Can We Detect Consciousness in Newborn Infants?[1]

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Abstract
Conscious experiences in infants remain poorly understood. In this NeuroView, Passos-Ferreira discusses recent evidence for and against consciousness in newborn babies. She argues that the weight of evidence from neuroimaging and behavioral studies supports the thesis that newborn infants are conscious.

The development of consciousness

When does consciousness emerge in development? Do newborn infants have conscious experiences of perceiving, feeling, and acting?

Newborns typically have open eyes, they have sleep-wake cycles, and they react to stimuli, so it may seem obvious that they are conscious. But we know that many cognitive processes can be unconscious: there is unconscious perception and unconscious action. For many years, newborns were not given anesthetics when they were circumcised, in part because many thought that they could not subjectively experience pain as they have immature brains.[1]

Today it is more widely believed that newborn infants are conscious and can experience pain,[2] but some theorists still reject the view. It is not obvious what evidence we can have for the presence of consciousness in early stages of infant development. Our best methods for detecting consciousness involve first-person verbal reports of conscious states as well as following verbal commands. When the capacity for first-person reports and command-following is absent, as in infants, non-human animals, and some neurological patients, our methods for studying consciousness are limited.

To address this challenge, developmental psychologists and neuroscientists have developed indirect methods for studying infant minds, relying on reaction to novelty or preferential looking to one of two stimuli measured by eye movement. However, it is not clear that these reactions require conscious perception. As a result, these studies relying on behavior indicators need to be complemented with other measures to assess infant consciousness comprehensively.

In recent years, the neuroscience of consciousness has developed some promising methods for detecting consciousness in the absence of verbal reports. These methods involve neural and behavioral markers of consciousness. These markers are initially developed using evidence from normal adults using verbal reports, sometimes guided by theories of consciousness. The markers can then be applied to non-verbal subjects such as non-human animals and non-verbal neurological patients.

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In exciting recent work, these methods have begun to be applied to detecting consciousness in infants. Developmental researchers have used neural signatures of consciousness from adult studies to investigate the infant case, with striking results. I will discuss recent findings involving four potential cognitive markers for consciousness in newborn infants: the detection of auditory expectation violations, functional connectivity in brain networks, the attentional blink phenomenon, and the presence and absence of visual masking. (I will not discuss socioemotional markers, which require a separate treatment.) Three of these cognitive markers offer potential evidence in favor of the hypothesis that newborn infants are conscious, while one marker offers potential evidence against it. After analyzing this conflicting evidence, I conclude that while the issue is still open, the positive case for consciousness in newborn infants is strong.

Detecting violations of global expectations

One source of evidence comes from the local-global violation paradigm that has been used to detect consciousness in adult patients with disorders of consciousness.[3] The local-global paradigm is an auditory oddball paradigm in which a novel sound is introduced after a series of repeated sounds. It operates on two levels of auditory regularity: local (within trials) and global (across trials). Local trials consist of a series of five successive sounds, in which the first four sounds are always identical (aaaa), and the fifth sound can either be identical (aaaaA) or different (aaaaB). When the fifth sound is different, this is a violation of local expectations, or a "local oddball." On top of the local rule, a global regularity can be added in which these sequences of sounds (such as aaaaB) are repeated, creating an expectation of a global sequence in a type of hierarchical perceptual learning. When these regularities are violated (e.g., aaaaB, aaaaB, aaaaB, aaaaA, where the final sequence of sounds is deviant relative to the previous sequences), this is a violation of global expectations, or a "global oddball."

In adults who are attentive and awake, local and global oddballs evoke two levels of brain responses in event-related potentials. There is an early mismatch negativity response, possibly indicating a non-conscious response, followed by a later neural response known as the P300 (or P3b) complex, which occurs around 300 ms after the presentation of the relevant stimulus.[3] While P300 responses have sometimes been seen as a marker of consciousness,[4] they can occur without consciousness, for example, in comatose patients.[5] P300 responses to local violations are not predictive of consciousness, as they can occur in both conscious and non-conscious conditions. However, P300 responses to global violations seem to be more strongly predictive of consciousness. These responses are not observed in comatose patients or in sleeping or inattentive adults. Detection of a global oddball requires maintaining perceptual representations over time, which arguably requires consciousness. In adults, statistical learning of local first-order regularities can occur automatically and non-consciously, but learning of global second-order regularities seems to occur with conscious processing. As a result, detection of global oddballs can be used as a marker of consciousness. This marker can be applied even in cases where verbal reports are absent, such as infants.

Basirat et al.[6] developed an auditory local–global paradigm to test three-month-old infants, using high-density recordings of event-related potentials. They found that, like adults, awake and attentive three-month-old infants have two levels of responses, including a P300-like 'late slow wave' response (occurring between 800 and 1,000 ms) to both local and global oddball stimuli. This suggests that these infants detect violations of both local and global expectancies. Insofar as global oddball detection is evidence of consciousness, these results suggest that three-month-old infants are conscious of the stimuli. Using magnetoencephalography in an auditory local-global paradigm presenting two levels of hierarchical regularities, Moser et al.[7] also found similar responses in awake newborns (measured by their heart acceleration, in neonates with high heart rate variability) in the first week of life.

These results provide significant evidence for consciousness in the first weeks of life. The evidence is not entirely conclusive, as one could argue that these infants are detecting global oddballs unconsciously. Still, unconscious detection of global oddballs has not been observed elsewhere, so these results provide a strong initial case for conscious perception in newborn infants.

Functional connectivity in brain networks

In adults, consciousness is associated with anti-correlated patterns of activity in networks with long-range connections associated with "external" and "internal" awareness.[8] Internal awareness is related to the default mode network (DMN), which is active during rest, involved in self-referential and self-awareness processing, and not engaged in external tasks. External awareness is associated with frontoparietal networks, including the dorsal attention network (DAN) and executive control network (ECN), which are implicated in attention-demanding external cognitive tasks. It is well-established that in adults, activation of DMN during mind wandering leads to decreased activation in the DAN and ECN and vice versa.

Multiple reports suggest that consciousness relies on a temporal dynamic of DMN and DAN-ECNs characterized by reciprocal accessibility of functional brain states. The disruption of this temporal dynamic, exhibiting limited accessibility in these brain networks, appears to be a common signature of unresponsiveness during anesthesia and in adult patients with disorders of consciousness.

Using advanced technology in brain imaging to study neonate brains, recent findings from two large sampled fMRI studies[9,10,] indicate that these functional connectivity patterns are present in newborns (or shortly after birth). The DMN, in additional to the DAN and ECN, are present in both full-term neonates and term-equivalent-age infants born prematurely, and the dynamics of reciprocal accessibility among these networks is present too. The structure of these networks is less well-organized than in adults, and their reciprocal relationship is weaker, indicating that the brain networks continue to develop after birth. Still, the presence of these networks in neonate brains suggests that the prefrontal areas involved in high-level cognition and selective attention are active earlier than was previously thought. (For a review of relevant studies, see Dehaene-Lambertz[11]).

Hu and colleagues[9] have suggested that the presence of these patterns of connectivity in newborns that are associated with consciousness in adults might show that newborns have the capacity for consciousness. It shows that crucial brain mechanisms underlying consciousness are already present in early stages, albeit in an immature form that will undergo maturation and acceleration during development.

To date, there is no conclusive evidence that these networks are necessary or sufficient for consciousness.[12] In some cases, it appears that DMN connectivity can be present without consciousness and vice versa. It remains possible that infants are such a case. Still, functional connectivity in these networks provides, at least, suggestive evidence that infants have the capacity for consciousness.

The attentional blink

A third source of evidence comes from studies on the attentional blink in infants. The attentional blink phenomenon reflects the brain's limitations in consciously focusing on multiple successive targets. When the cognitive system attends to a first stimulus, it fails to detect or attend to a second one presented shortly thereafter (200-500 ms later). In effect, successive stimuli are competing to be the focus of attention. In adults, the attentional blink only occurs if the observer consciously perceives the first target.

A recent study[13] measured infants' gaze toward target faces and found a sort of attentional blink in infants at five months of age, albeit with a longer duration (for a review, see Dopierala and Emberson[14]). Perception of a second face is blocked at around 1 s (1,200 ms) after the perception of the first face, suggesting an attentional blink much longer than in adults. This slow processing in infants is consistent with the reported findings of the EEG signature of a P300-like late slow wave occurring around 850-1,400 ms in five-month-old infants.[3] In a forthcoming study, using two competing stimuli (a teddy bear followed by a face), Leroy et al.[15,11] show that three-month-old infants exhibit a related effect: when they are processing the first stimulus, a P400 late event-related potential is induced, and pupil size is increased.

Doperiala and Emberson[14] suggest that the attentional blink is a signal of conscious perception, and therefore, that these results are evidence that infants are consciously perceiving. This evidence is suggestive, though it may have limitations. For example, it is not out of the question that there could be an attentional blink in unconscious perception. There have also been doubts about whether the P300-like wave is a reliable signature of consciousness,[5,16] and whether a genuine attentional blink is observed in infants before six months of age. Still, these results contribute to the cumulative case that young infants show the general profile of conscious perception.

Visual masking and recurrent processing

The last source of evidence suggests that recurrent (or feedback) processing is limited in young infants, and thereby raises some challenges for the view that infants are conscious in the first months after birth. A number of theories of consciousness hold that consciousness depends on recurrent (or feedback) loops of neural activity and that pure feedforward processing is not conscious.[17,18] These theories include the integrated information theory, which holds that consciousness requires a certain measure of integrated information (which is zero in pure feedforward systems) and some versions of the global workspace theory, which holds that visual consciousness involves a global workspace in the prefrontal cortex (which is supported by recurrent processing). Most explicitly, the recurrent processing theory of consciousness (RPT), also known as the local re-entry theory, holds that consciousness depends on recurrent loops of neural activity that are localized within visual sensory areas in the cortex.

I will use RPT to develop a challenge to early infant consciousness, though a similar challenge could be developed using the other theories. According to RPT, certain localized recurrent processes in sensory areas are necessary (and sufficient, given some background conditions) for phenomenal consciousness. To date, RPT has been developed primarily in relation to visual consciousness. There is strong evidence that visual processing starts with a feedforward sweep process from lower areas to higher areas within 150-200 ms. Recurrent processing (or feedback processing) from higher areas to lower areas starts within 100 ms. RPT holds that feedforward processes are always unconscious, while conscious vision always involves recurrent processes.[19]

RPT opens up the possibility that evidence for and against recurrent processing may be evidence for and against consciousness. In particular, visual backward masking, in which a later stimulus masks the perception of an earlier stimulus, is often taken to work by disturbing recurrent processing, and therefore, disturbing conscious vision. Object substitution masking is a type of visual masking that can be used to test for recurrent processing. In this form of masking, when a first object is followed by a contour or a four-dot mask surrounding the object target, the object is not consciously perceived.

Recently, Nakashima et al.[20] have found evidence that infants under seven months of age are immune to object substitution masking (and also infants under six months are immune to metacontrast masking, another type of visual masking[21]). On their interpretation, these findings suggest that recurrent processes are absent or undeveloped in young infants. This conclusion is supported by anatomical evidence from infant brain development suggesting that recurrent processing is immature until age of six months. If infants lack relevant recurrent processing in visual areas, then, according to RPT, they lack visual consciousness.

Where visual consciousness is concerned, these findings have, at least, three possible interpretations. A first interpretation is that infants lack relevant recurrent processing and, therefore, lack visual consciousness. A second interpretation is that infants lack relevant recurrent processing but are nevertheless visually conscious, suggesting that RPT is incorrect. A third interpretation is that infants have some recurrent processing and some conscious vision that is consistent with immunity to object substitution masking.

The third interpretation is perhaps the most attractive for RPT theorists. Fahrenfort, Scholte, and Lamme[22] have previously suggested that RPT theorists can distinguish two sorts of recurrent processes: early recurrent processing from higher to lower visual areas, which is required for visual consciousness, and later recurrent processing from frontal and parietal areas to visual areas, which is disrupted by backward visual masking. On this view, these failures of visual masking[20,21] are compatible with young infants having the relevant early recurrent processing, possibly without the later recurrent processes that are disrupted by masking. In older infants and adults, there are later recurrent processes that are disrupted by masking and that may disrupt early processes in turn, rendering masked stimuli unconscious. This interpretation is somewhat speculative, but it provides one way to reconcile these results with infant consciousness in the context of RPT. An alternative reconciliation would be to abandon RPT, along with other theories discussed earlier on which consciousness requires recurrent processing, and allow that feedforward visual processes can be conscious.

Fetal consciousness

What about consciousness before birth? It is widely believed among neuroscientists that consciousness requires a thalamocortical system, and this system develops at around 26 weeks of gestation. If this view is correct, it is unlikely that consciousness is present before 26 weeks of gestation. It is currently unknown precisely when, after the establishment of thalamocortical connectivity around week 26 of gestation, consciousness actually emerges, and there are divergent predictions regarding the timeline for the development of consciousness.[23,24] It is possible that even after brain structures associated with consciousness are developed, these might not be sufficient for fetal consciousness, as the chemical environment of the womb sedates the fetus and may limit its capacity for consciousness before birth.[25]

Perhaps the most significant positive evidence for fetal consciousness comes from the oddball paradigm discussed earlier.[26] Using fetal magnetoencephalography, Moser et al.[27] reproduced the P300-like effect following global oddballs in fetuses older than week 35 of gestation. The findings suggest that fetuses in the last weeks of gestation might be capable of consciously processing stimuli that reach them from outside the womb. If we accept the oddball results as evidence for consciousness in newborns, the same reasoning appears to also provide evidence for fetal consciousness after 35 weeks of gestation.

Another promising approach is the development of a variant of the perturbational complexity index (PCI) to detect fetal consciousness.[24] The PCI involves perturbing the cortex by applying transcranial magnetic stimulation pulses and measuring the complexity of the cortical response using electroencephalography. There is a growing body of evidence that, in adults, PCI can serve as a measure of consciousness. In a sensory version of this technique adapted to test infants and fetuses, sensory perturbations with visual or auditory stimuli could be used in place of electromagnetic perturbations, and the resulting cortical responses may serve as an indicator of consciousness.

Conclusion

To summarize: I would say that the converging evidence from studies of cortical responses to global oddballs, functional connectivity, and attentional blink tends to support the presence of consciousness in newborns (and potentially in late-term fetuses, in the first case). More conclusive evidence will require stronger neural markers of consciousness, which may require, in turn, better-grounded theories of consciousness.[1,28] (For a review of theoretical predictions on infant consciousness, see Passos-Ferreira[1]).

These recent developments have led to some striking convergence among consciousness theorists on the question of infant consciousness. In the last few decades, there has been a disagreement between *cognitive* theories of consciousness (such as global workspace theory and higher-order theories of consciousness) in which consciousness is fundamentally a cognitive phenomenon involving cognitive processes in the prefrontal cortex and *sensory* theories of consciousness (such as recurrent processing theory and integrated information theory) in which consciousness is fundamentally a sensory phenomenon involving processes in sensory cortex. For a long time, because sensory processes mature before cognitive processes in brain development, sensory theorists tended to accept that newborn infants are conscious, while cognitive theorists tended to deny it.[1] Recently, evidence from oddball paradigms, functional connectivity, and other sources has tended to suggest that cognitive processes relevant to consciousness, although immature, are functional earlier than had been thought. As a result, even some cognitive theorists[6,11,17] have agreed that there is evidence that newborn infants are conscious. This suggests that differences among theorists of consciousness are consistent with progress on the question of infant consciousness.

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References

1. Passos-Ferreira, C. (2023). Are infants conscious? Phil. Perspect. *37*, 308–329. https://doi.org/10.1111/phpe.12192

2. Goksan, S., Hartley, C., Emery, F., Cockrill, N., Poorun, R., Moultrie, F., Rogers, R., Campbell, J., Sanders, M., Adams, E., Clare, S., Jenkinson, M., Tracey, I., and Slater, R. (2015). fMRI reveals neural activity overlap between adult and infant pain. eLife, *4*, e06356. https://doi.org/10.7554/eLife.06356

3. Bekinschtein, T.A., Dehaene, S., Rohaut B, Tadel F, Cohen L, and Naccache L (2009) Neural signature of the conscious processing of auditory regularities. Proc Natl Acad Sci; *106* (5):1672-7. https://doi.org/10.1073/pnas.0809667106

4. Kouider, S., Stahlhut, C., Gelskov, S.V., Barbosa, L.S., Dutat, M., de Gardelle, V., Christophe, A., Dehaene, S., and Dehaene-Lambertz, G. (2013). A neural marker of perceptual consciousness in infants. Science *340*, 376–380. https://doi.org/10.1126/science.1232509

5. Koch, C., Massimini, M., Boly, M., and Tononi, G. (2016). Neural correlates of consciousness: progress and problems. Nature Reviews Neuroscience *17* (5), 307–321. https://doi.org/10.1038/nrn.2016.22

6. Basirat, A., Dehaene, S., and Dehaene-Lambertz, G. (2014). A hierarchy of cortical responses to sequence violations in three-month-old infants. Cognition *132*, 137–150. https://doi.org/10.1016/j.cognition.2014.03.013

7. Moser, J., Schleger, F., Weiss, M., Sippel, K., Dehaene-Lambertz, G., and Preissl, H. (2020). Magnetoencephalographic signatures of hierarchical rule learning in newborns. Dev. Cogn. Neurosci. *46*, 100871. https://doi.org/10.1016/j.dcn.2020.100871

8. Demertzi, A., Soddu, A., and Laureys, S. (2013) Consciousness supporting networks. Curr Opin Neurobiol. *23* (2), 239–244. https://doi.org/10.1016/j.conb.2012.12.003

9. Hu, H., Cusack, R., and Naci, L. (2022). Typical and disrupted brain circuitry for conscious awareness in full-term and preterm infants. Brain Commun. *4*, fcac071. https://doi.org/10.1093/braincomms/fcac071

10. Sylvester, C.M., Kaplan, S., Myers, M.J., Gordon, E.M., Schwarzlose, R.F., Alexopoulos, D., Nielsen, A.N., Kenley, J.K., Meyer, D., and Yu, Q. (2023). Network-specific selectivity of functional connections in the neonatal brain. *Cerebral Cortex*, *33* (5) 2200–2214. https://doi.org/10.1093/cercor/bhac202

11. Dehaene-Lambertz, G. (2024). Perceptual Awareness in Human Infants: What is the Evidence? J. Cognit. Neurosci. *1–11*. https://doi.org/10.1162/jocn_a_02149

12. Bayne, T., Frohlich, J., Cusack, R., Moser, J., and Naci, L. (2023). Consciousness in the cradle: on the emergence of infant experience. Trends Cogn. Sci. *27*, 1135–1149. https://doi.org/10.1016/j.tics.2023.08.018

13. Hochmann, J.-R., Kouider, S. (2022). Acceleration of information processing en route to perceptual awareness in infancy. Curr. Biol. *32*, 1206–1210.e3. https://doi.org/10.1016/j.cub.2022.01.029

14. Dopierala, A.A.W., and Emberson, L.L. (2022). Cognitive development: Looking for perceptual awareness in human infants. Curr. Biol. *32*, 322–324. https://doi.org/10.1016/j.cub.2022.02.045

15. Leroy, F., Naik, S., Gulbinaite, R., Palu, M., and Dehaene- Lambertz, G. (in prep.). Probing a global workspace in infants.

16. Pitts, M., Padwal, J., Fennelly, D.,, Martínez, A., and Hillyard, S.A. (2014). Gamma band activity and the P3 reflect post-perceptual processes, not visual awareness. NeuroImage *101*, 337–350. https://doi.org/10.1016/j.neuroimage.2014.07.024

17. Mashour, G.A., Roelfsema, P., Changeux, J.P., and Dehaene, S. (2020) Conscious processing and the global neuronal workspace hypothesis. Neuron. *105* (5):776–798. https://doi.org/10.1016/j.neuron.2020.01.026

18. Kozuch, B. (2023) A new low: Reassessing (and revising) the local recurrency theory of consciousness. British Journal for the Philosophy of Science. https://doi.org/10.1086/727890

19. Lamme, V.A.F. (2018) Challenges for theories of consciousness: seeing or knowing, the missing ingredient and how to deal with panpsychism. Phil. Trans. R. Soc. B, *373*, 20170344. http://dx.doi.org/10.1098/rstb.2017.0344

20. Nakashima, Y., Kanazawa, S., and Yamaguchi, M.K. (2021). Perception of invisible masked objects in early infancy. Proc. Natl. Acad. Sci. USA *118*, e2103040118. https://doi.org/10.1073/pnas.2103040118

21. Nakashima, Y., Kanazawa, S., and Yamaguchi, M.K., (2024). Metacontrast masking is ineffective in the first 6 months of life. Cognition *242,* 105666. https://doi.org/10.1016/j.cognition.2023.105666

22. Fahrenfort, J.J., Scholte, H.S., and Lamme, V.A.F. (2007). Masking disrupts reentrant processing in human visual cortex. J. Cogn. Neurosci. *19*, 1488–1497. https://doi.org/10.1162/jocn.2007.19.9.1488

23. Ciaunica, A., Safron, A., and Delafield-Butt, J. (2021) Back to square one: the bodily roots of conscious experiences in early life, Neuroscience of Consciousness, *7* (2), 1-10. https://doi.org/10.1093/nc/niab037

24. Frohlich, J., Bayne, T., Crone, J.S., DallaVecchia, A., Kirkeby-Hinrup, A., Mediano, P.A.M., Moser, J., Talar, K., Gharabaghi, A., and Preissl, H. (2023) Not with a "zap" but with a "beep": Measuring the origins of perinatal experience. Neuroimage; *273*, 120057. https://doi.org/10.1016/j.neuroimage.2023.120057

25. Lagercrantz, H., (2014). The emergence of consciousness: science and ethics. Semin. Fetal Neonatal Med. *19*, 300–305. https://doi.org/10.1016/j.siny.2014.08.003.

26. Panzani, M., Mahmoudzadeh, M., Wallois, F. and Dehaene-Lambertz, G. (2023). Detection of regularities in auditory sequences before and at term-age in human neonates, NeuroImage, *284*, https://doi.org/10.1016/j.neuroimage.2023.120428

27. Moser, J., Schleger, F., Weiss, M., Sippel, K., Semeia, L., and Preissl, H. (2021). Magnetoencephalographic signatures of conscious processing before birth. Developmental cognitive neuroscience, *49*, 100964. https://doi.org/10.1016/j.dcn.2021.100964

28. Kirkeby-Hinrup, A., and Overgaard, M. (2023). Ontogenetic emergence as a criterion for theories of consciousness: Comparing GNW, SOMA, and REFCON. PhiMiSci, *4*. https://doi.org/10.33735/phimisci.2023.9902

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