Seminars in Fetal & Neonatal Medicine 19 (2014) 300–305

Contents lists available at ScienceDirect

Seminars in Fetal & Neonatal Medicine

journal homepage: www.elsevier.com/locate/siny

Review

The emergence of consciousness: Science and ethics

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Keywords:
Consciousness
Resting-state activity
Newborn
Fetal life
Prematurity

SUMMARY

The newborn human infant is conscious at a minimal level. It is aware of its body, itself and to some extent of the outside world. It recognizes faces and vowels to which it has been exposed. It expresses emotions like joy. Functional magnetic resonance imaging of the newborn brain shows highest activity in the somatosensory, auditory, and visual cortex but less activity in association area and the prefrontal cortex as compared with adults. There is an incomplete default mode network which is assumed to be related to consciousness. Although the fetus reacts to pain, maternal speaking, etc., it is probably not aware of this due to the low oxygen level and sedation. Assuming that consciousness is mainly localized in the cortex, consciousness cannot emerge before 24 gestational weeks when the thalamocortical connections from the sense organs are established. Thus the limit of legal abortion at 22–24 weeks in many countries makes sense. It should also be possible to withdraw or withhold life-saving therapy of extremely preterm infants, especially if they are severely brain-damaged. This may also apply to full-term infants with grade III hypoxic–ischemic encephalopathy, who show no signs of consciousness.

1. Introduction

What is it like to be a bat? This important question was asked by Thomas Nagel in 1974 and has been discussed by philosophers ever since [1]. Nagel chose the bat as an example since it is so different from the human. It hangs upside-down and uses sonar to communicate. What is it like to be a human fetus or a baby? The fetus is also usually positioned upside-down and listens to the filtered voice of the mother. The newborn infant spends most of its time in a horizontal position and starts to imitate the facial expressions of adults, and it absorbs phonemes, which actually begins before birth. To what extent the newborn infant is conscious is discussed in this updated version of previous reviews [2,3]. The emergence of consciousness is related to the neurobiological and psychological development of the brain [4]. The question of what it's like to be a fetus may be elusive, but it does have important clinical implications.

1.1. Definition

A simple definition of consciousness is awareness of the body, oneself and the outside world. Consciousness is characterized with access to one's autobiography and mental time, self-description, and self-agency [5,6]. It is important to distinguish between the states of consciousness, i.e. wakefulness, sleep, coma, and general anaesthesia versus the content of consciousness. There is some controversy whether rapid-eye movement (REM) sleep with dreaming should be regarded as a conscious or non-conscious state. Since purposeful movements are usually not performed and cortex is not activated to the same extent as during wakefulness, it should be regarded as an essentially unconscious state. Furthermore, insight and self-reflection are absent during dreams.

With the new brain-imaging techniques it is now possible to investigate the processing in the brain. However, there is still a 'hard problem' [7] – how to bridge the gap from electrochemical events to subjective feeling [8].

1.2. Models

There are several theoretical models of consciousness. The Integrated Information Theory (IIT) has been proposed by Giulio Tononi [6]. It postulates that one can be conscious of multiple things and that they are highly integrated. For example, one can be conscious of uncountable scenes from all the movies one has seen. Experiences are highly integrated. Whereas family photos in a laptop are usually unlinked, they are very much integrated in the brain with memories. A number of neuronal circuits are involved in the integration of all the conscious experiences. This can be further estimated mathematically.

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http://dx.doi.org/10.1016/j.siny.2014.08.003
1744-165X/

Another model has been proposed by Jean-Pierre Changeux and Stanislas Dehaene [9,10]. Whenever we become conscious about something it can be retained in the working memory. It can then be processed in the global neuronal workspace (GNW), a number of long neurons interconnecting various hubs in the brain. In this way the impression from any sense organ such as a familiar face or voice, a taste or a smell can be associated with old memories and integrated. This can be tested by a special technique called ‘masking’. A face is shown briefly followed by a mask. It is registered in the primary visual cortex but the subject does not seem to be aware of it. If it is shown for a little longer, hubs in the whole brain are activiated, particularly the GNW. This activation is associated with the presence of event-related potentials which have been demonstrated in 5-, 12- and 15-month-old infants. Thus conscious perception is already present in infancy [11].

2. Neural correlates of consciousness

Human consciousness is assumed to be mainly localized in the cerebral cortex [5]. The ‘atoms’ of consciousness, i.e. the neurons, proliferate mainly between the 10th to the 20th gestational week [4]. There does not seem to be any neurogenesis in the cortex after birth [12]. The neurons begin to sprout, developing dendritic spines, during the third trimester. Synaptogenesis is also kindled during this period to peak at about one year after birth [13]. The ‘synaptic crosstalk’ between the neurons is essential for consciousness.

A prerequisite for the emergence of consciousness is that the thalamocortical fibers have developed [14]. The neurons from the sensory organs (except olfaction) terminate in the subplate of the cortex before about the 25 weeks of gestational age (Fig. 1). The subplate may be up to four times thicker than the cortical plate and serves as a waiting zone and as a guidance hub for the afferents from the thalamus and other areas of the brain. Subsequently the ingrowth of thalamocortical axons in the somatosensory, auditory, visual and frontal cortex commences. However, the corticocortical neuronal circuits develop later during infancy.

The immature brain circuitries are reflected by the pattern of the electroencephalogram. This has been found to be discontinuous in preterm infants interrupted by so-called spontaneous activity transients (SATs) or spindle bursts, which can be observed at about 23–24 weeks of gestation [15]. They may be generated by immature neurons establishing their connectivity. This is also reflected by the patterns of the somatosensory-evoked potentials [16] (Fig. 1).

2.1. Spontaneous resting state activity

Even without any task performance, there is a low-frequency spontaneous intrinsic brain activity as detected first with positron emission tomography and then with functional magnetic resonance imaging (fMRI). These fluctuations in blood-oxygen-level-dependent signals are called the resting activity, since it is not task-based. It corresponds to the uncensored thinking as random episodic memory, retrieving past experiences and planning for the future. It may also correspond to daydreaming and the inner monologue. This activity is localized in the so-called default mode network, including the cingulate, precuneus, and the dorsal and ventral prefrontal cortex [17]. It involves association areas with memories and the self-referential hub.

These signals – ‘slow cortical potentials’ – are generated by long-lasting depolarizations in the apical dendrites of superficial cortical pyramidal cells and closely related to the fMRI signals. They carry large-scale information integration. This makes sense since ‘conscious experience is always unitary and undivided whole’. This activity may correspond to the idea of William James that there is a ‘stream of consciousness’. It fits also with the global neuronal workspace model involving long branched neurons connecting the hubs for input from the sense organs with the working memory and association areas storing old memories.

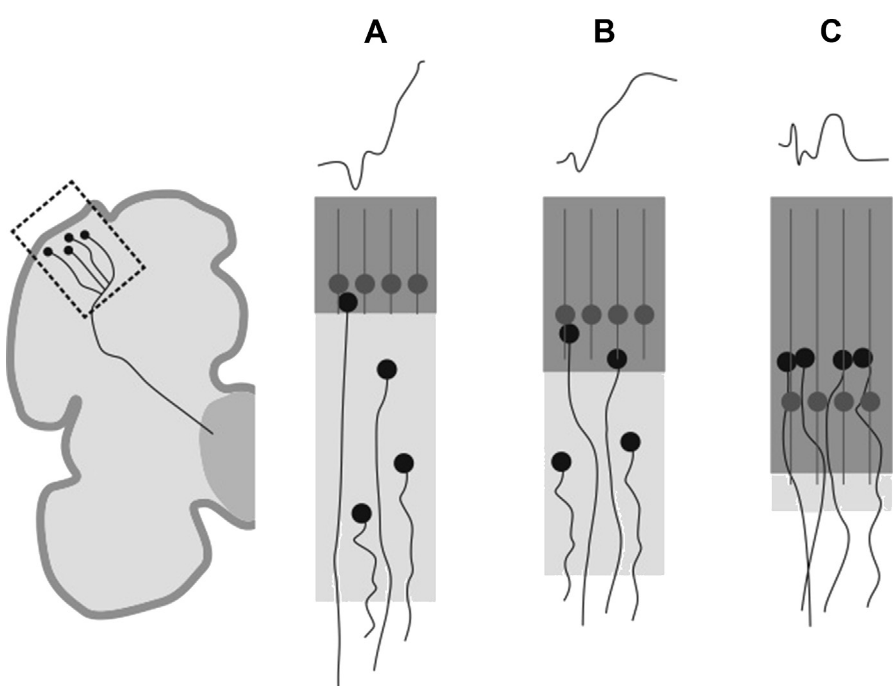

Fig. 1. Maturation of thalamocortical connections and somatosensory-evoked potentials. In early preterm infants (<24 gestational weeks) the neurons from the sensory organs terminate in the subplate (the waiting zone) (A). After 24 weeks they start to make connections in the cortical layer (B) and reach the final destination at term (C). This is also reflected by the patterns of spontaneous activity transients and somatosensory-evoked potentials. Modified after Vanhatalo et al. [16].

Resting-state networks have also been found in preterm infants at term age [18] and full-term infants soon after birth [19]. They encompass the occipital, somatomotor, temporal, parietal, and anterior prefrontal cortices. Thus the newborn brain can no longer be regarded as blank.

According to graph theory, five cortical hubs with high levels of connectivity have been identified in the primary sensory and motor regions of the infant brain (Fig. 2) [19]. By contrast, in adults ten hubs have been identified including the insula, precuneus and ventromedial prefrontal cortex. These findings seem logical; the infant is probably only aware of what it feels, sees, and hears in present time, whereas the adult relates the sensory input to memories, to itself, and to plans for the future. The default mode network was found to be incomplete by Fransson et al. [19], but more mature by Doria et al. [20].

Resting state activity has also been found in the fetal brain during the third trimester. However, the primary sensory cortex did not seem to be involved [21] in contrast to the findings in newborn babies. More connectivity was found along the medial–lateral axis than on the posterior–anterior axis [22]. Significant bilateral connectivity was found in about half of the tested areas.

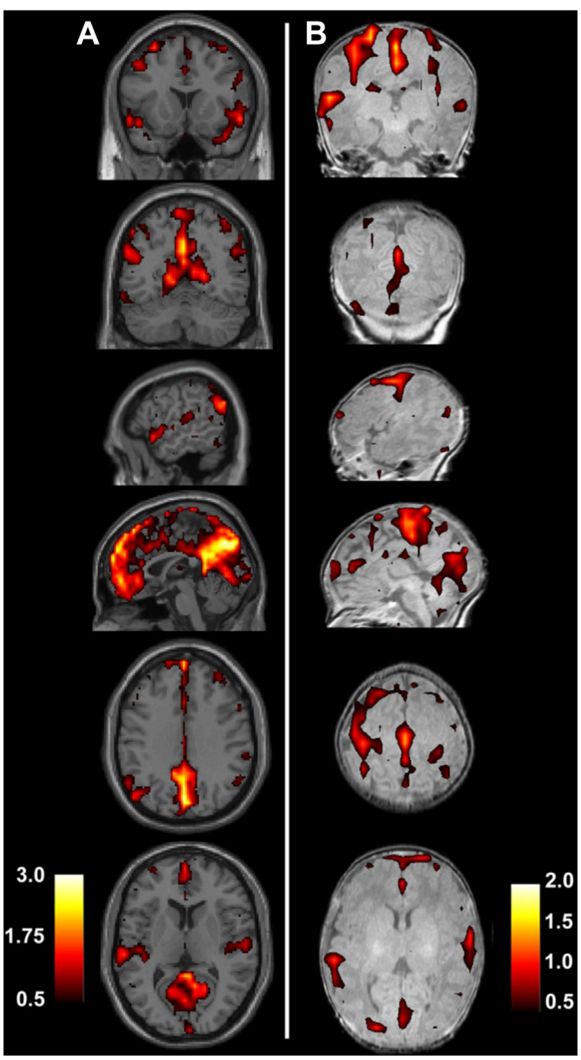

Fig. 2. Cortical hubs in adults (A) versus infants (B) analyzed by graph theory. Precuneus, cingulate cortex, medial prefrontal cortex, and insula are the main hubs in adults, whereas the hubs in the infant are located in the auditory, visual, and sensorimotor areas and to a lesser extent in the prefrontal cortex. From Fransson et al. [36].

3. Psychological criteria of consciousness

The basic criteria of consciousness involve the individual's awareness of its body, itself and the outside world. However, it is also important to be awake, to communicate with others, and to express emotions. To be conscious is thinking of the past and planning for the future, according to Henri Bergson. This certainly does not apply to the newborn infant, who is living very much in the present. But the infant probably fulfills some of the more basic criteria of being conscious in contrast to the fetus who is probably not conscious.

3.1. Awakefulness

A commonsense definition of awakefulness according to John Searle is those states of sentience and awareness that typically begin when we awake from a dreamless sleep and continue until we go to sleep again, or fall into coma, or die, or otherwise become ‘unconscious’ [8]. With this definition the fetus and the preterm infant born before 24 weeks are never conscious. The fetus and newborn infant spend most of their time in active sleep and are thus potentially dreaming. However, dreaming is tightly linked to the ability to imagine things visually, which is less likely to occur in the fetus and the extremely preterm infant. The fetal sheep, which has been studied extensively through a plexiglass window in the uterine wall, seems never to wake up and make purposeful movements [23]. It reacts to noxious stimuli such as pinching with inhibition rather than arousal.

The fetus is living at a very low oxygen level (‘Mount Everest in utero’) which probably suppresses fetal activity by increasing the level of adenosine. This degradation product of ATP acts as a sedatory neuromodulator. The level of the neurosteroid pregnenolone produced by the placenta is more than ten-fold higher in fetal blood [24]. Prostaglandin E_2 also occurs at higher concentrations and sedates the fetus.

On the other hand, the important neurotransmitter gamma-aminobutyric acid (GABA) is excitatory during early fetal life [4]. Thus there is probably a high activity in the fetal brain, which is of importance for the neuronal wiring. This noise in the fetal brain may be related to dream activity but it lacks integration and coherence and is less likely to generate consciousness.

The newborn infant seems to be awakened at birth. The eyes become wide open, usually with large pupils, and it may cry. This arousal is probably triggered by the stress of being born [25,26] and the transition from the warm environment in the womb to the cooler extrauterine environment. The evaporation of amniotic fluid has this cooling effect [27] even in a tropical milieu. This also triggers the first breaths of air. Cooling the fetal sheep can actually trigger deep respiratory movements. Since ancient times the first breaths of air have been regarded as the ignition of life, as indicated by the word ‘spiritus’. The newborn becomes animated in this way, and consciousness emerges. In modern times the Nuffield Council on Bioethics stated that the moment when the newborn ‘encompasses the capacity to breathe either independently, or with the support of a ventilator is the moral and legal point when human life must be preserved independent of gestational age’ [28,29].

The stress of being born is probably mainly due to the squeezing and squashing of the fetal head during vaginal delivery. This triggers an enormous catecholamine surge resulting in about 20-fold higher levels in umbilical arterial blood [27]. There is probably a parallel surge of the noradrenergic activity in the brain originating from the locus coeruleus, as indicated by studies of newborn rats [30].

The locus coeruleus is responsible for the arousal. After elective cesarean section, less catecholamines are released, which also has been shown to delay the transition at birth. However, the cooling and clamping of the umbilical cord, and the removal of the above-mentioned placental suppressors, seem to be sufficient to awake the newborn after cesarean section.

The cholinergic system, which also is important for vigilance, may also be activated at birth. Transgenic mice lacking the β_2-subunit of the nicotinic acetylcholine receptors do not arouse to the same extent as wild-type mice [31].

3.2. Awareness of the body and of the self

Newborn infants react differently when they are touched by another person than themselves: they must have some awareness of their own bodies [32]. They have a proprioceptive sense of their own bodies. They feel the world – they don't just sense it [33].

Newborns imitate gestures. Reciprocal imitation games support social bonding and affiliation. The 'like me' concept gives rise to a life-long ability to connect with other persons. This is vital for our survival as a species.

Imitation is mediated by mirror neurons, which seem to mature early in life. Neural mirroring mechanisms establish prelinguistic mapping between self and others [34]. This includes the anticipation of emotional reactions of other people. Thus, infant imitation is not an automatic uncontrolled impulse but under intentional control.

3.3. Sensory perception

Not only must sensory impressions be sensed but they must also be perceived if the fetus or infant is conscious. Assuming that consciousness is mainly processed in the cerebral cortex, the thalamocortical connections must be established. This does not occur until around gestational weeks 23–25 [14]. Before that time, the neurons from all the sensory organs end in the subplate, waiting for entrance to the cortex, except the neurons from the olfactory organ in the nose, which bypass the thalamus. Thus, for anatomical reasons it seems less likely that fetuses or extremely preterm infants can be conscious. However, after about 24 weeks sensory impressions can be processed at a cortical level, which is also suggested by the finding of spontaneous resting activity in primary visual areas and the somatosensory and auditory cortices of the newborn brain [35].

3.3.1. Pain

Pain can elicit withdrawal reflexes and release of cortisol, beta-endorphin and noradrenaline from about the 20th gestational week. These physiological reactions are mediated at levels below the cerebral cortex. From about 25 weeks, cortical responses in the somatosensory area have been recorded by near-infrared spectroscopy (NIRS). Facial expressions similar to those of adults sustaining pain have been observed in preterm infants after 25 weeks. Thus, these preterm infants are probably conscious of pain. Since the fetus is exposed to high endogenous sedatory and analgesic substances, it may not be conscious of pain even after 25 weeks. The fetus seems to be protected from noxious stimuli during birth. Vitamin K injection administered within an hour after vaginal delivery did not evoke any reaction, by contrast with infants delivered by cesarean section [36]. This could be due to the effect of oxytocin, which hyperpolarizes the GABAergic neuronal membranes.

3.3.2. Smell and taste

The fetus can probably smell from about the 20th week. It may remember certain smells and tastes to which it has been exposed after birth.

Newborns seem to remember the smell of amniotic fluid [37], which attracts them more than other cues. Behavioural responses to smell can be recorded in preterm infants from about the 29th week. Olfaction is processed in the orbitofrontal cortex, which has been demonstrated with NIRS. Pleasant smells such as vanilla and colostrum evoked increased hemodynamic responses [38] in contrast to unpleasant smells, e.g. the smell of disinfectant or detergent [39].

3.3.3. Vision

Newborn infants were previously assumed not to be able to see or recognize anything – they only saw a fog. Although their acuity is only about 0.1, several studies have demonstrated that s/he can process complex visual stimuli, recognize and imitate facial expressions [40]. They have developed preferential looking, and look longer on patterned than on grey fields. Even very preterm infants seem to fix the sight of their mothers briefly. Human newborn infants have an inborn capacity for face recognition, which is of crucial importance for the development of social networks.

3.3.4. Hearing

The cochlea becomes structurally developed from about the 18th gestational week, although the auditory does not function until after the 26th week when brainstem-evoked responses can then be recorded [41]. The fetus may react to sound by tachycardia from the 20th week. Cortical activation to sound was detected in the fetus from the 33rd week. The full-term infant can orient sounds by turning the head towards the source. If they are shown an object at the same time, they will move their eyes towards the sound rather than towards the object, indicating that hearing is more mature than seeing at birth.

3.4. Memory and language

Memory is a crucial component of consciousness. Our impressions are usually related to memories. Habituation – a very short-term memory – has been demonstrated in the human fetus at around 22–23 weeks of gestation. Fetuses exposed to repetitive vibrations of an electric toothbrush react with movements until habituation to the stimulus, with no further reaction [42].

Newborn infants remember sounds, melodies, and rhythmic poems they have been exposed to during fetal life [43]. Newborn infants can also learn a certain behaviour during sleep [44]. At about two months of age they form some kind of mental representation of faces and things [34]. Thus Piaget's concept 'out of sight, out of mind' may apply only before two months, not half a year as formerly believed.

Language is also an important component of human consciousness. The word 'infant' actually means someone without language. Newborns have been found to be able to discriminate between languages belonging to different rhythmic families [45]. Swedish newborn infants showed recognition when they were exposed to the vowel |y| by slowly sucking a pacifier with a pressure device, whereas they sucked vigorously when they heard the sound |i|, less common in Swedish [46]. American newborn infants behaved in the opposite way, seeming to recognize |i| but not |y|.

Preterm infants born two to three months before term distinguished spoken syllables in a similar way as adults. This was found by measuring cerebral blood oxygenation with NIRS when exposing the infants to sounds such as 'ga' and 'ba' and female versus male voices [47].

3.5. Integration of multiple sensory modalities and memory

Full-term infants can connect what they see and what they hear. A well-established example is that newborn infants exposed to nociceptive stimuli can be calmed by sucking sucrose. To obtain optimal effect, a four-week-old baby must also see the caregiver, whereas this has less effect in younger infants. Thus, the infant is able to integrate sensory signals from different modalities. This is in contrast to reptiles. A snake has no concept of a particular prey, e.g. a mouse, and no perception of object constancy i.e. it has no mental image of the prey. It is governed by sight to strike the prey, but, to start to swallow the head of the prey, it must use its smell. They lack the 'global conscious workspace' which develops later in evolution as well as during ontogenesis [2].

3.6. Emotions

Newborn human infants express so-called primordial emotions such as hunger and thirst [48]. The newborn infant is seeking for the breast areola soon after birth. The respiratory drive or 'hunger for air' which is initiated at birth can also be regarded as a primordial emotion. These primordial emotions can be regarded as marking the dawning of consciousness. An almost unique feature of the human newborn is the crying that follows awakening at birth. It may reflect a sign of discomfort with the new environment. It is probably essential to mobilize the caring instincts of the parents.

But the newborn infant also expresses facial expressions of joy (Fig. 3), particularly when it is taken up and placed at the mother's breast. Joy or hedonic feelings are important components of consciousness [49]. Fetuses may also show emotional facial expressions of pleasure and displeasure. Whether these should be regarded as signs of consciousness may be questioned.

4. Ethical implications

The capacity to be conscious can be regarded as the crucial sign of human life. It may be acceptable to terminate life-sustaining therapy when this is not fulfilled, for example chronically unconscious patients.

The newborn infant fulfills the criteria of displaying a basic level of consciousness. It is aware of its body and itself, and somewhat about the external world. It expresses emotions such as joy when cared and breastfed by the mother, and sorrow when subjected to pain. The fetus is asleep and probably not aware of itself and the environment. Thus it is hard to believe that it can be conscious. However, it is potentially conscious if it is born from around the 25th gestational week, when it can survive outside the womb and the thalamocortical connections become established. It can also develop into a thinking human being and become 'one of us' according to Michael Gazzaniga [50], a former member of the American President's Council on Bioethics. At this gestational age the fetus is protected from abortion according to the US Supreme Court.

Thus the preterm infant is probably conscious from around 25 gestational weeks. S/he can be awakened for brief periods and react to sensory and painful stimulation at a cortical level. Scoring infants when cared by Nidcap (Neonatal developmental care and assessment program) indicates that even very preterm infants are autonomic individuals [51]. They should receive the same respect as adult patients.

Extremely preterm infants born before 25 weeks are probably not conscious at birth. They do not wake up and show signs of consciousness. Their thalamocortical connections have not yet been established. However, since the survival rate of infants born in the 23rd week is >50% [52], it is difficult to set the earliest limit for receiving complete neonatal intensive care at 25 weeks. There must also be a security zone, with regard to wrong calculation of the gestational age. Therefore infants born at 23 weeks should probably be taken care of.

However, it might be legitimate to withdraw or withhold life-saving therapy if the extremely preterm infant shows signs of severe brain damage. Artificial ventilation of full-term infants suffering from neonatal ischemic encephalopathy of grade III with limited ability to develop a reasonable level of consciousness can probably also be terminated. The decision should be made by the parents. By contrast, these recommendations do not apply to newborn infants with impairments but with the capacity to be conscious, for example infants with Down syndrome. These infants, as well as very preterm infants showing signs of consciousness, should be offered the same intensive care as older children or adults.

Fig. 3. Preterm infant at about 27th gestational week. This infant girl seems to be joyfully interacting with her mother. 'She is one of us' [51]. Photo by Ann-Sofi Ingman, RN, with the permission of the parents.

Practice points

- The newborn infant is conscious of pain, expresses emotions, feels joy, and should be treated as an individual person.
- This also applies to the preterm infant from about the 23rd gestational week, when the thalamocortical connections have been established.
- The fetus is probably not conscious, since it lives at a very low oxygen level, is sedated, and does not seem to wake up.
- Assessment of consciousness by psychological and biophysical methods is important in clinical practice.

Research directions

- To improve neuroimaging techniques in order to understand the neurobiology of consciousness.
- To understand how the human being develops its mind and its self.
- To study the relationship between disturbances of consciousness in early life and later neuropsychiatric disorders.
- To assess unconsciousness more accurately to be able to make ethical decisions with regard to life-saving treatment.

Conflict of interest statement

None declared.

Funding source

European Union 7th Framework grant no. 223767.

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