple reflexes substage of the sensorimotor stage of cognitive development).
2. Two measurements under the within-subjects paradigm: "new stimuli" and "no change" conditions.
3. Parents were next to the child and could see the stimuli.

Evaluating the blinking rates of newborns is difficult because of methodological issues [84]. Although we expected a limited number of studies on the topic (considering the above limitation), we still sought to explore only academic articles in English that met rigorous research requirements. We searched SCOPUS and Web of Science databases to extract studies on blinking in infants; see the flowchart in Figure 1. In performing searches in June 2023, we converted the search problem into specific search strings. The topic was divided into parts, using the conventional terms blinking, emotions, and reflexes. We used "blinking" to find all references on the subject of our review. Then, we also used the Boolean operators "and" and "or" connecting the term "blinking" with the terms "emotions" and "reflexes" to form a search string with a focus on the issue of interest. We identified 50 articles in the databases using the keywords "blinking", "blinking and emotions", "blinking and reflexes", "blinking or emotions", and "blinking or reflexes".

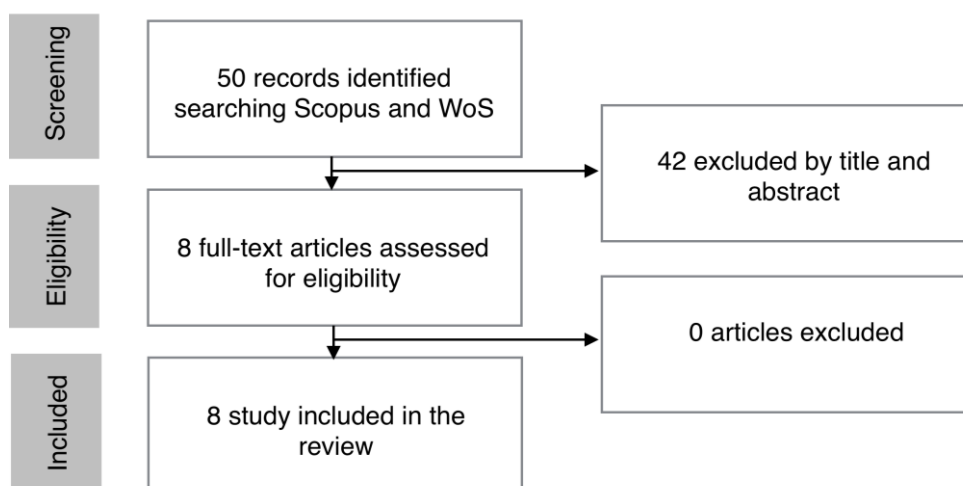


Figure 1 The flowchart of the search strategy of the review.

After screening the title and abstract of these 50 articles, we found eight studies on blinking in newborns and infants. Behind assessing them for eligibility, we included them in the analysis.

3. Results

According to the first goal of the study, the results are presented in Table 1, a catalog of eight studies of blinking simple reflexes in infants under 6 months of age.

Table 1 Eight studies of blinking in infants under 6 months of age.

Study	Subjects	Conditions	Stimuli	Parents	Outcome
Yonas et al., 1977 [84]	70 infants, from 1- to 2-month-olds, in 3 experiments	Measurements of episodes with eye blink	An increasing/moving dark silhouette	Parents presented at the experiment and could notice stimuli	There is no blinking rate. Increased blinking due to the increasing dark silhouette
Zametkin et al., 1979 [36]	269 children	One minute measurement	No data	Parents presented at the experiment and could notice stimuli	Spontaneous blinking rate 0.714 in 0-to 2-month-olds.
Lancioni & Hoogland, 1980 [85]	45 infants, from 90 to 113 days	Two measurements were made in baseline and paired conditioning	A tone conditioned stimulus and an unconditioned gentle puff of air to the right eye	Not specified	No blinking rate Conditioning of intermodal stimuli
Hoffman, Cohen, & English, 1985 [86]	15 sleeping neonates, from 13 to 90 h, in 5 experiments	Two measurements were made in baseline and paired conditioning	A tone of 70 dB re: 0.0002 dyne/cm*	Not specified	No blinking rate. Conditioning of intermodal stimuli
Nanez, 1988 [87]	40 infants, from 3- to 6-week-olds	Two conditions of measurements: the expansion and contraction dark silhouette	An increasing/decreasing dark silhouette upon a light screen	Not specified	No blinking rate. Increased blinking in the expansion condition
	20 infants, from 3- to 6-week-olds	Two conditions of measurements: the expansion and	A reversed-contrast con-	Not specified	No blinking rate. No changes

		contraction of the bright point	figuration: an increasing/decreasing bright point upon a dark background A rapid change in illumination of the screen without any motion	Not specified	No blinking rate. No changes
Ivkovich, Collins, Eckerman, Krasnegor, & Stanton, 1999 [88]	20 infants, from 3- to 6-week-olds	Two conditions measurements: a bright and dark screen	A tone conditioned stimulus and an unconditioned gentle puff of air to the right eye	Parents presented at the experiment and could notice stimuli	No blinking rate. Conditioning of intermodal stimuli
	57 infants, of 4- and 5-month-olds	Two measurements of trials with conditioned blinks were made in baseline and paired conditioning	The data collection of blinking was based on time averages of 7.5 ± 3.3 min before feeding, 8.3 ± 3.8 min during feeding, and 7.1 ± 2.3 min after feeding	Parents presented at the experiment and provided stimuli	The range of blink rates in infants before feeding was 2.7 ± 0.96 , $n = 7$. During and after feeding, the average rates of blinking were 3.7 ± 0.95 and 2.8 ± 1.1 , respectively
Bacher & Smotherman, 2004 [89]	9 infants, of 10- and 12-week-olds	For the feeding study, measurements were made in three conditions: before, during and after feeding	No change condition: data collection during the 4 min. New stimuli with stuffed toy animals: the 4 min	Parents presented at the experiment and could notice stimuli	The rate of blinking increased between the first (3.1 ± 1.7) and the second (5.0 ± 1.4 , $n = 9$) half of the observation for
	9 infants, of 10- and 12-week-olds (new stimuli condition). 10 infants, of 10- and 12-week-olds (no change condition)	For the visual attention study, measurements were made in two conditions: no change and new stimuli			

Lavezzo et al., 2008 [90]	50 neonates, from 0- to 30-day-olds	For the spontaneous blinking rate study, measurements were made three times over a 3-min period	Data about the observation target (a stimulus) is not available	after the stimulus change (second half). Not specified	infants who observed new visual stimuli The complete blink rate is 6.2 blinks/min. Total blink time in the 1st minute was 764.0 ± 139.0 ms, in the 2nd minute – 768.7 ± 124.3 ms, and in the 3rd minute 743.7 ± 123.3 ms
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In this section, we highlight the results of four studies by Lavezzo et al. [90], Hoffman, Cohen, and English [86], Náñez [87], and Bacher and Smotherman [89]. We focus on the data of these four studies because they allow us to discuss the association of affective cues with stimuli responsible for activating the neural pathways of simple reflexes in the next section.

Lavezzo et al. [90] measured spontaneous blinks by recording digital images of 50 fully awake newborns (aged up to 30 days) over 3 minutes. The study reported a decreased total blink time in newborns of 3.25% during the 3rd min; the total blink time in the 1st min was $M = 764.0 \pm 139.0$ ms, in the 2nd min was $M = 768.7 \pm 124.3$ ms, and in the 3rd min was $M = 743.7 \pm 123.3$ ms [90]. The total blink time was $M = 768.7$ ms under the "new stimuli" condition and $M = 743.7 \pm 123.3$ ms under the "no change" condition. Lavezzo et al. [90] measured total blink time (not blinking rate), corresponding to the blinking rate. The total blink time strongly correlates with the blinking rate in the same period because the total blink time and blinking rate tend to be constant under unchanging conditions [36-38]. Therefore, we considered these data the blinking rate measured in other units. Although the study by Lavezzo et al. [84] did not mention the caregivers' inclusion in the research, i.e., whether they were present with the child and could see the stimuli, we still considered it eligible, supposing the presence of parents given the very young age of the children; see the Discussion section for details.

Hoffman, Cohen, and English [86] reported observing altered blinking in sleeping neonates in a condition of intermodal stimuli, compared with baseline. Náñez [87] observed increased blinking in infants ($N = 40$, from 3- to 6-week-olds) in the expansion condition of a dark silhouette compared to its contraction. Bacher and Smotherman [89] reported that the rate of blinking increased between the first (3.1 ± 1.7) and the second (5.0 ± 1.4 , $n = 9$) half of the observation for infants (10- and 12-week-olds) who observed new visual stimuli.

4. Discussion

The data from Lavezzo et al.'s [90] study with a sample size of $N = 50$ subjects entirely fit the second research goal criteria. The data demonstrate the increased blinking rate under the "new stimuli" condition. As the Introduction noted, empirical data revealed that the blinking rate decreased during cognitive processing [37-40] and increased emotional excitement [38, 43, 44]. The discussion in the following sections poses more arguments as to why the increased blinking rate in newborns may only demonstrate emotional arousal. While the three articles—Hoffman, Cohen, and English [86]; Náñez [87]; Bacher and Smotherman [89]—do not entirely satisfy the criteria of the second research goal: the ability to compare results with the blinking rate baseline (the studies by Hoffman, Cohen, and English [86]; Náñez [87]) or the limitation of 30-day-olds age (the study of Bacher and Smotherman [89]), they are also essential in understanding emotional signatures in altered reflexes. Since their results are also interesting, we observe them below, noting their limitations. The review concludes with a hypothesis of pre-perceptual multimodal integration of affective cues and reflexes stimuli due to shared intentionality.

4.1 Blinking Rate Results

The Lavezzo et al.'s [90] study shows an increased blinking rate in 50 newborns by up to 3% due to observing an "observation target". While the experiment by Lavezzo et al. [84] did not specify the role of parents, we believe that parents also participated because it would be too difficult for

researchers to carry out the measurement procedure with fifty awake newborns without their parents.

Bacher and Smotherman [89] also reported measuring the blinking rate in nine 10- and 12-week-old infants ("new stimuli" condition) and comparing their outcome with another group of 10 peers ("no change" condition). They reported collecting data under the "no change" condition for 4 min and presenting the stimuli of stuffed toy animals to 10 newborns. Under the "new stimuli" condition, they offered the same stimuli to another group of nine young children during the 4-minute observation period. During this experiment, they changed the stimuli (other stuffed toy animals) and repeated the blinking rate for 4 min after changing the stimuli (second half). This experiment revealed that under the "new stimuli" condition, the blinking rate increased between the first ($M = 3.1 \pm 1.7$) and the second ($M = 5.0 \pm 1.4$) half of the observation for infants who observed new visual stimuli [89]. In summary, Bacher and Smotherman's [56] study supports the findings of Lavezzo et al. [84] by reporting an increased blinking rate in 10- and 12-week-olds (by up to 61%) due to observing a new "stuffed toy animal," respectively.

The limitation of both studies [89, 90] is that they have not clarified the specific observation targets (stuffed toy animals: habitable domestic animals or exotic animals, e.g., dinosaurs) they had shown to children and whether children had seen them before. This is likely the first reason for the significant difference in the blinking rate between these two studies. The second reason for the difference in outcome is the children's age in Lavezzo et al.'s [84] and Bacher and Smotherman's [89] studies. The children from each study could be attributed to different developmental stages: the simple reflex substage in Lavezzo et al.'s [84] study and the first habits and primary circular reactions substage of the sensorimotor stage of development in Bacher and Smotherman's [89] study. Accordingly, the children in Bacher and Smotherman's [89] research could already accomplish social learning independently. Regarding Lavezzo et al.'s [84] study, we must note that any sensory cue is inaccessible for organisms at the simple reflexes substage of the sensorimotor stage of cognitive development (more information is provided in the Introduction and Methods sections).

In the same article, Bacher and Smotherman [89] also reported a significantly increased blinking rate in infants during feeding by up to 37% (from $M = 2.7 \pm 0.96$ to $M = 3.7 \pm 0.95$). According to Berridge [91], brain reward systems mediate motivational "wanting" and hedonic "liking" for food rewards. Pleasant foods activate cortical sites in the front of the brain that are implicated in the regulation of emotions, such as the orbitofrontal cortex, anterior cingulate cortex, and insular cortex; subcortical forebrain limbic structures such as the amygdala, nucleus accumbens, and ventral pallidum; mesolimbic dopamine projections; and even deep brainstem sites [91, 92]. The increased blinking rate may only manifest as positive emotional arousal that connects taste sensations with taste preferences in a particular ecological context.

4.2 Altered Blinking Due to Conditioning

Fifteen sleeping neonates (from 13–90 h) exhibited reliable glabellar reflex augmentation (increased blinks) when mild tones were presented simultaneously with taps [86]. Notably, newborns learn classical conditioning during sleep. However, sleeping newborns react to sound stimuli that their senses cannot provide because of the brain's sensory isolation from meaningless and unfamiliar sounds. According to Andrillon and Kouider [93], sleepers enter standby mode, allowing them to balance the monitoring of their surroundings with sensory isolation. Sleepers are

sensitive to the semantic content of the auditory stream [93, 94] and amplify relevant and meaningful stimuli [93, 94]. The sleeping brain retains some residual information processing capacity and does not form enduring memories [95]. Therefore, sleepers do not process irrelevant, meaningless content [93, 94] and cannot perceive it. While sleeping neonates classified and conditioned sound stimuli by manifesting an increased blinking rate, they accomplished this cognitive task without the ability to sense the sound because of their brains' sensory isolation.

4.3 Increased Blinking due to Approaching Object

Nanez [87] revealed that 3–6-week-old infants ($N = 40$) consistently fired to an increasing shadow at the center of the receptive field but not to increasing/decreasing bright spots at the exact location [87]. However, while the research [87] counted blinks, they did not examine the blinking rate.

Another interesting finding was the increased blinking rate in 3–to 6-week-old infants due to the expansion (arrival or increase) of dark silhouette [84, 87]. The increased blinking rate of these very young organisms reveals newborns' emotional arousal (e.g., fear). Indeed, approaching dark objects almost always reflect less light than their terrain-sky background [87]. This may mean that organisms classify approaching stimuli that are darker than their surroundings as indicating imminent collisions or danger due to predatory attacks, and those lighter than their surroundings are not perceived as possessing these qualities [87]. To our knowledge, the autonomous understanding of the meanings of sensory cues is not an ability of organisms that only show automatic responses to stimuli (for more information, see Introduction).

4.4 Blinking Data Overview

Although research on blinking about emotions in newborns is not systematic and does not always yield consistent findings, some regularities can be noted.

First, to our knowledge, goal-directed behavior is only observed in pure reflexes at the simple reflexes sub-stage of the sensorimotor stage of cognitive development [21, 33, 67]. That is, any sensory cue (if not associated with reflexes) is inaccessible for these organisms (more information is provided in the Introduction and Methods sections) [21, 33, 67]. Newborns might not react to the "observation target" in Lavezzo colleagues [84] independently, and these stimuli were ineffective cues for them. The data analysis from the 4.3 section also revealed that newborns experience emotional arousal due to stimuli they cannot autonomously understand and recognize as affective cues [84, 87].

Second, Hoffman, Cohen, and English [86] reported that sleeping neonates classified and conditioned sound stimuli by manifesting an increased blinking rate. As shown in section 4.2, they could not perceive these cues not only because they were unintelligible stimuli for these organisms as meanings, but even more newborns could not perceive these cues because of their brains' sensory isolation.

Given the above arguments, although the neonates might not perform these tasks independently, they showed increasing reflective movements during stimulation with affective cues. What these data may mean? While observing altered reflective responses to stimuli, these studies also detected the mechanism of social learning when organisms in the simple reflexes substage of the sensorimotor stage of cognitive development assimilated the relevant stimulus (even asleep, as in the study of Hoffman et al. [86]) due to shared intentionality. The participants chose the relevant

stimulus from the cacophony of irrelevant stimuli because of this pre-perceptual communication with the mother. Again, shared intentionality enables organisms (that only show automatic responses to stimuli) to choose the relevant stimulus from a cacophony of irrelevant stimuli to attribute the stimulus to a proper reaction in an ecological context [21, 67].

4.5 Hypothesis of Pre-perceptual Multimodal Integration

We believe that the assimilation of affective meanings (or valence- and arousal-based categories) can begin with perception development at the simple reflexes stage. Our literature review considered the data on the altered rate of spontaneous blinking in newborns during stimulation with affective cues. The empirical data revealed that affective cues alter a newborn's blinking rate. However, in the simple reflexes substage of the sensorimotor stage of cognitive development, organisms automatically respond to stimuli and can only react to stimuli relevant to reflexes [21, 33, 67]. Newborns cannot independently respond to affective cues unrelated to their reflexes [21, 33, 67].

Since affective cues alter the blinking rate, we suppose that affective cues join the stimuli of other modalities responsible for activating afferent and efferent nerves in reflexes. This integration changes the neural signals and increases the response of the neural pathway that controls the reflex. Therefore, we believe that pre-perceptual multimodal integration provides an increased response to the neural pathways of reflexes—a higher blinking rate. This mechanism of the emotion-reflex stimuli conjunction further develops these simple innate neuronal assemblies—prototypes of the neuronal networks of emotions—shaping the emotions neuronal patterns in statistical learning that are continuously connected with the neuronal pathways of reflexes. How does this pre-perceptual multimodal integration succeed, and how do affective cues join the stimuli of other modalities responsible for reflexes? How do young organisms with simple reflexes correctly choose a proper affective cue from the cacophony of irrelevant stimuli? Significantly, as noted in Section 1.3, these organisms must first choose affective cues in the chaos of other stimuli and, second, link them with stimuli of different modalities that provide simple reflexes [21, 33, 67]. However, this conjunction is only part of a more complex process that connects a specific ecological context with the corresponding basic neural structures (even achieving the outcome more simply at this stage of development without understanding this affective meaning). This is a complex problem for organisms during the simple reflexes stage of development [21, 33, 67]. Because newborns cannot correctly choose and link affective cues independently, divergence from the physiological blinking rate may indicate the outcome of social learning in young children. We believe that the affecting cues join the stimuli of other modalities responsible for reflexes due to the mother-child interaction—shared intentionality. We suppose that the development of emotions begins because of this pre-perceptual multimodal integration of affective cues and reflex stimuli that emerges with shared intentionality in the dyad, even during the prenatal period [67].

However, this is the only hypothesis, which, according to a consensus in the scientific community, is a proposed explanation with limited evidence for a phenomenon that can be further tested by observation or experiment. More data should be provided about the alteration of blinking rate by affective cues and more evidence of shared intentionality to propose the robust theory of pre-perceptual multimodal integration.

The idea of the pre-perceptual multimodal integration in organisms in the reflexes stage allows future research to develop the neurophysiological mechanism of emotions development that, first, ensures the association of the affective cues with neural pathways of reflexes—"reflex arcs"—second, provides further developing specific neuron assemblies connected with these neural pathways of reflexes.

4.6 Limitations

The current narrative review presents direct and indirect evidence of a positive association between emotions and increased newborn blinking rates. While the direct evidence relies on robust data ($N = 50$ subjects) from Lavezzo and colleagues [90], this is the only study. These data are not subjected to a meta-analysis. A post hoc analysis cannot yield more information about the sample than we have already inferred. Further, more specific research on the co-evolution of reflexes and emotions in fetuses and newborns is needed to provide measurements with post-hoc statistical power.

Other study's limitations stem from the research's main limitations on children's emotions. According to Vygotsky and Piaget, social learning begins at the onset of cognition and continues throughout the lifespan, assuming that social learning can start even in the womb (see Subsection 1.1). Therefore, research should consider these circumstances and exclude previous and present ecological contexts from the outcomes of the experiments. The environmental context during the experiments should be carefully examined because caregivers (in most cases, mothers) can influence children's reactions explicitly and implicitly. This can change performance outcomes, as noted in the 1.3 subsection, which discusses the contrary results of the descriptive vs. experimental data collection methods for detecting infant intentions.

For instance, psychophysiological studies have shown contrasting outcomes: newborns could discriminate between happy and fearful expressions [96-98], whereas 3- and 4-month-olds did not reliably discriminate between positive and negative facial expressions [99, 100].

Studies on blinking have similar limitations. We believe that the studies in our review describe their research methodology and the resources of all materials, data, and protocols in sufficient detail, following the publishing requirements for well-established methods that successive studies can only briefly explain. However, research on blinking began a hundred years ago, when Cason [101] and Ponder and Kennedy [38] carefully described the method in detail (this was before Vygotsky's and Piaget's theories). Similar to many other studies, our review used this classic method, which did not consider infants' social learning before and during the experiments. Two articles [89, 90] did not specify the type of observation target or whether this stimulus was familiar to the participants. Three studies [87, 89, 90] did not explain the ecological context of the experiments—whether young children participated with their mothers and, if not mothers, then with whom (neonates could not participate in the research alone). As far as we can tell, the target was unfamiliar to newborns, at least to most of them, and the studies invited the children with their mothers to participate in the experiments. These assumptions are confirmed by the results of the experiments since otherwise, the experiments would be difficult to conduct without parents, and the blinking rating would not have been altered. From this account, the divergence from the physiological rate of blinking under the excited stimulus shows that newborns (organisms with only automatic responses to stimuli) either already knew how to react to affective cues (had studied before with the caregivers) or

studied how to do this in social learning with their caregivers during the experiments (due to shared intentionality). In any case, the emotional component emerged because of past or present interactions within the dyads (see more about the PDE problem in Subsection 1.3 of the Introduction and the emotional component of blinking in Section 2. Method). Further research is required to scrutinize this issue.

5. Conclusions

This study reviewed the literature on the alteration of spontaneous blinking in newborns. The empirical data revealed that affective cues alter blinking rates. This study hypothesizes that emotion development begins with the association of affective cues with stimuli responsible for activating the neural pathways of simple reflexes—the mechanism of pre-perceptual multimodal integration. The hypothesis assumes that pre-perceptual multimodal integration could succeed because of shared intentionality in mother-child dyads, even in the prenatal period. This mechanism of the emotion-reflex stimuli conjunction further develops these simple innate neuronal assemblies—prototypes of the neuronal networks of emotions—shaping the emotion neuronal patterns in statistical learning that are continuously connected with the neuronal pathways of reflexes. We believe that the two arguments regarding emotion development due to pre-perceptual multimodal integration and the beginning of social learning in the prenatal period can contribute to both naturalism and constructivism by improving knowledge of the origins of emotions. This hypothesis integrates the presumably opposing naturalist and constructivist viewpoints about emotion development. Both approaches are based on similar neural mechanisms that, during the prenatal period, ensure the association of affective cues (in the form of valence) with the temporally coordinated activity of specific neural ensembles.

Author Contributions

Sandra Mihailova (SM) and Igor Val Danilov (IVal) created the method of the review and searched articles together. IVal formulated the hypothesis and wrote the first draft of the manuscript. SM and IVal improved the text over several iterations.

Competing Interests

The authors have declared that no competing interests exist.

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