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.

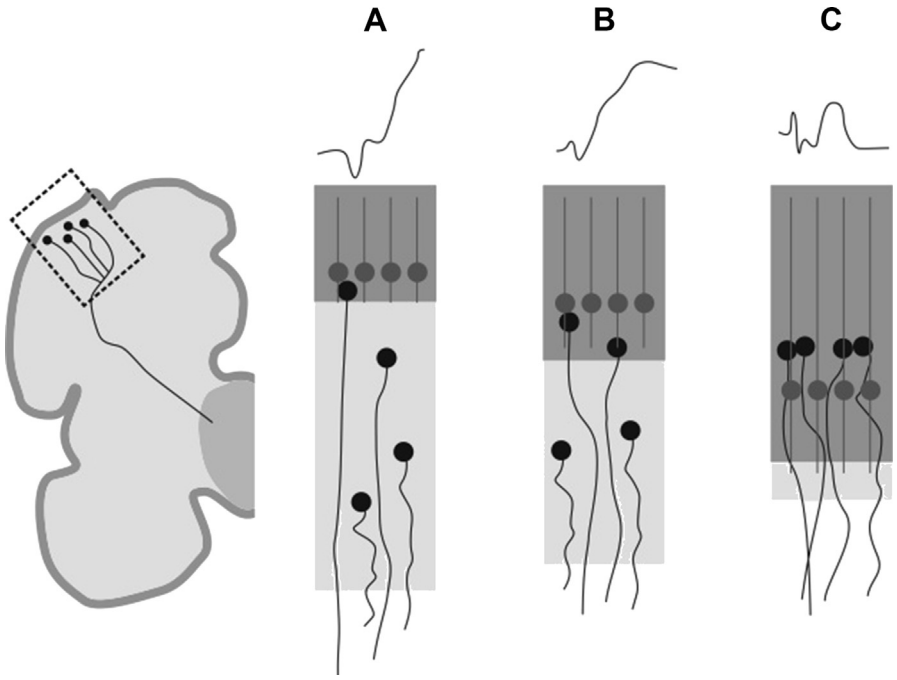

Fig. 1. Maturation of thalamocortical connections and somatosensory-evoked potentials. In early preterm infants (<24 gestational weeks) the neurons from the sensory organs terminate in the subplate (the waiting zone) (A). After 24 weeks they start to make connections in the cortical layer (B) and reach 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].