Medical Hypotheses 126 (2019) 135–148

Contents lists available at ScienceDirect

Medical Hypotheses

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

The near-death experience (NDE) as an inherited predisposition: Possible genetic, epigenetic, neural and symbolic mechanisms

James Lake

Center for Integrative Medicine, University of Arizona College of Medicine, Tucson, AZ, United States

The argument in overview

The paper is divided into four parts. In Part I, I review principle NDE models, important recent research findings and limitations of NDE research I remark on the absence of consensus on an explanatory model of NDEs. Part II begins with an overview of NDE evolutionary thinking up until now. I define an NDE *predisposition* as a specialized kind of higher cognitive trait and argue that this predisposition probably originated from a pre-adaptation that permitted early hominins to have self-reflective awareness and experience specialized states of consciousness involving complex mental imagery ensuring flexible adaptive responses to unpredictable or life-threatening situations. I argue that a model of evolutionary dynamics underlying an NDE predisposition must be contextualized in a more general theory that views body-brain-environment as a dynamic complex system influenced by biological, psychological and symbolic processes. I describe evolutionary scenarios that may have led to the origin and persistence of an NDE predisposition in populations through direct, indirect or neutral selection involving both biological and nonbiological inheritance mechanisms. Specifically, I examine the evolutionary dynamics of an NDE predisposition from the perspectives of multi-factorial fitness landscapes, the neuronal replicator hypothesis, socio-cultural, behavioral and symbolic inheritance systems. I contrast NDEs reported in the context of life-threatening situations to phenomenologically similar experiences that frequently take place in non-life-threatening contexts such as dreams and in trance. I examine claims of spiritual and psychological changes following both pleasant and frightening NDEs in the context of different evolutionary scenarios. In Part III I discuss possible neural mechanisms underlying evolutionary dynamics of an NDE predisposition. Topics covered include heritable modules that solve problems related to survival, implications of functional integration of the limbic system and neocortex, the concept of brain-to-brain replication of semantic information as a pre-adaptation required for socio-cultural transmission of NDE narratives as memes, and the possible roles of epigenetic mechanisms in shaping the inheritance and transmission of an NDE predisposition.

In Part IV I critique the various evolutionary scenarios discussed in the paper and argue that an NDE predisposition probably originated and persists through the operation of multi-factorial biological, social and symbolic processes that shape inheritance. I argue that an NDE predisposition could have resulted from direct or indirect selection or both direct and indirect selection depending on factors that shape evolutionary dynamics of different populations at different times. Finally, I make recommendations for improvements in methodology in near-death research broadly, and propose field studies that may clarify the relative contributions of genetic, epigenetic and social mechanisms influencing the evolutionary dynamics of an NDE predisposition.

Part I: background

Principle NDE models and recent research

Near-death experiences (NDE) have been characterized as “unusual, often vivid and realistic, sometimes profound life-changing experiences reported by people who have been either physiologically close to death, as in cardiac arrest or other life-threatening medical conditions or emergencies, or by people who believed that death was imminent [27,36].” NDE features vary significantly between individuals in ways that may be context-dependent (see below) hence there is no prototypical or *core* NDE. However, studies consistently report four recurring features: out-of-body experiences, ‘seeing a bright light,’ ‘encountering entities,’ and ‘feelings of peace [48].’ Individuals who have NDEs frequently report significant changes in values and beliefs, including increased spirituality, greater concern for others, a heightened sense of purpose and appreciation of life, and decreased fear of death [55,64,74]. It is important to note that not all NDEs are pleasant and some experiences are described as ‘nightmarish’ or ‘hellish’ however unpleasant NDEs are probably less common than pleasant NDEs. Estimates of the incidence of NDEs in the general population range from 9 to 18% [30,34]. Findings of a small retrospective study suggest that as many as 26% of individuals who are hospitalized following a suicide attempt have NDEs [82].

The paucity of evidence that NDEs *take place* in the actual moments of trauma or *anticipated* trauma, has led some writers to argue that at least *some* NDE features can be adequately explained on the basis of “retrospective imaginative reconstruction” of perceptions that take place when the brain is unconscious; memories of objects or events that may have been perceived just before losing consciousness or just after

E-mail address: contact@integrativementalhealth.net.

https://doi.org/10.1016/j.mehy.2019.03.016
Received 22 January 2019; Accepted 21 March 2019

regaining consciousness; or on the basis of expectations about what was "likely to have occurred" following return of "normal" waking consciousness [77]. Kelly & Kelly object to the memory reconstruction hypothesis, citing studies demonstrating that memory of events that take place just before or following loss of consciousness as typically experienced during general anesthesia are "usually confused or completely absent" – in contrast to the lucid states of consciousness and highly detailed recall typical of NDEs ([40], p. 387).

Numerous psychological, neurobiological and transpersonal models have been proposed in efforts to explain NDE phenomenology however no single model adequately explains all NDE features ([40]; Ch 6 pp. 367–421). Most neurobiological models emphasize abnormal serotonergic or medial temporal lobe activity [52,6] and argue that phenomenological resemblances between NDEs and psychedelic-induced experiences imply a common neural mechanism [53,69,9,10]. Subjective experiences reported during NDEs and states induced by psychedelics such as the serotonergic agent N, N-Dimethyltryptamine (DMT), share many features including a feeling of transcending the body, entering an alternative realm, and perceiving and communicating with sentient beings. In a small placebo-controlled open study 13 participants randomized to DMT versus placebo reported significantly more NDE-like features compared to the control group [73]. The study found an overlap in nearly all NDE and DMT-induced features. Further, individuals in the DMT group who reported more mystical experiences had higher NDE scores and also scored higher on scales measuring absorption compared to the control group. These findings are consistent with the hypothesis that the intensity and quality of both DMT-induced experiences and NDEs are related to an individual's capacity for absorption and possibly other personality traits [8]. In a large retrospective review Martial et al. [47] analyzed semantic similarities between over 15,000 narratives linked to 165 psychoactive substances, and 625 NDE narratives. Narratives obtained from individuals using the N-methyl-D-aspartate (NMDA) receptor antagonist ketamine and DMT most closely resembled NDE narratives. The above findings suggest that there is a significant overlap between psychedelic-induced experiences and NDEs, however large controlled studies are needed on a range of substances to clarify the relationships between NDE phenomenology and different neuropharmacological and neurophysiological mechanisms. Finally, although psychedelic studies suggest that serotonin probably mediates at least some NDE features, findings from animal and human studies (see below) cast doubt on models based on a single neurotransmitter system and suggest that complex psychological, cultural and neural processes probably mediate NDE phenomenology.

Findings of studies showing a "flat line" during a period of temporary loss of consciousness after which an NDE was reported following cardiopulmonary resuscitation are limited by the fact that widely used EEG recording methods may not be able to detect subtle electrical activity in the cortex, and provide no information about electrical activity in sub-cortical brain regions. In contrast to these findings, recent studies using specialized EEG recording techniques and sophisticated data analysis methods show that a surge of highly coherent brain electrical activity takes place in humans and rodents in the moments immediately before death. Two recent animal studies reported findings of transiently increased brain activity at near death [4,46] consistent with the hypothesis that NDE phenomenology is caused by transient, highly organized spikes of brain electrical activity at moments near-death. Li et al. [46] found consistent heart rate changes in rats undergoing experimental asphyxia, including four distinct stages starting with onset of asphyxia and ending in ventricular tachycardia and asystole. Continuous electrocorticographic recordings made using electrodes implanted in left and right frontal, parietal, and occipital lobes revealed increased coherence in the gamma band (65–115 Hz) and the theta band (5–10 Hz) between all cortical sites. Increased functional connectivity was found between frontal, parietal, and occipital cortices in multiple frequency bands. The degree of connectivity between neural networks, feedback, and feed-forward directions in which network connectivity between brain regions increased, and the frequency band in which connectivity was principally observed, varied in a consistent way in relationship to the stage of asphyxia. Significantly, the same pattern of dynamic variation in connectivity over time was found in all subjects. Increased cortical coherence and connectivity paralleled changes in cardiac rhythms (i.e., cortico-cardiac coherence) during asphyxia but not in healthy, awake animals prior to onset of asphyxia. A surge in cortico-cardiac connectivity took place in both feed-forward (from the heart to each cortical region) and feedback (from each cortical region to the heart) directions, and the degree of connectivity varied with respect to EEG frequency and stage-dependent changes in cardiac rhythm during asphyxia. In all subjects, cortical coherence declined precipitously at the onset of ventricular fibrillation which occurred in the moments immediately before asystole.

In another animal study Li et al. [46] found dramatic surges in the levels of multiple neurotransmitters in the rodent brain including norepinephrine, serotonin, dopamine, GABA, and acetylcholine in both frontal and occipital cortex which remained elevated as long as 20 min following onset of experimental asphyxia. The authors conjectured that surges in neurotransmitters in the first minute of asphyxia may help explain widely reported features of NDE phenomenology. They postulated that an observed 30-fold increase in central norepinephrine may be consistent with transiently increased alertness, attention, and arousal; a 12-fold increase in central dopamine may be consistent with increases in arousal, attention cognition, and affective emotions; and an observed 20-fold increase in central serotonin may help explain visual hallucinations and mystical experiences. Li et al. inferred from these findings that the observed surge in synchronized cortical gamma activity stimulated by asphyxia signifies an *internally aroused brain* consistent with the view that the mammalian brain is capable of high levels of complex information processing at moments near death.

Preliminary findings of a small case series (N = 7) of critically ill but neurologically intact patients hospitalized following cardiac arrest, show that a transient "spike" in high frequency (gamma wave) EEG activity takes place in the moments immediately before cessation of cardiac function when there is no discernible blood pressure [13]. In this small series, transient spikes in brain electrical activity were observed in roughly one half of individuals who subsequently succumbed in the I.C.U. following cardiac arrest. The authors speculated that end of life electrical surges (ELES) are triggered by a critical level of hypoxia that causes a loss in Na-K ion potentials in large numbers of neurons resulting in a cascade of electrical activity observed as a high frequency EEG current that rapidly dissipates as neurons lose their resting potential. In this model patients who are successfully resuscitated following cardiac arrest have vivid recall of images and memories triggered by a cascade of neuronal activity.

The finding of surges in coherent electrical activity at near death in both the rodent brain and the human brain suggests the involvement of common neural mechanisms in both species, and perhaps more broadly in other mammalian species. From these findings it can be inferred that the mammalian brain is highly activated at near death as evidenced by the ordered release of neurotransmitters in multiple brain regions, and a surge in previously unreported neurophysiological coherence that takes place in the cerebral cortex and heart at multiple frequency bands in the final moments of life. The finding of increased feedback and feedforward coherence between the cortex and the heart at moments near death suggests that modulatory influences take place in both directions, and affect both brain activity and cardiac function.

Limitations of NDE research

In recent decades there has been a shift away from investigations of spontaneous NDEs in diverse circumstances toward the study of NDEs that take place in controlled hospital settings following medical emergencies such as cardiac arrest in which an individual is being closely monitored [74]. The focus on identifying putative correlations between

NDEs and discrete neurophysiological factors has resulted in a paucity of data on the frequency of 'rescue efforts' (see below) and environmental and psychological factors that may play important roles in triggering NDEs. The high incidence rate of NDEs does *not necessarily* indicate the rate at which such experiences actually take place. French has pointed out, for example, that report or non-report of NDEs following cardiac arrest may reflect individual differences in memories, and that false memories may explain at least some NDE reports [19]. The ability to recall and talk about an NDE may be highly variable and influenced by personality and environmental factors that are difficult to measure, and may reflect differences in the medical or psychological context in which an NDE takes place. Further, the apparently low incidence of disturbing NDEs compared to pleasant experiences may be influenced by reluctance to share disturbing experiences, unconscious repression of traumatic memories, or biased sampling in survey studies favoring pleasant NDEs over unpleasant ones [29,24].

The findings of Chawla et al., Borjigin et al., and Li et al. [13,5,46] appear to corroborate each other and point to a specific neurophysiological mechanism linking reports of vivid imagery at near death and critically low brain oxygen levels. However, the significance of these findings is limited for several reasons. In an open letter published in the Proceedings of the National Academy of Sciences, Borjigin et al. [4] remarked on important differences between the methods and findings of their study on rats and methods used by Chawla et al. in their study of critically ill humans that preclude making generalizations from findings in rats to a neural mechanism underlying NDEs in humans. Borjigin et al. commented that it wasn't possible to compare their findings with the human data because the algorithm used by Chawla et al. to generate EEG data was proprietary. Further, scalp EEG electrodes used in the human study are not as reliable for recording high-frequency and low-amplitude brain activity as the intracranial electrodes used in the Borjigin et al. study on rats. Finally, the critically ill patients in the Chawla et al. study may not have been neurologically intact, possibly resulting in different EEG characteristics compared with patients who report near-death experiences, most of whom are cardiac arrest survivors with no known neurological deficits. In contrast, Borjigin et al. investigated brain function in healthy rats that were neurologically intact at the time of experimental asphyxia.

Another important limitation of NDE research is the absence of a method for determining relationships between the timing of specific neurophysiological processes and highly subjective experiences retrospectively interpreted as NDEs. The same methodological problems that preclude making generalizations about NDE mechanisms limit investigations of NDE-like experiences that take place in the context of intense fear, lucid dreams or altered states in the absence of acute physiological insults to brain function.

Absence of consensus on NDE model

The absence of agreement on an explanatory model of the NDE may reflect divergent world-views premised on non-reconcilable assumptions about the nature of human consciousness. Most theories of consciousness describe brain states related to perception or cognition, but fail to delineate processes that *cause* consciousness and do not explain how consciousness *causes* physical or mental processes. Scientific models of consciousness assume that NDEs—like all *mental experiences*—are *explainable* by neuroscience and will eventually be *fully explained* by current scientific theories. In contrast to science-driven explanations grounded in physicalism, transpersonal models not only *do not assume* the primacy of scientific explanation but posit a different *order* of reality all together in which human consciousness may function independently of the brain or possibly outside of so-called *ordinary* space–time. Along these lines Kelly and Kelly have argued that contemporary science grounded in physicalism cannot provide an adequate model of complex relationships between brain function and consciousness [40]. A future more integral theory of consciousness may be needed to adequately characterize complex dynamic relationships between established neurophysiological mechanisms and postulated quantum-like and other non-classical processes that may be associated with different aspects of conscious experience.

Part II: evolutionary scenarios

Following a concise review of previous writings on the possible evolutionary significance of NDEs, Part II explores scenarios for direct, indirect and neutral selection of an NDE predisposition.

NDE evolutionary models up to now: an overview

Numerous psychological models have been put forward in efforts to explain the evolutionary dynamics of an NDE predisposition. Noyes argued that individuals facing a life-threatening situation initially focus on the external environment and make efforts to save themselves but when circumstances overwhelm them, they direct their attention to internal experiences, including the flow of memories and the typical effects of the "mystical consciousness" [54]. Noyes & Kletti [57] described this as an adaptive form of depersonalization in response to life-threatening situations in which the individual dissociates from conscious awareness of pain and impending death, experiences increased speed of thought, and (in some cases) makes extraordinary efforts to save themselves ([57,58]). According to Noyes and Kletti "As long as any possibility of rescue remains, enormous energy may be directed toward life-saving actions." [56]. In one series, 50% of 189 NDE survivors of life-threatening accidents reported undertaking extraordinary physical or mental efforts to save themselves [59]. Survey respondents felt that their efforts were enhanced or made possible by changes in mental functioning during the NDE including a feeling of hyper-alertness, depersonalization and mystical states. Noyes & Kletti equated depersonalization in the context of NDEs to instinctual fight-or-flight reactions observed in animals (Noyes & Kletti, [56], p. 106). It is significant that changes in time perception take place in 78% of cases of NDEs [58,57]. Arstila [1] has proposed that the experience of increased 'speed of thought' commonly reported during NDEs alters the perception of time and makes the world seem slower permitting the individual to engage in purposeful rescue actions that can be life-saving. The correlation between changes in mental functioning and increased rescue efforts during NDEs may be consistent with an evolutionary scenario in which an NDE predisposition is directly selected because it increases survival probability.

Drawing on the early work of Noyes & Kletti, Evrard et al. [17] recently proposed a psychodynamic model that characterizes enhanced cognitive functioning reported during NDEs as *hyperembodied consciousness*, which they define as a component of a general adaptive psychosomatic response to the perception of imminent death. In contrast to neurophysiological models, Evrard et al. [17] argue that all biological causes of NDEs are secondary to the "fear of imminent death" and that the evolutionary value of NDEs can be seen as a confirmation of James McClenon's Ritual Healing Theory [50] which hypothesizes that a capacity to experience dissociative states and anomalous perceptions has a physiological basis that originated in early hominid evolution and enhanced the individual's ability to cope with trauma. According to the model, later hominids created rituals that conferred greater advantages on individuals with more developed dissociative capacities. This hypothesis is consistent with Greyson's view that NDEs are associated with altered states of consciousness that benefit individuals who have such experiences [26].

In contrast to NDEs triggered by physiological changes in the context of a life-threatening situation, NDE-like experiences that take place in non-life-threatening situations are triggered by a strong fear of dying in the absence of a life-threatening medical emergency [79,12]. On this basis Sabom [80] proposed a distinction between 'true' NDEs and NDE-like experiences in response to intense fear and a belief that death is imminent as "acute dying experiences" (ADEs) [80]. According to Sabom, the ADE consists of psychological dissociation and heightened arousal characterized by speeding thought, narrowing and sharpening perception, and preparation for action. In this model the ADE is a highly adaptive response in traumatic situations because it improves survival probability. Noyes and Slymen suggested that there is a continuum between the ADE and classical NDE in which some individuals report hyper-alertness but not mystical experiences while others report intense mystical experiences but not enhanced cognitive functioning [59]. In fact, survey findings show that most NDEs have both features [74,23]. Based on a large survey of NDE survivors Greyson has argued that "Surrender to the process of dying and to the possibility of death is strongly associated with near-death experiences and their affective and transcendental components" [25].

It is important to note that the above evolutionary arguments are based on psychological theories, and do not attempt to integrate findings from neuroscience or population genetics into a model of NDE evolutionary dynamics.

An NDE predisposition as a specialized higher cognitive trait

Contemporary evolutionary theory posits that refinements in the capacity for mental imagery and other so-called *higher* cognitive traits accrued gradually over millennia through natural selection, enhanced the fitness of small populations of proto-hominids and, following the invention of culture and language, spread rapidly in populations significantly enhancing the fitness of the human gene pool on a global level. In early humans a latent capacity for complex mental imagery, visual memory and abstract reasoning functioned as a pre-adaptation that led to *the possibility* of imagination—the capacity for making inferences about distant or future events based on visual memories or visual images constructed in the brain *de novo*. Through memory, imagination, anticipation of future events and associative reasoning, an almost infinite range of linguistic referents to objects and processes in the world and conceptual constructs representing those objects and processes became possible.

Genetic and non-genetic inheritance mechanisms that made possible the conservation of cognitive abilities or predispositions resulted in superior memory, reasoning and imagination and were strongly conserved in human populations since individuals that possessed these mental faculties increased the fitness of their respective reproductive and social groups relative to the gene pools of competing groups. Over countless generations genetic and epigenetic inheritance, drift, and—in historically recent times—social and cultural factors, gradually shaped higher cognitive traits optimizing advantages such traits conferred on different populations.

Direct, indirect and neutral selection

A comparison of NDE phenomenology across cultures reveals both common themes and significant differences in core NDE features [2]. The reasons for differences haven't been elucidated but may be related to variability in interpreting and verbalizing NDEs in the context of cultural differences. Because of the rapid pace and wide reach of globalization many traditional societies such as hunter-gatherers and herders, have been influenced by beliefs and values of Western culture which, in turn, may influence both the content and interpretation of NDEs [39].

Adaptationist and neutral perspectives

The evolutionary significance of the high incidence of NDEs can be interpreted along three distinct lines yielding disparate explanatory models. One model argues that an NDE predisposition exists and is subject to *direct* selection, confers fitness benefits on *H. sapiens* and plays a significant role in human evolution. Alternatively, the high incidence of reports of NDEs (between 9 and 18% [30,34]) may be an *epiphenomenon* which has no intrinsic evolutionary significance that results from selection of another trait to which it is genetically linked. A third possibility is that an NDE predisposition is a product of random genetic drift that persists at small stable rates in different populations and as in indirect selection, confers no fitness benefits on populations in which it takes place. Because most studies are retrospective it has not been established whether or to what degree particular NDE features may be related to specific precipitating factors such as acute changes in blood gases or neurotransmitters, psychological response to trauma, personality traits, culturally shaped expectations or other variables. By the same token, it has not been determined whether discrete physiological or personality factors or combinations of particular factors are predictive of NDEs.

Depending on the assumptions of a particular evolutionary model for an NDE predisposition, one may embrace either an *adaptationist* or a *neutral* perspective. The adaptationist perspective assumes that an NDE predisposition *directly* or *indirectly* contributes to fitness. In contrast the neutral perspective argues that the vast majority of mutations in animals (including hominins) have *neutral* effects on fitness because fitness-enhancing mutations are extremely unlikely to take place in genes whose contributions to fitness have *already been optimized* over millions of years of evolutionary history. The same kind of neutral effect would be expected with respect to frankly deleterious mutations which are seldom observed in nature because they are rapidly eliminated from the gene pool. In the neutral perspective, most mutations would be expected to have either *neutral* or *non-significant beneficial effects* on fitness. Both perspectives may offer plausible explanations of the evolutionary dynamics of cognitive capacities in hominins including a capacity for complex mental imagery however both perspectives also have limitations. It is important to contextualize arguments from both perspectives in a discussion of non-genetic (i.e., epigenetic, behavioral, symbolic) inheritance systems known to play a central role in human evolution.

Table 1 summarizes arguments developed in this paper purporting direct, indirect and neutral selection of an NDE predisposition and includes comments on possible evolutionary mechanisms.

The origin and dissemination of an NDE predisposition through the founder effect followed by adaptive radiation

The *founder effect* may help explain the origin, evolution and spread of an NDE predisposition and a latent capacity for transpersonal experiences broadly. In the founder effect random genetic drift in a small group results in a novel combination of genes manifesting as a highly adaptive new trait that significantly increases fitness resulting in rapid growth in population size and rapid dissemination of the new trait ([63], p. 53–54). Assuming that early hominins existed for the most part in widely separated small population centers, the founder effect may have resulted in rapid growth in size of populations that contained individuals who had highly adaptive insights or changes in behavior that enhanced group fitness following an NDE. Assuming that genetic drift resulted in a *neural preadaptation* for complex mental imagery in small isolated populations of early hominins it is plausible that fitness advantages conferred on populations containing such *gifted* individuals (i.e. individuals who have an NDE predisposition) would have resulted in differentially higher survival or population growth rates compared to populations with fewer or no *gifted* individuals.

Adaptive radiation refers to the emergence of ecological and phenotypic diversity in the context of rapid population growth and often takes place following a key innovation which opens new ecological niches or new paths for evolution of a species ([63], p. 53–54). Adaptive radiation also increases species fitness in new ecological niches resulting in novel evolutionary pathways that permit further evolutionary change ([63], p. 68). Assuming that an NDE predisposition resulted from the founder effect and represented a key innovation in

Table 1
Evolutionary models of an NDE predisposition.

Model	Argument	Possible mechanism(s)
Direct selection	An NDE predisposition is directly selected, strongly conserved and confers fitness benefits on populations	*Founder effect followed by adaptive radiation:* An NDE predisposition originated as a product of random genetic drift in one or more small populations, conferred fitness benefits that led to rapid growth in population size resulting in rapid dissemination of the new trait. *Social learning:* An NDE predisposition originated as a highly specialized consequence of symbolic communication of memes and other higher-level (i.e., non-genetic) inheritance mechanisms, conferred important fitness benefits, and was rapidly disseminated through horizontal transmission of epigenetic or symbolic information bypassing the need for genetic inheritance. *Multi-dimensional fitness landscape:* An NDE predisposition is a specialized cognitive phenotype that remains latent until it is released in response to critical biological, psychological, socio-cultural or environmental factors or cues in contexts in which its expression enhances fitness. NOTE: this model assumes that NDEs *can take place only in those persons in whom a latent capacity for NDEs is present* and that neuro-endocrinological *priming* required for activation of an predisposition takes place during development. *Epigenetic mechanisms:* An NDE predisposition is a product of heritable stress-induced changes in brain function originally caused by intense fear associated with actual or anticipated trauma subsequently activated by one or more epigenetic factors.
Indirect selection	An NDE predisposition is a *spandrel* resulting from direct selection of another trait or traits possibly including a capacity for vivid mental imagery or anomaly proneness, that itself confers fitness benefits	An NDE predisposition is an artifact of direct selection of a different, possibly related cognitive trait, that does not itself confer fitness benefits. *NDE-like experiences in non-life-threatening contexts:* Indirect selection may explain the high prevalence of experiences that are phenomenologically similar to NDEs that take place in *non-life-threatening* contexts including vivid dreams and trance states. In this scenario an NDE predisposition would be an indirect result of selection of a general predisposition to dissociative states or anomaly proneness (traits that may be associated with increased neural and cognitive connectivity, relatively greater creativity and increased vividness of mental imagery).
Neutral selection	An NDE predisposition resulted from random genetic drift in one or more small isolated populations and persists at relatively low but stable rates, and does not confers fitness benefits on populations in which it takes place.	Genetic differences associated with a predisposition for mental imagery (or more specifically an NDE predisposition) reflect intrinsic variability that is *neutral,* i.e.*, that does not* correspond to differentially higher degrees of fitness in different ecological contexts or in different populations. An NDE predisposition would be expected to be variably expressed in genetically isolated populations in relationship to unique multi-dimensional fitness landscapes shaping those populations.

human evolution, it is plausible that such an innovation resulted in rapid adaptive radiation manifesting as novel cognitive capacities and enhanced adaptive functioning in response to unpredictable changes in the environment. This model is consistent with an evolutionary scenario in which an NDE predisposition originated suddenly in small isolated groups of early hominins which subsequently increased in population size resulting in widespread dissemination of the predisposition.

The evolutionary dynamics affecting the transmission of an NDE predisposition probably shifted with the advent of agriculture which led to rapid growth in stable populations, large-scale migrations and genetic mixing among previously isolated populations.

The transmission of symbolic information and its possible role in the inheritance of an NDE predisposition

In genetic inheritance the direction of information transmission is vertical, i.e., from parents to offspring. In epigenetic inheritance information may be transmitted vertically (across generations) or horizontally (between individuals or groups that are contemporaneous). Therefore, to the extent that genetic inheritance is involved in the transmission of a novel trait, the origin and spread of the trait will require several generations to occur. In contrast, to the extent that inheritance of a novel trait involves epigenetic factors or socially mediated learning, there may be less or, in some cases, no requirement for genetic mechanisms underlying information transmission required for the dissemination of the trait. In socially mediated learning an individual "knows or does something or has a particular preference, influences another (naïve) individual in a way that makes the latter develop and practice a similar behavior or have a similar preference ([38], pp. 333–336)."

In the framework of social learning theory an evolutionary scenario that may explain the persistence of an NDE predisposition involves the rapid or widespread horizontal transmission of epigenetic or symbolic information required to establish a novel trait in a population bypassing the need for genetic inheritance. Jablonka & Lamb have suggested that an innate human predisposition for language may have emerged from continuous interactions between genetic, epigenetic and cultural systems of inheritance ([38], p. 340). In the same vein, it is plausible that multiple interacting environmental, biological and symbolic inheritance systems were necessary for the evolution and persistence of an NDE predisposition.

The emergence of symbolic communication in early hominins accelerated the rate of cultural change. Non-genetic inheritance systems soon began to play a central role in human evolution. The *higher-level* inheritance of symbolic communication has been a principle factor shaping evolutionary change in humans for millennia modifying traits established through *lower-level* biological inheritance based on genetic and epigenetic mechanisms ([38] p. 342). In this scenario an NDE predisposition may have originated as a highly specialized evolutionary consequence of symbolic communication and other higher-level inheritance mechanisms. In the symbolic communication inheritance model key innovations in the inheritance of early hominins presumably resulted in a general predisposition for experiences like the near-death experience. Assuming that symbolic inheritance also plays a role in the conservation of a predisposition for transpersonal experiences broadly, this self-reinforcing mechanism may help explain the pervasiveness of NDEs and possibly other kinds of transpersonal experiences. A contemporary neural interpretation of Jungian archetype theory may be consistent with the hypothesis that an NDE predisposition is an example of a recurrent universal symbol or *symbol pattern generator* that has its evolutionary roots in the *old mammal* brain (i.e., the limbic system) and remains largely outside of conscious awareness [61]. This model predicts that recurrent imagery associated with *old mammal* brain regions would be highly conserved, automatically *released* in response to stress, and emotionally highly charged [62].

A meme is a hypothesized *unit of cultural inheritance* analogous to a structural gene in terms of its role as a kind of *information-bearing replicator*. Memes are postulated to provide a mechanism for the transmission of symbolic information between individuals and across generations. ([38], p. 207). A meme may be phenotypically *expressed* as words, music, visual images or other symbolic manifestations of culture. Assuming that symbolic inheritance plays a central role in human evolution an NDE predisposition can be conceptualized as the phenotypic *effects* of one or more memes that are conserved in *H. sapiens* because of their contribution to *psycho-spiritual fitness*.

Memes may have played an important role in the evolution of human cognitive capacities as well as the origin and transmission of culture generally. Intra-brain replication of memes followed by brain-to-brain replication of semantic information in the form of interacting memes was probably a principle mechanism for cultural transmission. Because the evolution of memes depends on transmission of symbolic information or *meanings* between individuals and groups change takes place much more rapidly than evolution driven exclusively by genetic or epigenetic mechanisms. In this view an NDE predisposition may represent a complex meme or (more likely) the product of interactions between several memes including spiritual and cultural beliefs and values. Pigliucci & Muller have suggested that the *cognitive explosion phase* of human evolution was driven by intense competition between memes [20] resulting in the rapid emergence of different kinds of human cognitive capacities. Individual differences in an NDE predisposition—and possibly a predisposition for transpersonal experiences broadly—may reflect unique inter-individual differences in physiological, psychological or environmental factors that *prime* transpersonal experiences increasing the probability of their *expression* at the level of the individual or group in response to stress. In this view patterns of core features reported in a particular NDE may reflect unique interactions between memes, genes, epigenetic and environmental factors both developmentally and in the immediate moments leading up to the *release* or *expression* of the NDE.

Psychological changes following NDEs may enhance group fitness through increased social cohesiveness

From a group selection perspective, it is important to ask about potential fitness contributions of enhanced psychological and spiritual understandings of death widely reported following NDEs. Evidence that deeper psychological and spiritual understandings of death confer fitness advantages on a particular population or culture would constitute indirect evidence for group-selection benefits of NDEs. Surveys of NDE survivors consistently report permanent and dramatic changes in attitudes, beliefs and values resulting from positive after-effects of NDEs including increased spirituality, increased concern for others (i.e. empathy), heightened appreciation of life, heightened sense of purpose, decreases in fear of death, decreases in materialistic values and decreases in competitiveness [64,74,31,68,60]. However, as previously noted, not all NDEs are pleasant, and some NDEs are experienced as terrifying or 'hellish.' Survey studies have not identified particular contextual factors or personality traits that predispose to unpleasant NDEs and the relative incidence of frightening versus positive NDEs has not been clearly established [29,24].

It is significant that patients who experience cardiac arrest and report NDEs are more than twice as likely to die compared to patients who do not report NDEs ([40], p. 414). This observation may be consistent with two disparate hypotheses. On the one hand it is plausible that the relative depth or complexity of an NDE is strongly correlated with closer proximity to biological death predisposing the experiencer to greater subsequent biological vulnerability. In contrast to this biological explanation, NDEs may result in psycho-spiritual preparation or *integration* that makes dying easier. A possible role of NDEs in enhancing psycho-spiritual preparation for dying may be consistent with findings of a study on the frequency of daily spiritual experiences among 229 persons before and after a close brush with death [41]. While no correlation was found between the frequency of spiritual experiences before a close brush with death and the likelihood of having an NDE, persons who reported NDEs had more frequent spiritual experiences following a close brush with death compared to persons who did not report NDEs and the frequency of spiritual experiences was positively correlated with the depth of an NDE.

Positive changes in values and an increased frequency of spiritual experiences following NDEs would be expected to be associated with increases in positive interactions between NDE survivors and their kinship group or social peers. However, unpleasant or 'hellish' NDEs might be expected to have disruptive effects or neutral effects depending on the degree to which such experiences are recalled and how they are shared. In this scenario relatively greater social cohesiveness would be expected in populations in which pleasant NDEs are reported more frequently than unpleasant NDEs. Following the invention of agriculture and the establishment of large stable population centers it is plausible that changes in values and beliefs resulting from NDEs would be disseminated as memes both *horizontally* across different populations at a given time, and *vertically* over generations in the same population. In this scenario cultural transmission of positive values would constitute a non-biological inheritance mechanism resulting in rapid spreading of transformative insights about non-material or spiritual aspects of dying and death that might not otherwise take place or might occur less frequently in populations where NDEs are less often experienced or shared. Along the same lines, it is equally plausible that narrative re-telling of frightening NDEs could have led to the rapid dissemination of memes casting a fearful light on death and concepts of an afterlife. Memes from both pleasant and frightening NDEs could have led to shared beliefs and values resulting in greater social cohesion. In this scenario disparate memes resulting from narrative re-telling of both pleasant and frightening NDEs would have been constellated as disparate beliefs about death and an afterlife, orally transmitted as myths, and eventually formalized as religious and spiritual dogmas. This scenario is consistent with a general argument made by Pigliucci and Muller [63] (p. 139) that it is unlikely that mutation alone can explain the origin or persistence of a predisposition for transpersonal experiences broadly.

Evidence that a deeper spiritual understanding of death increases the cohesiveness of tribes is available from field studies of traditional societies showing beneficial social effects of death rituals and beliefs on measures of social cohesiveness [15]. However, a putative role of NDEs with respect to enhancing group social cohesiveness is not straightforward. While most surveys of NDE survivors from different cultures report widely shared features and positive changes in personality and values ([11], pp. 136–149; [39]) some surveys report negative social consequences of NDEs [24]. For example, some NDE survivors report difficulties integrating their experience into their day to day life, have relationship problems, become depressed, or don't share their experiences for fear of being ostracized by family members or society at large [32,64]. Other NDE survivors who experience changes in spiritual beliefs or values fail to integrate these changes into their day to day social life resulting in social isolation. In such cases it is likely that NDEs would have neutral or negative effects on group social cohesiveness [33].

Evolution of an NDE predisposition in the context of multi-dimensional fitness landscapes

Recent advances in evolutionary theory go beyond explanations of strictly genetic inheritance mechanisms of anatomical structures to considerations of complex multi-factorial mechanisms that generate phenotypic plasticity during development permitting organisms to respond rapidly to changing environmental conditions with novel highly adaptive behaviors ([63], p. 139).

The theory of multi-dimensional fitness landscapes provides useful tools for understanding traits influenced by multiple interacting factors. In contemporary evolutionary theory a *fitness landscape* specifies fitness components as unique sets of genotypes or phenotypes ([63], p. 46–49). An organism is conceptualized as a *point* on a fitness landscape and a population is represented as a *cloud of points* which changes its structure and position in response to disparate evolutionary factors such as natural selection, sexual selection, mutation, recombination, drift, and migration. The fitness landscapes of all organisms are shaped by thousands of genes that determine anatomy, physiology and behavior thus fitness landscapes are inherently both *highly dynamic* and *multi-dimensional*. In humans, fitness landscapes are shaped by biological as well as social and cultural factors. Selection of traits that enhance fitness in a specific environment results in a *high-fitness* landscape.

An NDE predisposition can be conceptualized as a specialized cognitive phenotype that can be described as a multi-dimensional fitness landscape that remains latent until it is released in response to critical biological, psychological, socio-cultural or environmental factors or cues ([63], p. 324). In this scenario the likelihood of a unique individual having a particular NDE is influenced by a combination of physiological, psychological, socio-cultural and environmental factors that trigger neural mechanisms resulting in the *release* an NDE in contexts in which the experience somehow enhances fitness at the level of the experiencer or the population. This evolutionary-developmental model is based on the assumptions that NDEs *can take place only in those persons in whom a latent capacity for NDEs is present* and that neuroendocrinological *priming* required for activation of an NDE predisposition takes place during development.

The occurrence of NDEs in non-life-threatening contexts may imply a general predisposition toward anomaly proneness

In contrast to NDEs that take place in the context of life-threatening situations humans frequently report experiences that are, for all intents and purposes, *phenomenologically identical* to NDEs but which take place in *non-life-threatening* contexts including vivid dreams, when using psychedelics, in response to intense fear, and in trance. Individuals who have experiences that are phenomenologically similar to NDEs in non-life-threatening situations typically resume their former roles in society and frequently report changed values, new spiritual beliefs, and loss of fear of death. Greyson has argued that the widespread occurrence of experiences resembling NDEs that do not occur in the context of life-threatening circumstances may be consistent with a more general predisposition to dissociative states [28]. Frequent reports of NDE-like experiences that occur in non-life-threatening contexts may be consistent with a multi-factorial model proposed by Roberts and Owen in which disparate kinds of physiological and psychological factors precipitate such experiences [65].

Individuals who report having an NDE are more than 3 times as likely to have had a previous experience that they retrospectively interpret as an NDE consistent with a relationship between a tendency to dissociate and an NDE predisposition [74]. A correlation between the likelihood of having one or more NDEs and dissociative tendencies is consistent with Hartmann's model of permeable barriers between supraliminal and subliminal levels of consciousness [35]. Individuals who have more permeable (i.e. *thinner*) barriers are more predisposed to have dissociative or *transliminal* experiences in which the degree of permeability varies with respect to numerous physiological and psychological factors [72–74,37]. Along similar lines, *anomaly proneness* has been proposed as a trait characterized by a propensity to have uncommon or unusual experiences including mystical experiences and transpersonal experiences ([66], p. 174–180). There is evidence that anomaly-proneness may be associated with increased neural and cognitive connectivity, as well as relatively greater creativity and increased vividness of mental imagery both of which would be expected to confer general evolutionary advantages. In this scenario an NDE predisposition may be only one component of a more general predisposition to anomaly proneness. The recent finding of a strong relationship between fantasy proneness and NDE-like experiences in individuals who are not facing life-threatening situations may be consistent with an evolutionary model in which boundary thinness and anomaly proneness confer general fitness benefits [49]. It is important to note that a clear link between NDEs and anomaly proneness has not been empirically established. As NDEs occur spontaneously in a variety of contexts their occurrence may be completely independent of a trait that predisposes individuals to dissociate or to have so-called *anomalous* experiences. Finally, even among near-death experiencers who meet criteria for anomaly proneness, it is impossible to determine whether anomaly proneness is a cause or after-effect of an NDE.

An important unanswered question in NDE research is whether there are differences in the extent to which individuals who experience NDEs and NDE-like experiences disseminate such experiences as memes that could potentially influence beliefs, values and behaviors and hence affect group fitness. Excluding cases in which NDE-like experiences take place in dreams or in altered states, all individuals who report NDEs have survived a situation that was life-threatening or *perceived* to be life-threatening. So-called *true* NDEs and NDE-like experiences are probably triggered by a multiplicity of overlapping physiological, psychological and cultural factors, and represent a seamless continuum of individualized responses to a variety of circumstances, perceptions and culturally shaped expectations. Strengthened social bonds, reduced fear of death and increased altruism widely reported by near-death experiencers are adaptive changes at the population level that could plausibly result from narrative sharing irrespective of whether such experiences take place in life-threatening contexts, in response to the perception of danger, in dreams or in altered states.

Persistence of an NDE predisposition through indirect selection: spandrels and exaptations

Evolutionary change takes place when natural selection, mutation or drift act on multiple interconnected components of living systems ([63], p. 313). Change in one component necessarily affects other interconnected components of the system resulting in the evolution of novel structures, behaviors or cognitive capacities that were not the original targets of selection, drift or mutation. This concept is useful for understanding the evolutionary origins of traits that *indirectly* result from selection or mutation of a disparate but—*inter-related*—trait that itself is the object of selection or mutation. By analogy *indirectly selected* traits have been described [22] as *spandrels* (i.e., the spaces that exist between the wall and flying buttresses in medieval cathedrals) in that they are an *unplanned* novel consequence of the intended design goal of the architect, namely, flying buttresses. Evolutionary *hitchhiking* of a structural or behavioral trait on another trait is widespread in the animal kingdom ([63], p. 345). The persistence or extinction of a particular trait is often determined not by its relative contribution to fitness but by its chance association with (i.e., genetic linkage to) another trait that is strongly selected in the population. Indirect selection of an NDE predisposition through genetic linkage to a trait that is itself *directly* selected is a plausible *alternative* genetic explanation to inheritance through direct selection. In this scenario, genes coding for an NDE predisposition would persist in a population even when the predisposition itself functions as a *spandrel*, i.e. a trait that confers no fitness benefits.

In contrast to spandrels, exaptations are features that did not originally arise for their current use but were selected for a different evolutionary purpose and were subsequently co-opted for new adaptive purposes. Gould believed that spandrels and exaptations played a more significant role in the evolution of cognition than did strict adaptations [7]. One can only speculate on possible early roles of cognitive traits and how they may have changed in response to new selective pressures over evolutionary timeframes.

Persistence of an NDE predisposition as a neutral trait

There is considerable built-in redundancy in the genotype-to-fitness relationship in most species resulting in different genotypes with similar fitnesses ([63], p. 55). The modern synthesis of evolutionary theory holds that not all traits are adaptive and may represent special cases of *ordinary variation* ([63], p. 308). Applying this model to individuals with different cognitive capacities, *gifted* individuals and *non-gifted* individuals would be expected to have similar or identical genotypes and this appears to be the case. In this scenario an NDE predisposition would be expected to be variably expressed in relationship to unique multi-dimensional fitness landscapes resulting in the *differential expression of the trait in unique populations and individuals*.

Persons predisposed to have NDEs and persons who are *not* predisposed to have such experiences would presumably have similar genotypes and any genetic differences associated with a predisposition for mental imagery may reflect intrinsic variability that is *neutral,* i.e., *that would not* correspond to differentially higher degrees of fitness in different ecological contexts or in different populations. The neutral scenario is consistent with the view that an NDE predisposition has a neutral impact on fitness and unique NDEs are variably expressed in relationship to differences in multi-dimensional fitness landscapes.

Part III: possible neural mechanisms underlying evolutionary dynamics of an NDE predisposition

Any discussion of evolutionary dynamics of human cognition and behavior that pertain to an NDE predisposition need to be contextualized in a more general discussion of the evolution of the brain. In this section I inquire into how neural and psychological mechanisms underlying an NDE predisposition could have come into existence in the first place. More specifically, can plausible evolutionary scenarios be put forward consistent with the persistence of neural or psychological mechanisms underlying an NDE predisposition?

An NDE predisposition as a specialized module conserved to solve problems related to survival

Evolutionary psychology posits that the mind is composed of a large number of *adaptive specializations* or *modules* that are functionally organized to solve complex problems of survival and reproduction and that such modules are shaped by natural selection [14]. This concept is consistent with the view that modularity is a robust feature of living systems as modularity may be associated with enhanced adaptability of living systems in general by reducing the number of heritable phenotypes on which natural selection can act [42]. Along similar lines neural network theory regards the brain as a system organized as a hierarchical array of intricately inter-connected structural and functional modules that operate on different temporal and spatial scales permitting the functional integration of neural networks serving perceptual and cognitive tasks that are essential for adaptability of complex organisms to environmental changes [67]. In this view an NDE predisposition can be conceptualized as a specialized module strongly conserved in populations to solve problems related to biological or psychological survival in the context of life-threatening crises.

Functional integration of the limbic system and neocortex and the neural basis of self-awareness

An evolutionary theory for an NDE predisposition is incomplete in the absence of a plausible mechanism for the evolution of a *neural capacity for self-awareness* because highly charged experiences like the NDE can *potentially* have adaptive value *only* in organisms that are self-aware of their emotions and thoughts. Since, by definition, organisms that are not self-aware lack the capacity to deliberately respond to internal states or perceptions in adaptive ways a neural mechanism underlying the capacity for internal states would *not be expected to be directly selected and strongly conserved in species that lack the neural capacity for self-awareness*. Following this logic, it is plausible that selection for an NDE predisposition would have taken place *only after* a neural capacity for self-awareness had already been firmly established.

Eccles argued that the neural basis of a predisposition for complex visual processing in higher mammals was strongly selected because it conferred fitness benefits related to increased speed and accuracy of perceptual tasks required to successfully hunt and evade predators ([16], p. 175). Continued evolution of the mammalian brain starting with early mammals resulted in higher levels of functional integration of limbic centers and neocortex including sensory, pre-motor and motor areas. This evolutionary process further enhanced perceptual abilities through cross-modal processing eventually conferring on primates what Eccles calls *unified mental experiences*, or a capacity to experience strong affective responses to visual stimuli thus increasing the probability of adaptive responses to environmental cues related to mate selection, predator avoidance and territorial conflicts, significantly increasing fitness and survival probability.

According to Eccles, the functional integration of visual cortex and limbic structures was strongly selected in hominid evolution and may have pre-adapted the brain of *H. sapiens* (or early hominins generally) to rapidly evolve a capacity for self-awareness as well as psychological experiences characterized by complex visual imagery and strong emotions that conferred fitness benefits by strengthening social cohesion in small isolated groups through shared beliefs or values enhancing co-operation in times of resource scarcity ([16], p. 175). Eccles' hypothesis is consistent with findings from functional brain imaging research showing that mental imagery in awake healthy adults is associated with increased activity in the frontotemporal network [43,78].

According to Eccles pre-synaptic vesicular grids, which initially evolved to permit efficient signal transmission at chemical synapses, provided the requisite neural infrastructure for bi-directional information flow between neural circuits called *psychons* that embody a sense of *self,* and neural circuits underlying sensory and motor functions ([16], p. 189–191). Eccles' work bears on evolutionary mechanisms associated with a general predisposition for visual imagery and cross-modal relationships between imagery and emotion in humans, other primates and among higher mammals in general.

Brain-to-brain replication of semantic information as a pre-adaptation required for the socio-cultural transmission of an NDE predisposition

Biological models proposed in efforts to apply selectionist principles to intra-brain processes include neural selectionism, synaptic replicators and synfire chains. All of these models have converged in a synthetic model called the neuronal replicator hypothesis ([63], p. 214–229). According to this hypothesis a human predisposition to perform complex cognitive tasks involves natural selection of *neuronal replicators* in the brain [18]. Dynamical neuronal replicators have been described that are capable of orders of magnitude faster evolution than possible with classical Darwinian evolution only ([63], p. 226) consistent with scenarios in which an NDE predisposition emerged suddenly in human evolutionary history.

If shared narratives of NDEs are regarded as specialized memes brain-to-brain replication of semantic information may have been a pre-adaptation required for the socio-cultural transmission of an NDE predisposition. A neural model of memes posits the existence of neuronal networks linked together in several layers or *pools* in multiple feed-forward loops ([63], p. 222). In this model a *syn-fire chain* is a "feed-forward network of neurons with several layers (or pools).” Synfire chains are believed to function in ways that are consistent with the information-bearing replicators described in mimetic theory.

Very weak neurophysiological or other biological signals can sometimes elicit extremely complex responses ([63], p. 265). This phenomenon may help explain how complex behavioral predispositions such as fixed action patterns in fishes, birds and insects take place in response to weak signals from other organisms. An analogous mechanism may help explain how complex mental imagery is released in the human brain in response to weak biological or socio-cultural signals. For example, a decrease in cerebral oxygenation below a critical threshold, or a sudden increase in central norepinephrine or another neurotransmitter may constitute a weak signal which in a person whose brain has acquired specific neuronal replicator memes evokes a pre-programmed response in particular *syn*-fire chains which in turn release a unique pattern of mental imagery and emotions retrospectively interpreted as an NDE.

The neural dynamics of *syn*-fire chains may be consistent with a network model of brain activity in which the unique features of NDEs are shaped by complex feed-forward and feedback loops between multiple neocortical and limbic circuits associated with visual memory and affect regulation. In a separate paper the author proposes a multi-factorial model in which complex combinations of neurophysiological and psychological factors lead to activation of dynamically inter-connected brain networks (i.e. the *connectome*) resulting in complex phenomenal content retrospectively interpreted as NDEs [44]. Multi-factorial models may be consistent with the observation that many NDE survivors ([40], p. 386) who are cognitively intact prior to a medical crisis (i.e., after which they report having an NDE) experience normal or heightened cognition that *apparently takes place during a medical crisis* when brain function is grossly impaired and normal or heightened cognitive functioning would not be expected. However, such case reports are rare and it is difficult to interpret their significance since in the vast majority of NDEs it is impossible to confirm the exact timing of subjective experiences retrospectively interpreted as NDEs.

Recent findings of highly coherent brain activity in animals and humans at near-death as measured by EEG may be consistent with dramatic improvements in cognitive functioning in the final moments of life [44]. Case reports of apparent return of normal or even heightened mental functioning in demented or severely mentally ill persons at near death may be consistent with a general neural mechanism that operates in the final moments of life resulting in a dramatic shift in the quality and type of cognition ([40], p. 410). Enhanced cognitive functioning in the moments before death when NDEs are likely to occur may permit the experiencer to transmit positive emotional and spiritual values among relatives and loved ones that are subsequently conserved as a meme in the population resulting in increased group fitness by reducing fear of dying and death.

For this model to make sense feed forward and feedback loops between discrete neural circuits would presumably be necessary to permit *optimally rewarding* changes in brain states in *real time*. Dynamical neuronal replicators have been described that are capable of orders of magnitude faster evolution than possible with classical Darwinian evolution only ([63], p. 226). The rapid acquisition of novel cognitive or behavioral predispositions via neuronal replicators is consistent with scenarios in which an NDE predisposition emerged suddenly in human evolutionary history.

Epigenetic mechanisms and their possible role in the evolution of brain mechanisms underlying an NDE predisposition

Epigenetic inheritance involves the transfer of information between two or more organisms that takes place through developmental interactions and is not mediated by DNA ([63], p. 144). Epigenetic inheritance is common in the animal kingdom and over one hundred cases of epigenetic inheritance have been documented in 42 species [37].

Epigenetic learning occurs when a factor in the environment—the *inducing agent*—elicits a physiological or behavioral response that leaves a persistent epigenetic trace which upon subsequent induction results in a more effective or adaptive response [21]. Research findings suggest that epigenetically acquired traits are transmitted both within the same generation and across generations in all species including humans ([63], p. 163). Epigenetic learning or *induction* of a novel trait and its cross-generational transmission may be a useful concept for examining mechanisms underlying a latent NDE predisposition which may be *activated* in relationship to environmental factors that trigger or *induce* acute physiological or psychological responses. Important unanswered questions are whether neuro-endocrinologic or socio-cultural epigenetic changes that accompany an NDE are somehow *epigenetically transmitted* to other individuals within the same group (i.e., horizontal transmission) or *trans*-generationally (i.e. vertical transmission). In other words, is an NDE predisposition mediated in part through epigenetic learning?

Persisting stress-induced changes in brain function might help explain widespread reports of NDEs in response to environmental, cultural, or symbolic cues. Stress-induced hormonal change is an example of direct induction epigenetic inheritance that may persist in a species across generations ([63], p. 154). Behavioral changes in rats have been shown to be caused by stress-induced changes in gene expression that affect the hypothalamic–pituitaryadrenal (HPA) axis [51]. Animal studies confirm that the *same epigenetic variation may be induced in multiple organisms at the same time* who subsequently *independently inherit* a capacity to exhibit the *non-genetically induced change* ([63], p. 164).

One or more epigenetic mechanisms may be associated with the evolution and persistence of an NDE predisposition in human populations. For example, stress-mediated changes in serum cortisol levels may result in a *persistent epigenetic trace* in the body and brain including changes in CNS levels of certain neurotransmitters or changes in the relative activity of particular neural circuits which on subsequent induction by epigenetic factors could manifest as a burst of affectively charged imagery, perceptual changes or other features characteristic of NDEs. A recent study found that epigenetically mediated changes in expression of the glucocorticoid receptor gene in humans increase the risk of post-traumatic stress disorder (PTSD). Glucocorticoid receptor signaling is known to be involved in regulation of emotional memory processing. This finding has implications for the role of stress-mediated epigenetic changes in the brain on a predisposition for NDEs *released* in the context of severe stress [75]. It is plausible that epigenetically induced changes in glucocorticoid receptor signaling may affect neuronal gene expression influencing biosynthetic pathways of norepinephrine or other neurotransmitter systems that mediate visual imagery and emotionally charged responses to severe stress.

Stress-induced epigenetic changes that take place at the same time in many persons exposed to the same stressful stimulus may be consistent with a neuropsychoendocrinologic *group effect* of life-threatening trauma in isolated populations of early hominins whose members had been collectively *primed* to have NDEs through common stress-mediated changes in neuroendocrinologic function in response to the narrative re-telling of a particular NDE to the kinship group by a fatally injured or psychologically traumatized person. Along these lines it is plausible that shared exposure to a life-threatening event and subsequent exposure to the ritual re-telling of an NDE *induced* in one person could result in similar neuroendocrinologic changes in other persons in the group, in effect priming them for having a multiplicity of unique NDEs in the future. In cases where narrative re-telling results in intense empathic union between the near-death experiencer and members of his or her kinship group a *melting of boundaries* between many participants in the shared narrative could take place resulting in rapid, highly adaptive social or spiritual transformation [76]. Narrative re-telling in the context of neuroendocrinogical priming following shared exposure to trauma is essentially an evo-devo model and may be consistent with symbolic inheritance as described by Jablonka and Lamb [38] (p. 193–231). The role of symbolic transmission mediated through ritual re-telling of potent NDEs adds an important non-biological dimension to the genetic and epigenetic layers of a multi-dimensional inheritance system that may help explain the persistence of an NDE predisposition.

Reports of recurring themes and visual patterns in shamanic imagery during ritually induced altered states may be consistent with a neuropsychological model of stress-induced changes in brain function and perception proposed to explain recurring motifs in rock art across disparate cultures [45]. This model may help to explain at least some aspects of imagery and intense emotions reported by NDE survivors. It has been suggested that different *stages* reported in shamanic journeys and NDEs may correspond to recurring patterns of activity in discrete brain regions starting with simple geometric (i.e. *entoptic*) shapes generated in the retina, progressing to affectively charged images and memories generated in the hippocampus and other limbic structures, and continuing on to more complex imagery including fully formed visual or other sensory hallucinations frequently interpreted as a *tunnel* or *vortex* presumably mediated by occipital (visual) cortex. Bokkon and Mallick recently proposed the *biophysical physical representation model* which postulates that the perception of bright light in NDEs, dreams and visual imagery is caused by the transient overproduction of free radicals and energetically excited molecules in the retina and visual cortex and the generation of bioluminescent biophotons which the brain interprets as originating in the external world [3]. This model provides a testable neurophysiological hypothesis for both entoptic shapes experienced in Shamanic journeys and *brilliant light* frequently reported in NDEs. Neurophysiological models may help explain some cases of *brilliant light* or other recurring features or patterns of imagery reported in NDEs however they do not explain reports of lucidity frequently experienced during prolonged NDEs that take place in the context of complete loss of consciousness due to transient cessation of cardiac and/or brain function.

Part IV: discussion: reconciling disparate evolutionary scenarios

In this section I evaluate the plausibility of arguments for evolutionary scenarios for direct, indirect and neutral selection and I comment on data from future studies that would favor each scenario.

Inferences about the evolutionary dynamics and fitness benefits conferred on populations by an NDE predisposition lead to disparate scenarios in support of direct, indirect and neutral selection, respectively. A neutral scenario is unlikely both in view of the high incidence of NDEs across diverse populations and reports of consistent social and psycho-spiritual aftereffects of NDEs that may enhance social cohesiveness. According to the modern synthesis of evolutionary theory human evolutionary dynamics are influenced by a multiplicity of biological, psychological, social and symbolic processes [38]. Even though the dilemma of direct versus indirect selection cannot be resolved through analysis of evolutionary evidence or by inference, it is plausible that an NDE predisposition originated and persists through the operation of multiple processes that shape inheritance. Depending on evolutionary dynamics shaping a particular population, an NDE predisposition may have resulted from *direct or indirect* selection in a particular population or both *direct and indirect* selection in the same population over time.

I have argued that there is no real dichotomy between so-called *true* NDEs triggered by life-threatening situations, and NDE-like experiences that take place in dreams and in altered states induced by psychedelics. Both kinds of experiences are probably mediated by overlapping physiological, psychological and cultural factors, and both kinds of experience probably have similar effects on values and behaviors, hence contribute to fitness in the same way and to the same degree.

I have argued that the high reported incidence of NDEs (i.e., between 9 and 18% [30,34] does *not necessarily* indicate the rate at which such experiences *actually* take place because report and non-report of NDEs is influenced by factors that are difficult to characterize [19]. At issue is that the *actual* incidence of NDEs has yet not been established, nor is it clear whether significant variability occurs in the incidence of NDEs in different populations and cultures. If an NDE predisposition is heritable and persists in populations through operation of established genetic and epigenetic mechanisms and is directly selected because it confers significant fitness benefits on populations, large stable populations would be expected to report NDEs at similar incidences reflecting an *average* inheritance rate of the predisposition regardless of individual differences in values or beliefs about death or dying. By the same token, the incidence of an NDE predisposition in small or isolated populations might show significant variability depending on whether:

- genes coding for the trait—or epigenetic factors shaping the trait—are uniformly present in all populations
- differences in relative fitness advantages conferred by an NDE predisposition characterize different (genetically or culturally) isolated populations
- an NDE predisposition originated in a population through the founder effect and spread through adaptive radiation

Conversely a finding of a lower incidence of NDEs in geographically isolated or small populations would be consistent with a scenario in which an NDE predisposition originated through genetic drift and persisted as a neutral trait. In other words, variability in the incidence of NDEs across populations or cultures does *not in itself provide evidence in favor of either direct or indirect selection*.

The majority of survey studies on individuals reporting NDEs have been done in Western countries and to date, no formal surveys have been conducted in populations that are genetically or culturally isolated from Western culture. Although findings of cross-cultural studies on NDEs suggest that some NDE features—for example the *tunnel* and *life-review*—vary significantly across cultures that embody different religious or spiritual beliefs about death and an afterlife, other NDE features—such as pervasive feelings of peacefulness and time distortion—may be fairly constant across cultures. Future studies showing consistent differences between Western cultures and genetically or culturally isolated non-Western cultures would support a multi-factorial model in which certain NDE features are shaped mainly by culture while other features are primarily an expression of underlying neural mechanisms [39].

I have reviewed psychological models purporting evolutionary benefits of NDEs including a model advanced by Noyes & Kletti characterizing NDEs as an adaptive form of depersonalization in response to life-threatening situations in which individuals experience a state of hyper-alertness, increased 'speed of thought' and make extraordinary efforts to save themselves [57,58]. Evrard et al. [17] recently expanded this concept into a psychodynamic model in which enhanced cognitive functioning widely reported during NDEs is a part of a general psychosomatic response that leads to more effective rescue actions in response to the perception of imminent death. Future studies confirming high rates of depersonalization and increased 'speed of thought' would support an evolutionary scenario in which an NDE predisposition is directly selected because it increases survival probability when NDEs take place in the context of life-threatening situations.

If inheritance of an NDE predisposition takes place primarily on a cultural level and its persistence and dissemination within and across populations is largely or exclusively mediated by symbolic inheritance (i.e. through the creation and transmission of memes) and the predisposition confers important fitness benefits on populations in which it takes place, the incidence of NDEs *would be expected to vary between populations corresponding to differences in values or beliefs attributed to NDEs by disparate cultures or populations*. A finding of significant variability in the incidence of NDEs between populations that correlate to differences in shared beliefs about death or an afterlife, or differences in measures of social cohesiveness would provide evidence that symbolic inheritance plays an important role in the conservation and dissemination of an NDE predisposition. By the same token large homogeneous populations characterized by widely shared values and beliefs about death and an afterlife would be expected to show stable rates of an NDE predisposition.

Arguments in favor of direct selection are weakened by surveys that report negative social consequences of NDEs including difficulties integrating the experience into day to day life, relationship problems, depression, social isolation and fear of being ostracized. As discussed in this paper, it is not clear how frequently negative consequences of NDEs occur but in such cases NDEs would likely have neutral or even negative effects on group social cohesiveness.

The origin and dissemination of an NDE predisposition may have resulted from genetic drift followed by the founder effect and subsequent direct selection. This scenario entails the assumption that genetic drift initially resulted in a *neural preadaptation* for complex mental imagery, represented a key innovation in human evolution and was followed by rapid adaptive radiation manifesting as novel cognitive capacities and enhanced adaptive functioning in response to unpredictable changes in the environment. The counter position argues that NDEs *could not conceivably have* enhanced fitness over evolutionary time frames, and thus an NDE predisposition could not have been *directly* selected, because in the overwhelming majority of cases NDEs take place in contexts where death is inevitable or imminent i.e., in the absence of recently available life-saving medical interventions that could not have influenced evolution.

I have reviewed arguments in support of an evolutionary scenario in which inheritance of novel traits involves epigenetic factors or socially mediated learning bypassing a requirement for genetic mechanisms underlying information transmission across generations. The *higher-level* inheritance of symbolic communication has been a principle factor shaping evolutionary change in humans for millennia modifying traits established through *lower-level* biological inheritance based on genetic and epigenetic mechanisms ([38], p. 342). This scenario is consistent with a multi-factorial fitness landscape in which multiple interacting environmental, biological and symbolic inheritance systems contributed to the evolutionary dynamics of an NDE predisposition. Another epigenetic model for an NDE predisposition involves stress-induced changes in brain function caused by intense fear associated with an actual or anticipated life-threatening situation and transmission of stress-induced changes in brain function within populations in response to environmental, cultural, or symbolic cues.

I have argued that stress-induced epigenetic changes that take place at the same time in many persons exposed to the same stressful stimulus may be consistent with a neuropsychoendocrinologic *group effect* of life-threatening trauma in isolated populations of early hominins. In this evolutionary-developmental scenario many individuals are *collectively primed* to have NDEs through common stress-mediated changes in neuroendocrinologic function in response to the narrative re-telling of a particular NDE. It is plausible that repetition of emotionally charged NDE narratives could lead to rapid dissemination of adaptive social changes. Future studies showing a correlation between stress-induced changes in brain function and a high incidence of NDEs in different culturally or genetically isolated populations would be consistent with neuropsychoendocrinologic *group effects* of life-threatening trauma.

It is plausible that cultural transmission of values and beliefs through narrative re-telling of individual NDEs could have resulted in rapid spreading of *psycho-spiritual insights* about dying and death that might occur less frequently in populations where NDEs are less often experienced or reported. For example, cardiac arrest survivors who report NDEs are more than twice as likely to die compared to patients who do not report NDEs ([40], p. 414). I have argued that this observation may be consistent with two disparate hypotheses. On the one hand, the relative depth or complexity of an NDE is strongly correlated with closer proximity to biological death predisposing the experiencer to greater subsequent biological vulnerability. In contrast to a strictly biological explanation, NDEs may result in psycho-spiritual preparation or *integration* that makes dying easier.

If shared narratives of NDEs are regarded as specialized memes brain-to-brain replication of semantic information may have been a preadaptation required for the socio-cultural transmission of an NDE predisposition. According to the neural model of memes feed-forward loops operate in a complex network of neurons replicating and storing information contained in memes. In this model a unique NDE corresponds to the release of neuronal replicator memes when a weak biological or socio-cultural signal reaches a critical threshold level. This model may be consistent with a scenario in which NDEs are shaped by dynamic complex feed-forward and feedback loops between neocortical and limbic circuits associated with visual memory and affect regulation [13,4,46]. If confirmed by future animal and human studies, a finding of enhanced cognitive functioning in the moments before death would be consistent with an evolutionary scenario in which near-death experiencers are able to transmit values and beliefs that function as memes and enhance group fitness by increasing social cohesiveness.

In addition to models purporting direct selection, in this paper I have reviewed plausible evolutionary scenarios for an indirect selection model. If an NDE predisposition is inherited through an established genetic mechanism, is *indirectly* selected by virtue of being linked to a different trait that itself is directly selected, the incidence of NDEs would be expected to be similar in large homogeneous populations reflecting the fitness benefits conferred by the trait (or traits) to which genes coding for an NDE predisposition are linked. A plausible scenario for indirect selection leading to the persistence of an NDE predisposition involves direct selection of a general cognitive capacity for complex mental imagery [28]. The finding that individuals who report NDEs are more prone to dissociate and have anomalous or transliminal experiences is consistent with McClenon's Ritual Healing Theory [50] which hypothesizes that a capacity to experience dissociative states and anomalous perceptions has a physiological basis that originated in early hominid evolution and enhanced the individual's ability to cope with trauma.

In addition to direct and indirect selection, it is plausible that an NDE predisposition could have resulted from random genetic drift in one or more small isolated populations and persists at relatively stable but low rates as a neutral trait, a trait that confers no fitness benefits and has no intrinsic evolutionary value. In this scenario genes or epigenetic factors underlying an NDE predisposition would be conserved in small populations in spite of the absence of demonstrable fitness benefits as conventionally defined, and would be expected to be variably expressed in relationship to unique multi-dimensional fitness landscapes shaping different populations. Future findings of low stable rates of NDEs in culturally or genetically isolated populations in which social or psychological benefits of such experiences are not reported would be consistent with a neutral scenario.

Finally, it is important to note that direct, indirect and neutral selection are not mutually exclusive evolutionary scenarios. For example, a trait may originate as the result of genetic drift (neutral selection) and subsequently become subject to direct or indirect selection. By the same token, a trait that originates through indirect selection may confer important fitness benefits on a population and subsequently become strongly conserved through direct selection or both direct and indirect selection depending on the constellation of dynamic forces that shape the fitness landscape of the trait in disparate populations and at different times.

Conclusions

The absence of consensus on an explanatory model of the NDE probably reflects divergent non-reconcilable assumptions about the nature of human consciousness. Current NDE models rely on highly subjective self-reports by individuals most of whom reside in Western cultures and assume that individuals accurately recall details of their experiences, often years afterward. Most NDE survey data come from large homogeneous populations and provide little useful information for examining variability in the incidence and features of NDEs across different cultures and populations. These issues challenge the generalizability of NDE models that purport the existence of universal NDE features across different populations, cultures and historical time periods. A future more integral theory of consciousness may be needed to adequately characterize complex dynamic relationships between neurophysiological mechanisms and processes underlying different experiences including NDEs and other so-called transpersonal experiences.

Findings from animal and human studies are consistent with the hypothesis that NDEs take place in a wide range of life-threatening and non-life-threatening circumstances in response to a multiplicity of neurophysiological and psychological factors and that disparate initial circumstances may lead to the "activation" of different psychological, physiological and neurophysiological factors that manifest as NDEs and NDE-like experiences [65,44,48]. Multi-factorial models predict that NDEs or NDE-like experiences take place in a variety of contexts, including:

- moments when consciousness is altered but before loss of consciousness is complete
- moments following loss of consciousness when the brain continues to function normally
- following more prolonged periods of loss of consciousness when cortical brain function as measured by EEG electrodes is absent
- moments at near-death associated with transient surges of highly coherent brain activity
- during dreams
- in response to psychedelics
- in response to intense fear or the anticipation of a life-threatening emergency
- after waking consciousness returns following cardio-pulmonary resuscitation

Multi-factorial models imply that no real dichotomy exists between so-called *true* NDEs triggered by life-threatening situations, and NDE-like experiences that are not associated with a medical emergency. Further, both kinds of experience are probably mediated by overlapping physiological, psychological and cultural factors, and both kinds of experience may have similar effects on values and behaviors that influence fitness.

The recent finding of surges in coherent electrical activity at near death in both the rodent brain and the human brain suggests the involvement of common neural mechanisms in both species, and perhaps broadly in other mammalian species [13,4,46]. These findings may be consistent with the models put forward by Noyes & Kletti and Evrard et al. postulating that NDEs are associated with enhanced cognitive functioning and extraordinary efforts at near death that increase survival probability [58,58,17].

In this paper I have advanced plausible evolutionary scenarios for the origin and persistence of an NDE predisposition through direct and indirect selection. It is likely that a capacity for self-reflective awareness preceded and constituted an essential pre-adaptation that led to the origin of an NDE predisposition in early hominins. Available data do not favor one scenario over any other and it is possible that more than one scenario operated in different populations or at different times. Future findings consistent with a scenario in which an NDE predisposition is subject to direct selection would have important implications for human evolutionary dynamics. In that case the connotation of *fitness* may have to be expanded to include mechanisms that influence natural selection outside of established genetic factors, for example, heritable epigenetic influences, the postulated transmission of memes as a symbolic inheritance mechanism, and the concept of *psycho-spiritual fitness*. Conversely, should arguments for an NDE predisposition as a spandrel or a neutral trait be confirmed by future research findings—this would weaken or negate the argument for enhanced fitness conferred by an NDE predisposition which, by definition, would be viewed as having no intrinsic evolutionary significance.

Recommendations for future research

Novel physiological monitoring and functional brain imaging techniques and sophisticated data analysis methods are needed to demonstrate temporal correlations between brain activity and NDE phenomenology. Without this information, inferences about putative causal mechanisms underlying NDEs will remain elusive.

Field studies investigating NDEs in culturally and genetically isolated populations are needed to elucidate the roles disparate genetic, epigenetic, psychological and cultural factors that may influence evolutionary dynamics of an NDE predisposition. Novel research methods developed to gather evidence for evolutionary dynamics underlying different kinds of traits may be able to improve the rigor and reliability of NDE surveys ([81], 2005, p. 133–139). For example, sample surveys and formal theoretical studies could be used to maximize the generalizability of research findings across different persons, settings or times. Before findings of surveys or theoretical studies are generalized to different populations, they should first be checked for external validity based on relevance and robustness ([81]; p. 131). Relevance refers to the degree to which findings help solve social problems or improve the quality of life. Robustness reflects the degree to which a finding is replicable across different settings, people, and historical contexts.

Findings from numerous surveys of NDE survivors [11] have been replicated across different populations, socio-cultural settings and historical contexts fulfilling the criterion of robustness. On this basis it is arguable that an evolutionary model for an NDE predisposition has strong *external validity*. Surveys of large homogeneous populations and small isolated populations should be conducted to determine whether this model applies to different populations.

Another important concept in evolutionary research methods that bears on analysis of an NDE predisposition is construct validity. Construct validity asks "does a finding reveal a causal relationship between variable X and variable Y, between variable Z and variable Y, or with some other outcome variable ([81]; p. 131)." While some processes that influence evolutionary dynamics are probably correlated with other processes; some processes probably function independently of one another. Because of the multiplicity of correlated and independent variables that influence human evolution experimental field studies could yield findings consistent with multiple hypotheses without confirming the role of any particular causative factor ([81]; p. 131). Along these lines Simpson & Campbell have remarked that evolved adaptations might be difficult to substantiate because complex traits often have *mixed designs*. In other words, complex traits are influenced by multiple factors resulting in different adaptive functions over evolutionary timescales ([81]; p. 127).

Evolutionary science has developed a *multi-trait multi-method matrix* approach and other multi-method research approaches to obtain different types of evidence for hypotheses purporting *special design* in complex psychological traits. Multi-method approaches investigate traits at different levels including neural mechanisms, context-specific information processing, emotional reactions and behavioral responses, and subsequently test for correlations between causative levels [83]. In order to adequately characterize complex causative inter-relationships between multiple variables that influence inheritance and persistence of an NDE predisposition future surveys should test for correlations between the social and psychological dimensions of NDEs at the level of both individuals and populations.

Conflicts of interest

I am the sole author of this manuscript and declare that I have no financial or personal relationships with any third party whose interests could be positively or negatively influenced by the article's content.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.mehy.2019.03.016.

References

[1] Arstila V. Time slows down during accidents. Front Psychol 2012;3(196):1–10.
[2] Belanti J, Perera M, Jagadheesan K. Phenomenology of near-death experiences: a cross-cultural perspective. Transcult Psychiatry 2008;45(1):121–33.
[3] Bókkon I, Mallick BN. Activation of retinotopic areas is central to REM sleep associated dreams: visual dreams and visual imagery possibly co-emerged in evolution. Act Nerv Super 2012;54:10–25.
[4] Borjigin J, Wang MM, Mashour GA. Reply to Chawla and Seneff: near-death electrical brain activity in humans and animals requires additional studies. Proc Natl Acad Sci USA 2013;110(44).
[5] Borjigin J, Un Cheol L, Tiecheng L, Dinesh P, Sean H, Daniel K, Mashour GA. Surge of neurophysiological coherence and connectivity in the dying brain. Proc Natl Acad Sci USA 2013;110(35):14432–7.
[6] Britton WB, Bootzin RR. Near-death experiences and the temporal lobe. Psychol Sci 2004;15:254–8.
[7] Buss DM, Haselton MG, Shackelford TK, Bleske AL, Wakefield JC. Adaptations, exaptations, and spandrels. Am Psychol 1998;53(5):533–48.
[8] Carhart-Harris R. The entropic brain – revisited. Neuropharmacology 2018.
[9] Carhart-Harris RL, Muthukumaraswamy S, Roseman L, Kaelen M, Droog W, Nutt DJ. Neural correlates of the LSD experience revealed by multimodal neuroimaging. Proc Natl Acad Sci USA 2016;113:4853–8.
[10] Carhart-Harris R, Nutt D. Was it a vision or a waking dream? Front Psychol 2014;5:255.
[11] Carter C. Science and the near-death experience: how consciousness survives death. Rochester, VT; Toronto, Canada: Inner Traditions; 2010.
[12] Charland-Verville V, Jourdan J-P, Thonnard M, Ledoux D, Donneau A-F, Quertemont E, et al. Near-death experiences in non-life-threatening events and coma of different etiologies. Front Human Neurosci 2014;8:203.
[13] Chawla LS, Akst S, Junker C, Jacobs B, Seneff MG. Surges of electroencephalogram activity at death: a case series. J Palliative Med 2009;12(12):1095–100.
[14] Cosmides L, Tooby J. Evolutionary psychology: new perspectives on cognition and motivation. Annu Rev Psychol 2013;64(2013):201–29.
[15] Durkheim E. The elementary forms of religious life. New York, NY: The Free Press; 1995.
[16] Eccles JC. Evolution of the brain creation of the self. London and New York: Routledge; 1989.
[17] Evrard R, Jacob C, Glazier J, Malefan P. The energy of despair: do near-death experiences have an evolutionary value? Psychol Consciousness: Theory, Res, Pract 2018.
[18] Fernando C, Karishma KK, Szathmary E. Copying of neuronal topology by spike-time dependent plasticity and error-correction. PLoSONE 2008;3:33775.
[19] French C. Dying to know the truth: visions of a dying brain, or false memories? Lancet 2001;358(9298):2010–1.
[20] Gavrilets S, Vose A. Dynamic patterns of adaptive radiation. Proc Natl Acad Sci USA 2005;102(50):18040–5.
[21] Ginsburg S, Jablonka E. Epigenetic learning in non-neural organisms. Biosciences 2009;34(4):633–46.
[22] Gould SJ, Lewontin RC. The spandrels of San Marco and the Panglossian paradigm: a critique of the adaptationist programme. Proc R Soc Lond B Biol Sci 1979;205(1161):581–98.
[23] Goza TH. Combat near-death experiences: an exploratory, mixed-methods study. Dissertation thesis in philosophy. University of North Texas; 2011.
[24] Greyson B, Bush NE. Distressing near-death experiences. Psychiatry 1992;55(1):95–110.
[25] Greyson B. Varieties of near-death experience. Psychiatry 1993;56(4):390–9.
[26] Greyson B. Near-death experiences. In: Cardeña E, Lynn SJ, Krippner S, editors. Varieties of anomalous experiences. 2nd ed.Washington, DC: American Psychological Association; 2013. p. 333–67.
[27] Greyson B. Defining near-death experiences. Mortality 1999;4:7–19.
[28] Greyson B. Dissociation in people who have near-death experiences: out of their bodies or out of their minds? Lancet 2000;355:460–3.
[29] Greyson B, Bush N. Distressing near-death experiences. Psychiatry 1992;55(1):95–110.
[30] Greyson B. The incidence of near-death experiences. Med Psychiatry 1998:92–9.
[31] Greyson B. Near-death experiences and personal values. Am J Psychiatry 1983;140:618–20.
[32] Greyson B. Post-traumatic stress symptoms following near-death experiences. Am J Orthopsychiatry 2001;71:358–73.
[33] Greyson B. The near-death experience as a focus of clinical attention. J Nerv Mental Dis 1997;185:327–34.
[34] Haldane JBS. A mathematical theory of natural and artificial selection, part V: selection and mutation. Proc Cambridge Philos Soc 1927;23:833–44.
[35] Hartmann E. Boundaries of dreams, boundaries of dreamers: thin and thick boundaries as a new personality measure. Psychiatric J Univ Ottawa 1989;14:557–60.
[36] Holden JM, Greyson B, James D. Veridical perception in near-death experiences. Handbook of near-death experiences: thirty years of investigation. Santa Barbara, CA: Praeger; 2009.
[37] Jablonka E, Raz G. Transgenerational epigenetic inheritance: prevalence, mechanisms, and implications for the study of heredity and evolution. Q Rev Biol 2009;84:131–76.
[38] Jablonka E, Lamb M. Evolution in four dimensions: genetic, epigenetic, behavioral and symbolic variation in the history of life. Cambridge, MA and London: MIT Press; 2006.
[39] Kellehear A. Culture, biology and the near-death experience. J Nerv Mental Dis 1993;181(3):148–56.
[40] Kelly E, Kelly EW, Crabtree A, Gauld A, Grosso M, Greyson B. Irreducible mind: toward a psychology for the 21st century. Rowman & Littlefield Publishers, Inc; 2007.
[41] Khanna B, Greyson B. Daily spiritual experiences before and after near-death experiences. Psychol Religion Spirituality 2013;6(4):302–9.
[42] Kirschner M, Gerhart J. Evolvability. Proc Natl Acad Sci USA 1998;95:8420–7.
[43] Kreiman G, Koch C, Fried I. Imagery neurons in the human brain. Nature 2002;408:357–61.
[44] Lake J. The near-death experience: a testable neural model. J Psychol Consciousness: Theory, Res Pract 2017;4(1):115–34.
[45] Lewis-Williams JD, Dowson TA. The signs of all times: entoptic phenomena in upper Paleolithic Art. Curr Anthropol 1988;29:201–45.
[46] Li D, Mabrouk OS, Liu T, Tian F, Xu G, Rengio S, Borjigin J. Asphyxia-activated cortico-cardiac signaling accelerates onset of cardiac arrest. Proc Natl Acad Sci 2015;112(16):E2073–82.
[47] Martial C, Cassol H, Charland-Verville V, Pallavicini C, Sanz C, Zamberlan F, et al. Neurochemical models of near-death experiences: a large-scale study based on the semantic similarity of written reports. Conscious Cogn 2019;69:52–69.
[48] Martial C, Cassol H, Antonopoulos G, Charlier T, Heros J, Donneau AF, et al. Temporality of features in near-death experience narratives. Front Human Neurosci 2017;11:311. https://doi.org/10.3389/fnhum.2017.00311.
[49] Martial C, Cassol H, Charland-Verville V, Merckelbach H, Laureys S. Fantasy proneness correlates with the intensity of near-death experience. Front Psychiatry 2018;9:190.
[50] McClenon J. Wondrous healing: shamanism, human evolution and the origin of religion. DeKalb, IL: Northern Illinois University Press; 2002.
[51] Meaney MJ. Maternal care, gene expression, and the transmission of individual differences in stress reactivity across generations. Annu Rev Neurosci 2001;24(2001):1161–92.
[52] Morse ML, Venecia D, Milstein J. Near-death experiences: a neurophysiologic explanatory model. J. Near Death Stud 1989;8:45–53.
[53] Nichols DE. Psychedelics. Pharmacol Rev 2016;68:264–355.
[54] Noyes R. The encounter with life-threatening danger: its nature and impact. Essence 1981;5:21–32.
[55] Noyes R. Attitude changes following near-death experiences. Psychiatry 1980;43(1980):234–42.
[56] Noyes R, Kletti R. Depersonalization in the face of life-threatening danger: an interpretation. Omega 1976;7:103–14.
[57] Noyes R, Kletti R. Depersonalization in response to life-threatening danger. Compr Psychiatry 1977;18:375–84.
[58] Noyes R, Kletti R. Panoramic memory: a response to the threat of death. Omega 1977;8:181–94.
[59] Noyes R, Slymen D. The subjective response to life-threatening danger. Omega 1979;9:313–21.
[60] Noyes R, Fenwick P, Holden JM, Christian SR. Aftereffects of pleasurable Western adult near-death experiences. In: Holden JM, Greyson B, James D, editors. The handbook of near-death experiences: thirty years of investigation. Santa Barbara, CA: ABC-CLIO/Praeger; 2009. p. 41–62.
[61] Nelson E, Panksepp J. Brain substrates of infant-mother attachment: contributions of opioids, oxytocin, and norepinephrine. Neurosci Biobehav Rev 1998;22(3):437–52.
[62] Panksepp J. Affective consciousness: core emotional feelings in animals and humans. Conscious Cogn 2005;14(1):30–80.
[63] Pugliucci M, Muller G. Evolution: the extended synthesis. Cambridge, MA and London, England: The MIT Press; 2010.
[64] Ring K. Life at death: a scientific investigation of the near-death experience. N.Y.: Coward, McCann and Geoghegan; 1980.
[65] Roberts G, Owen J. The near-death experience. Br J Psychiatry 1988;153:607–17.
[66] Simmonds-Moore C. Exceptional experience and health: essays on mind, body and human potential. Jefferson, North Carolina, London, England: McFarland & Company, Inc.; 2012.
[67] Sporns O. Economy, efficiency and evolution (Ch. 7) in networks of the brain. Cambridge, MA, London, England: The MIT Press; 2011.
[68] Sutherland C. Reborn in the light: life after near-death experiences. New York, NY: Bantam; 1995.
[69] Tagliazucchi E, Carhart-Harris R, Leech R, Nutt D, Chialvo DR. Enhanced repertoire of brain dynamical states during the psychedelic experience. Hum Brain Mapp 2014;35:5442–56.
[70] Thalbourne MA. The psychology of mystical experience. Exceptional Hum Exp 1991;9:168–86.
[71] Thalbourne MA. Relation of transliminality and vividness of visual imagery. Percept Mot Skills 1999;89:915–6.
[72] Thalbourne MA. Transliminality: a fundamental mechanism in psychology and parapsychology. Aust J Parapsychol 2010;10:70–81.

[73] Timmermann C, Roseman Leor, Williams Luke, Erritzoe David, Martial Charlotte, Cassol Héléna, et al. DMT models the near-death experience. Front Psychol 2018;15:1–12.
[74] van Lommel P, van Wees R, Meyers V, Elfferich I. Near-death experience in survivors of cardiac arrest: a prospective study in the Netherlands. Lancet 2001;358(9298):2039–45.
[75] Vukojevic V, Kolassa IT, Fastenrath M, Gschwind L, Spalek K, Milnik A, et al. Epigenetic modification of the glucocorticoid receptor gene is linked to traumatic memory and post-traumatic stress disorder risk in genocide survivors. J Neurosci 2014;34(31):10274–84.
[76] Walach H, Schmidt S, Schneider R, Seiter C, Bosch H. Melting boundaries: subjectivity and intersubjectivity in the light of parapsychological data. Eur J Parapsychol 2002;17:72–96.
[77] Woerlee GM. Cardiac arrest and near-death experiences. J Near-death Stud 2004;22:235–49.
[78] Zimmer HD. Visual and spatial working memory: from boxes to networks. Neurosci Behav Rev 2008;32:1373–95.
[79] Zingrone NL, Alvarado CS. Pleasurable Western adult near-death experiences: features, circumstances, and incidence. In: Holden JM, Greyson B, James D, editors. The handbook of near-death experiences: thirty years of investigation. Santa Barbara, CA: Praeger/ABC-Clio; 2009. p. 17–40.
[80] Sabom M. The acute dying experience. J Near-Death Stud 2008;26(3):181–218.
[81] Simpson JA, Campbell L. Methods of evolutionary sciences. In: Buss DM, editor. The Handbook of Evolutionary Psychology. New York: Wiley; 2005. p. 119–44.
[82] Greyson B. Incidence of near-death experiences following attempted suicide. Suicide Life Threat Behav 1986;16(1):40–5.
[83] Wilson EO. Consilience: The Unity of Knowledge. New York: Knopf; 1998.