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Understanding Free Will as a Biological Phenomenon

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Abstract

The capacity for free will follows from the evolution of a conscious brain with additional power of rational thoughts and an awareness of self. Our free will is based on cognitive deliberation, which is one of several strategies designed to guide behaviour. Other strategies can be engaged simultaneously, our free will is therefore restricted by the relative dominance of the various strategies; as well as by the obvious limits of mental and physical abilities. The philosophical question of whether we have free will may be answered by stating that we have a sufficient amount to choose whether the answer is 'yes' or 'no;' we can set the arbitrary cut-off required to quality either above or below the level of free will bestowed upon us. Conscious input is needed to make a cognitive choice, but conscious content is generated by activity in the unconscious part of the brain. If the conscious decision itself must be formed by the unconscious, which of the two comes first? The answer may reflect that of the chicken-or-egg-dilemma; conscious and unconscious activity develop gradually and interdependently culminating in the awareness of a willed decision.

Keywords

Free will, Evolution, Eeurobiology, Behavioural control, Cognition, Agency

Introduction

The concept of a free will

Most people will accept that humans have a 'sense of free will,' in that we feel capable of making choices based on personal preferences. We have the capacity of volition and a sense of agency. Yet, some scientists claim free will to be an illusion [1]. The question is whether the choices we make are predetermined by the design of the brain and ultimately by the laws of physics - either reflecting supernatural destiny or a natural form of determinism. The stance taken here is that *free will* is a useful concept when describing how the human brain functions; for the present treatise, it is therefore not necessary to deal with the query of whether it is to some extent predetermined.

The above stance implies that the phenomenon of free will can, and should, be investigated scientifically. I believe the old adage, 'Nothing in biology makes sense except in the light of evolution' [2], to be true even when exploring something as philosophical in nature as free will. I shall address the following two questions: 1) What is the evolutionary rational and history of the phenomenon; and 2) What is the neurological correlate? There is sufficient data to offer reasonable answers to both, and the answers form a coherent picture of what free will is about. I shall start with a brief evolutionary history of the components the phenomenon requires.

The evolution of nervous systems

Some 600 million years ago, evolution introduced nervous systems for the purpose of managing behaviour. Behaviour means movement, and most animals need mobility in order to care for the interest of the genes, which means moving *toward* what is beneficial and *away* from anything detrimental. All proper nervous systems are based on the same scheme: Sensory neurons send signal to a processing unit that again passes on signals to effector neurons that activate muscles. The main form of variance between species rests with how the processing units, or brains, make behavioural decisions. Evolution has devised a range of strategies in an attempt to ensure optimal results.

Humans have, arguably, the most advanced brain, but it. It has retained 'primitive' strategies like reflexes, but has many add-ons that allows for more advanced and fine-tuned decisions. One of these add-ons came with the introduction of feelings. The term *feeling* is here used for any form of experience with a positive or negative connotation, corresponding to respectively the need to either take advantage of options promoting the genes (moving toward) or to avoid (moving away) an adverse outcome [3]. Feelings

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probably evolved some 300 million years ago in the early amniotes [4]. They serve as a 'common currency' allowing the brain to weigh advantages against detriments [5]. As they require the capacity to *feel*, they may have been the factor initiating the evolution of consciousness [6]. In the case of humans, consciousness was further developed to include add-ons, such as self-consciousness and deliberate thoughts, in order to allow for an even more advanced assessment of a situation. The phenomenon we refer to as free will presumably came as a consequence of these added tools. It reflects the subjective experience of, for one, volition, and two, being the agent responsible for actions. As such, it is not per se a function, or module, selected for by evolution, but perhaps best described as either an exaptation or an indirect consequence of our cognitive tools.

With this outline of the history behind our free will in mind, I shall first consider how free will relates to the various strategies for behavioural control inherent in the human brain, and then consider experiments and observations made regarding the neurological correlate. Finally, I shall discuss the level of free will, both within humans and in other species, and the relevance for ethical and legal issues.

Evolutionary Strategies for Control of Behaviour

Level of conscious involvement

Behaviour can be defined as the internally coordinated responses (in the form of actions or inactions) of living organisms to internal and/or external stimuli [7]. The actions generally imply a neurological activation of muscles. Reflexes, such as the knee-jerk (patellar reflex), represent the simplest form of behavioural control. When you activate proprioceptors associated with the patellar tendon by hitting them with a hammer, you tap into a system that helps retain balance. The response only requires minimal processing in the spinal cord. It involves voluntary muscles, and is subject to free will in that you can choose to resist movement if warned ahead. The knee-jerk is brought to conscious attention, but the continuous regulation of muscle tone is not. Smooth muscles, such as those controlling gut movement and size of pupils, are generally outside of both voluntary control and conscious awareness. Yet, it is possible to 'hack into' their control mechanisms by conscious effort; for example, thinking of something dark or light is sufficient to respectively slightly open or close the pupils [8].

Feelings evolved as a more advanced and adaptable strategy for orchestrating behaviour, but they are designed to control (or sway) you, rather than you controlling them [9]. Evolution did not install an ability to turn off, for example fear or pain, by personal choice, as this could easily be disastrous for the genes; which means that feelings are normally initiated in the unconscious part of the brain. Generally, they are made available to consciousness, but you can be influenced by feelings without realizing that you actually have a feeling [10]. On the other hand, it is possible to have a conscious impact on how feelings affect what we experience [11].

Other strategies include fixed action patterns (where a sequence of activity is carried out in response to a stimulus) and instincts (or instinctive tendencies). Most forms of behavioural control is subject to learning in that the neuronal circuits responsible can be modulated by environmental input. The statement is true even for the simplest nervous systems such as those of nematodes [12]. In invertebrates, unconscious processes can presumably be responsible for advanced forms of behaviour; in humans, they may affect conscious control without the person being aware of the input; for example, in the form of what we refer to as intuition.

Although behaviour typically implies the activation of muscles, humans are endowed with the capacity to make purely cognitive decisions; for example, whom to marry. These decisions are clearly within the frame of our free will, yet they tend to be swayed by unconscious motivators such as feelings -we are likely to marry the person we fall in love with.

The importance of response time

Conscious processing (that is, conscious decisions) is generally slow and presumably costly in terms of required brain resources [13]. Moreover, it can only focus on one task at the time (although it can jump rapidly between tasks); while unconscious processing can care for several tasks simultaneously, such as regulating heart bit and pupil size. We are consequently designed to engage our capacity for cognitive deliberation only when immediate action is not required and in situations that cannot be dealt with by strategies that are more elementary. In order to understand why evolution moved in the direction of a free will type of strategy, it is relevant to consider the time nervous systems require in order to elicit various forms of response.

The knee-jerk only takes some 20 ms [14] reflecting the importance of continuous, rapid control of muscle tone in order to retain desired posture. A startle response, for example the initiation of a fear reaction as measured by eye-blinks after a sudden sound, typically takes some 40 ms [15] reflecting a somewhat more elaborate processing compared to the knee-jerk. A voluntary reaction to sensory stimuli requires even more processing time. In general, the reaction to auditory signals tends to be faster than in the case of visual signals; in experiments where the subject needs to push a button, the response can take respectively 280 ms and 330 ms [16]. Top athletes can start movement some 100 ms after hearing the start pistol, which is used to define a false start in sprint competitions and presumably is close to the minimum auditory reaction time [17]. In all these cases, the time includes perception, signalling from sensory cells to the central nervous system (CNS), processing, signalling from CNS to muscle, and muscle activation. In the case of a knee-jerk, the processing time is close to zero ms; the 20 ms required reflects the time needed for the signal to pass through axons, which in vertebrates is at the most 12 cm/ms [18].

The responses described in the above paragraph do not require actual deliberation after the signal is given, here free will enters the picture by making a decision *prior* to the sensory signal. For example, in order to block the knee-jerk you need to know that the hammer will soon hit your knee. If there is no forewarning, the actual awareness of the situation occurs after the reaction, both in the case of the knee-jerk and the startle response.

According to the *global neuronal workspace theory* of consciousness, a conscious experience is due to the ignition of a particular neuronal network that encodes a representation of the information experienced at that moment [19]. The process of bringing the information to conscious awareness, what may be referred to as 'broadcasting,' is expected to require at least 200-300 ms. Conscious deliberation as to how one ought to respond to the signal, can only start at that point, meaning that cognitive, or free will type, decisions are only suitable when one have at least a few seconds to make a choice.

The conclusion to be made from the discussion in Section 2 is that the way the brain operates imply a considerable 'grey zone' as to what sort of power is within the scope of our free will. In other words, free will is not an either/or question, but a phenomenon that varies in level depending on a range of factors.

The Neurobiology of Free Will

Neuroanatomy

Studies based on neuro imaging (mostly fMRI) suggest that the exertion of free will primarily involves activity in select regions of the cortex, particularly in parts of the prefrontal cortex (PFC) such as the ventromedial PFC and the dorsolateral PFC [20,21]. Finding a hotspot in the PFC is not surprising, as this region is associated with executive cognitive function and went through exceptional expansion in our branch of the evolutionary tree, presumably in concordance with the need for a more cognitive form of decision-making [22]. I would not expect there to be dedicated brain regions, or neuronal circuits, for the explicit purpose of free will, thus the actual activity in the PFC may reflect a general deliberation on various options – including thoughts about moral issues and the future. The dorsolateral PFC seems to be of particular importance for planning, initiative, attention, and rational decisions; as damage to this region results in *apathetic syndrome*, a condition that causes loss of interest and initiative, and in the more severe form can lead to a lethargic state [23].

Although the PFC seems to take a key role in the cognitive part of making a decision, other regions are also involved when it comes to free will. At least that seems to be the case if one expands a bit on the concept; that is, by partitioning it into four faculties: *attention* (being able to focus on a task), *volition* (wanting something to happen), sense of *agency* (self-consciousness), and *action* (activation of motor neurons). While attention is primarily associated with the PFC, the other three faculties seem to engage other parts of the brain as well.

Patients with *akinetic mutism* have limited motor function, but they are not paralyzed; apparently, they lack the *will* to move, that is, volition. Patients with *alien limb syndrome* feel that someone else generates their movements, which suggest a disruption of agency [24]. The responsible lesions for these disorders occur in a variety of brain locations, but those causing akinetic mutism fall within one network defined by connectivity to the anterior cingulate cortex (situated in the interior, midline surface of cortex and considered a part of the limbic lobe); while those causing alien limb syndrome belong to a different network connected to the precuneus (in the parietal cortex) [25]. These networks also match with data on locations in the brain that upon stimulation can disrupt free will, as well as with neuroimaging abnormalities in patients with psychiatric disorders related to the capacity of free will. Furthermore, the importance of the parietal cortex in self-consciousness is reflected in that patients with *anosognosia* (considered a deficit in self-consciousness) typically have lesions here [26]; and in studies of 'out-of-body experiences' using either electrodes or ketamine [27]. The brain's primary motor-control system is spread out over the motor cortex in the posterior frontal cortex, but other regions of the brain - including the cerebellum, the supplementary motor area (SMA, in front of the motor cortex), and spinal cord - are required to fine-tune and pass on signals to the muscles.

Neurological activity associated with willed decisions

Activation of muscles typically involves activity in several parts of the brain; the SMA, with its projections to the spinal cord, is part of this system. It is presumably involved in the control of movements that are willed (rather than triggered by sensory events), and these are consistently preceded by a readiness potential (RP). The RP is part of the preparatory activity for action, it entails a build-up of negative activity in the SMA that starts about 500 ms prior to movement [28,29] found that the RP also appeared to precede, by some 300 ms, the subjective experience of making the decision to perform the action. That is, the decision was apparently made by the unconscious brain, which subsequently created an illusion of a decision in the conscious brain. If so, it means that true free will does not exist. We can still have a 'sense of free will,' the question is whether the action is actually predetermined. Later experiments appear to confirm that activity in the SMA is sufficient to make a person take action [30]. Low intensity stimulation (in connection with epilepsy evaluation) causes the patient to experience an urge to move contralateral body parts; while if the stimulation is more intense, movements are typically initiated, and they are perceived as voluntary. I shall discuss possible interpretations of the above observations in light of the evolutionary rational behind this form of decision-making.

The apparent abolition of free will has met with resistance [31]. For example, it has been argued that the RP is not necessarily involved in the normal way of making a cognitive decision. In Libet type experiments, the subject is asked to perform a specific task at a time of his personal choice (or to choose among two rather similar options such as left or right arm), and then to record at what time he experienced the decision to start. In a normal situation, the person first needs to determine what to do. It is possible that the RP is not primarily about the decision to make a movement, but is better described as a biomarker that reflects a preparation either to make a particular type of movement (lift a hand) or to do a voluntary task [32]. Movements that are non-consequential (the decision to lift the hand is already made) or are part of a list of actions required to reach a particular goal (such as putting one foot in front of the other when walking) are typically not monitored in any detail by consciousness [33]. That is, the cognitive involvement is primarily about executing and monitoring the movements to see that they serve the larger purpose, not to re-evaluate the choice made. The RP could be part of this executive function.

In line with the above argument, resection of the SMA typically causes a transient inability to perform non-stimulus-driven, voluntary actions; but it does not appear to be associated with a loss of sense of volition or will power - only with a profound disruption of executive function and/or cognitive control [30]. That is, the RP is not required for the subjective experience of free will. A related observation has been made with subjects being hypnotized [34]. The researchers compared participants who performed a series of simple movement tasks either under hypnotic suggestion or upon normal instruction. The RP was present even when subjects made self-timed, endogenously-initiated movements suggested to them by the hypnotist; in order words, without a conscious feeling of having willed those movements.

The point of having the capacity to make decisions based on conscious deliberation is to do a better job at evaluating relevant factors. Cognition, and thus 'free will,' is an integral part of that strategy, as such it seems (at least semantically) more appropriate to state that there is an element of free will in connection with that type of decisions. Unfortunately, even if the RP can be accounted for by the above comments, the problem of preceding unconscious activity lingers, as discussed below.

Most of the work on how an experience is broadcasted for conscious awareness is done in connection with sensory (visual or auditory) perception [19]. In these experiments, the broadcasting requires 200-300 ms or more; and it is assumed that other forms of conscious content, such as thoughts and memory retrieval, require a somewhat similar broadcasting process. The act of making a decision, or the awareness of that act, is in itself a conscious experience. That is, in order to have conscious awareness of the decision, you first need subconscious broadcasting activity. So how can consciousness initiate the unconscious broadcasting of its own conscious decisions or thoughts? The problem appears to be a variant of the philosophical question, "which came first: the chicken or the egg?"

The answer to the chicken-and-egg question is that the two evolved gradually together. A similar answer seems reasonable in the case of the brain activity required to make a decision. In short, neurological activity associated with conscious deliberations interact with the activity required for broadcasting; implying a gradual, interdependent process. The RP can be a part of this process; for example by reflecting an element in the choice to make the movement, or by representing intention [35]. Actually, the RP of the SMA is only one example of neural activity associated with the preparation for movement; other activity in both the SMA and the neighbouring pre-SMA also seems to precede voluntary actions [35,36].

Moreover, it is possible to find correlating activity, not only in the pre-SMA and SMA, but also in other parts of the prefrontal and parietal cortices starting several seconds before an awareness of the actual choice of behavior [37]. The results are in line with the observation that unconscious changes in skin conductance can precede risky decisions [38]. The first unconscious precursors of a motor decision seem to originate in the frontopolar cortex (the anterior part of the PFC) up to 10 seconds before action [37]. This part of the brain has been associated with the storage of conscious action plans [39,40]. Other experiments suggest that an awareness of intention is accessible at early stages of motor preparation [41].

A plausible interpretation of the observations presented above is that a motor decision is an ongoing process with input stemming from both unconscious and (more or less) conscious brain activity. The outcome may be what the person in a Libet type experiment recognizes, or remembers, as the decision he/she made; even though the process was also informed by more subtle awareness prior to that. A similar picture may be the case with any form of cognitive deliberation. However, the subtle awareness is less obvious in a setup, such as that of Libet where the actual decision is predetermined, compared to a situation where deliberation is required.

Who Has Free Will?

In the section on *Neuroanatomy*, I suggested that free will could be separated into four faculties: attention, volition, agency, and action. Any animal with a nervous system can exert motor control; that is, take action. Some form of consciousness, including the ability to direct attention, is presumably present in mammals and birds, and perhaps reptiles [11], but the final two features may be more restricted. Agency requires self-consciousness. The same is arguably the case for volition [21]. Various experiments, most famously those involving mirror recognition, probe the presence of self-consciousness in animals; it is generally agreed that the feature is present in apes, and possibly in monkeys, cetaceans and certain birds [42,43]. It seems reasonable to assume that this list also reflects animals that can be said to have some form of free will.

When comparing humans with other species of animals, it should be noted that the terms we coin to describe features of living organisms are generally designed for us. Whether homologous (or analogous) features in animals deserve the same term is a question of semantics. The point is exemplified by asking whether dogs have a nose; some people will answer 'yes' while others will claim 'no, they have a snout.' Homologs of the brain structures associated with free will are generally present in other mammals, and to some extent birds and reptiles, but the actual phenomenon presumably rests with the specific qualities of the neurological circuits, which we are unable to describe in sufficient detail to tell how they compare in different species. Presumably there are both quantitative (such as the power of attention) and qualitative (such as how agency is perceived) differences between species; thus the answer depends on the cut-off chosen as to how different the feature is in an animal before the human term is inappropriate. Obviously, the issue is even more difficult to resolve in a trait that is invisible compared to, for example, the nose.

A free will is not an either or quality, but rather a question of level - whether one compares species or individual humans. For one, it depends on attention, which in humans varies from the focus required in chess to being asleep. In my opinion, there is no sense in saying that moving the pieces in a chess match is not a question of exercising will power, while one may claim that a sleepwalker does not act out of free will. Moreover, the use of various types of drugs can have a drastic impact on our capacity for attention and the maintenance of free will [27]. Free will also depends on age [44], and on diseases affecting the brain.

The debate as to who has a free will typically focuses on moral and legal issues [45]. A key question is whether a person can, and should, be held responsible for his or her actions. In this context, it is particularly important to note that free will is a question of level. The overall level can be partitioned into three somewhat independent levels: attention, competing decision strategies, and competence. Most countries have legal systems that take the level of free will into account. Although the legislation, and practice, varies, there seems to be a consensus that certain individuals should not be held responsible, such as the very young and those with severe mental handicaps.

Conclusion

A deliberation of a complex issue tends to require considerable time and use of brain resources; evolution has adapted behavioural control accordingly, which implies a limit to our free will. That is, strategies for making decisions that do not involve a free will may take precedence. In fact, even our best conscious efforts of making what we conceive as a willed decision, are swayed by forces outside the control of will power in the form of these other strategies; for example, in the form of feelings. On the other hand, upon training the mind some level of conscious control can be exerted over a range of features normally cared for by the unconscious brain, such as physical pain [46] and heartbeat [47].

The actual level of free will varies between individuals, states of mind, situations, and species of animals; but the highest score is presumably obtained with a healthy adult human in an attentive state. It follows that the question of whether we have free will may be answered by stating that we have a sufficient amount to choose whether the answer is 'yes' or 'no;' in that we can set the arbitrary cut-off required to qualify either above or below the level of free will bestowed upon us by evolution.

The point of being able to make conscious decisions is to find the optimal action in situation where pre programed solutions are less likely to work; for example, where many factors ought to be weighed against each other and no immediate action is required. I hold that the will is free to the extent that conscious deliberation is included as an input to decision-making. While I can see arguments in favour of the whole universe being deterministic, I see no reason to abolish the use of the term 'free will' in relation to human behaviour. There are noticeable qualities of how our brain functions that leave room for this term. Moreover, the concept may serve a purpose. A belief in free will seems to bring advantages such as a higher level of self- control, a meaning of life, and fostering a propensity for prosocial behaviour [48,49]. Even if these outcomes have been questioned [50,51], it seems best to stick to a definition of free will that bestow us with this quality – given that quality of life should be a guiding principle for human endeavour [3].

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References

1. Caruso GD (2012) Free will and consciousness: A determinist account of the illusion of free will. New York: Lexington Books.
2. Dobzhansky T (1973) Nothing in biology makes sense except in the light of evolution. The American Biological Teacher 35: 125-129.
3. Grinde B (2012) The biology of happiness. Dordrecht, Netherlands: Springer.
4. Cabanac M (2009) Do birds experience sensory pleasure? Evolutionary Psychology 7: 40-47.
5. Cabanac M (2002) What is emotion? Behavioural Processes 60: 69-83.
6. Grinde B (2018) Did consciousness first evolve in the amniotes? Psychology of Consciousness: Theory, Research and Practice 5: 239-257.
7. Levitis DA, Lidicker WZ, Freund G (2009) Behavioural biologists do not agree on what constitutes behaviour. Animal Behaviour 78: 103-110.
8. Laeng B, Sulutvedt U (2013) The eye pupil adjusts to imaginary light. Psychological Science 25: 188-197.
9. Panksepp J (2004) Affective neuroscience: The foundations of human and animal emotions. Oxford: Oxford University Press.
10. Tamietto M, de Gelder B (2010) Neural bases of the non-conscious perception of emotional signals. Nature Reviews Neuroscience 11: 697-709.
11. Grinde B (2016) The evolution of consciousness. Switzerland: Springer.
12. Zhang Y (2008) Neuronal mechanisms of Caenorhabditis elegans and pathogenic bacteria interactions. Current Opinions in Microbiology 11: 257-261.
13. Dehaene S (2014) Consciousness and the brain: Deciphering how the brain codes our thoughts. New York: Viking.
14. Vickery HS, Smith PA (2012) Surface electromyography reveals males have a slower patellar reflex than females. Journal of Electromyography 22: 990-996.
15. Larson CL, Ruffalo D, Nietert JY, et al. (2000) Temporal stability of the emotion modulated startle response. Journal of Psychophysiology 37: 92-101.

16. Jose S, Gideon PK (2010) Comparison between auditory and visual simple reaction times. Neuroscience & Medicine.
17. Pain MT, Hibbs A (2007) Sprint starts and the minimum auditory reaction time. Journal of Sports Sciences 25: 79-86.
18. Salzer J, Zalc B (2016) Myelination. Current Biology 26: R971-R975.
19. Mashour GA, Roelfsema P, Changeux JP, et al. (2020) Conscious processing and the global neuronal workspace hypothesis. Neuron 105: 776-798.
20. Hauser M, Cushman F, Young L, et al. (2007) A dissociation between moral judgments and justifications. Mind & Language 22: 1-21.
21. Haggard P (2019) The neuro cognitive bases of human volition. Annual Review of Psychology 70: 9-28.
22. Smaers JB, Gómez Robles A, Parks AN, et al. (2017) Exceptional evolutionary expansion of prefrontal cortex in great apes and humans. Current Biology 27: 714-720.
23. Chirchiglia D, Chirchiglia P, Marotta R, et al. (2019) The dorsolateral prefrontal cortex, the apathetic syndrome, and free will. Activitas Nervosa Superior 61: 136-141.
24. Kranick SM, Hallett M (2013) Neurology of volition. Experimental Brain Research 229: 313-327.
25. Darby RR, Joutsa J, Burke MJ, et al. (2018) Lesion network localization of free will. Proceedings of the National Academy of Sciences 115: 10792-10797.
26. Vuilleumier P (2004) Anosognosia: the neurology of beliefs and uncertainties. Cortex 40: 9-17.
27. Grinde B, Stewart L (2020) A global workspace, evolution-based model of the effect of psychedelics on consciousness. Psychology of Consciousness 7: 262-278.
28. Kornhuber HH, Deecke L (1965) Hirnpotentialänderungen bei Willkürbewegungen und passiven Bewegungen des Menschen: Bereitschaftspotential und reafferente Potentiale. Pflüger's Archiv für die gesamte Physiologie des Menschen und der Tiere 284: 1-17.
29. Libet B, Gleason CA, Wright EW, et al. (1993) Time of conscious intention to act in relation to onset of cerebral activity (readiness-potential). In Neurophysiology of Consciousness 13: 249-268.
30. Sjöberg RL (2021) Free will and neurosurgical resections of the supplementary motor area: a critical review. Acta Neurochirurgica 163: 1229-1237.
31. Guggisberg AG, Mottaz A (2013) Timing and awareness of movement decisions: does consciousness really come too late? Frontiers in Human Neuroscience 7: 385.
32. Mele AR, William H (2009) Effective intentions: The power of conscious will. Oxford: Oxford University Press.
33. Horga G, Maia TV (2012) Conscious and unconscious processes in cognitive control: A theoretical perspective and a novel empirical approach. Frontiers in Human Neuroscience 6: 199.
34. Schlegel A, Alexander P, Armstrong S, et al. (2015) Hypnotizing Libet: Readiness potentials with non-conscious volition. Consciousness and Cognition 33: 196-203.
35. Lau HC, Rogers RD, Haggard P, et al. (2004) Attention to intention. Science 303: 1208-1210.
36. Nachev P, Kennard C, Husain M (2008) Functional role of the supplementary and pre-supplementary motor areas. Nature Reviews Neuroscience 9: 856-869.
37. Soon CS, Brass M, Heinze, et al. (2008) Unconscious determinants of free decisions in the human brain. Nature Neuroscience 11: 543-545.
38. Bechara A, Damasio H, Tranel D, et al. (1997) Deciding advantageously before knowing the advantageous strategy. Science 275: 1293-1295.
39. Koechlin E, Basso G, Pietrini P, et al. (1999) The role of the anterior prefrontal cortex in human cognition. Nature 399: 148-151.
40. Haynes JD, Sakai K, Rees G, et al. (2007) Reading hidden intentions in the human brain. Current Biology 17: 323-328.
41. Parés Pujolràs E, Kim YW, Im CH, et al. (2019) Latent awareness: Early conscious access to motor preparation processes is linked to the readiness potential. NeuroImage 202: 116140.
42. Leary MR, Tangney JP (2013) Handbook of self and identity. New York, Guilford Press.
43. Chang L, Zhang S, Poo MM, et al. (2017) Spontaneous expression of mirror self-recognition in monkeys after learning precise visual-proprioceptive association for mirror images. Proceedings of the National Academy of Sciences USA 114: 3258-3263.
44. Kushnir T, Gopnik A, Chernyak N, et al. (2015) Developing intuitions about free will between ages four and six. Cognition 138: 79-101.
45. Ekstrom L (2018) Free will. New York: Routledge.
46. Bushnell MC, Čeko M, Low LA (2013) Cognitive and emotional control of pain and its disruption in chronic pain. Nature Review Neuroscience 14: 502-511.
47. Pokrovskii VM, Polischuk LV (2012) On the conscious control of the human heart. Journal of Integrative Neuroscience 11: 213-223.
48. Vohs KD, Schooler JW (2008) The value of believing in free will: Encouraging a belief in determinism increases cheating. Psychological Science 19: 49-54.
49. Moynihan AB, Igou ER, van Tilburg WA (2017) Free, connected, and meaningful: Free will beliefs promote meaningfulness through belongingness. Personality and Individual Differences 107: 54-65.
50. Ewusi Boisvert E, Racine E (2018) A critical review of methodologies and results in recent research on belief in free will. Neuroethics 11: 97-110.
51. Crone DL, Levy NL (2019) Are free will believers nicer people? (Four studies suggest not). Social Psychological Personality Science 10: 612-619.

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