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Can physics and neuroscience allow for free will?

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Abstract. While most of us feel we make decisions and can act out of free will, science seems to say we cannot. Neither deterministic laws of nature, acting in our macroscopic world, nor indeterministic quantum processes at microscopic levels, appear to allow for any free will. In addition, psychophysical experiments of voluntary actions by Libet and others seem to indicate that the brain decides our actions up to seconds before we are aware that we make a decision to act. All of these reasons have been taken as arguments for free will being an illusion. Here, I will discuss some of the perceived problems with free will, and how alternative interpretations of theories and experiments may lead to a different conclusion regarding the existence of free will. I will also argue that contemporary physics is insufficient for dealing with the behavior of complex biological systems, and in particular consciousness and agency. I conclude that, in order to allow for consciousness and free will, science needs to be extended beyond *chance and necessity*, which currently are the only models of explanation science can provide.

1. The problem of free will

For a long time, I have intended to go to Prague, but haven't got the opportunity until now, when I got an invitation to give a talk at a conference there. But how should I travel? Should I fly or take the train? Flying is not good for the climate, but fast. Travelling by train is better for the climate, but takes longer time – but you also see more of the landscape. Yet, the train is more expensive than an air ticket to Prague. And if my wife should come along, she would prefer the train. And if we travel together, what should we see and do there during our free time? That time will be limited, so we have to prioritize, but how, since we have different preferences? Regardless if I travel with my wife or go alone, I have to book tickets soon, and have to make a quick decision for the traveling, while the decision for what to do in Prague can wait. Time, money, consideration for the climate and for each other – what is most important? What will ultimately determine our decisions? Do we really have a choice? What does science actually say about all this?

In the search for the cause of a particular decision, one can try to find the neural processes behind the decision and where in the brain the first traceable activity is in the causal chain, and what kind of activity it is (see e.g. Haggard, 2009, 2019). In connection with such an analysis, the question may arise whether the recorded brain activity came before, at the same time, or after the perceived feeling that I made my decision. In the first case, one could interpret the result as implying that the brain made the decision before I became aware of it. In that case, my *will* had no influence on the decision, and thus the experience of volition would be conditioned by the preceding brain processes. In the latter cases, it would be reasonable to think that my (free) will manifested itself in various neural processes, which eventually led to an action. This would imply that consciousness had a causal effect on matter, which would be problematic for natural science,

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which typically assumes that the physical, material world can cause and affect consciousness, but not the other way around.

So the crucial question remains: Are our actions totally governed by our genes and environment, by chance and natural laws, or do we have free will, and if so, how free is it? Most of us experience that we have free will, but that is not the same as it being real. Many times, there might not be a rational explanation for our behavior, and the “action” can be seen as merely a whim or the result of chaotic or random processes in our brains, possibly triggered by external signals or events. It may also involve processes that we have no control over, or that cannot be traced, neither externally nor internally.

Further, much of our behavior is governed by unconscious processes and events, in the present or in the past. These include, forgotten memories that can affect us unconsciously, or hidden unconscious feelings that we cannot perceive, much less explain. We may also be influenced by external factors, such as subliminal advertising or pheromones, which cause us to act differently than we would have done without these signals. In addition, we are influenced by our social relationships and the will of others. So, could we really argue that our decisions and actions are truly free, a result of me as a conscious agent?

2. What does science say about free will?

According to modern science, there seems to be no support for free will. Generally, only natural laws and randomness serve as explanatory models for phenomena and events in the world (Monod, 1971). There is no room for any conscious will or influence on matter that is outside or beyond “chance and necessity”. It seems that actions are either causally predetermined by physical laws or occur due to chance. So, how should science approach and investigate the experience of free will — the sense that it is "I" who freely decides if, when, or what to do?

Another challenge is that science typically relies on “upward causation”, meaning that higher levels of organization are determined by lower ones — for instance, the behavior of biological systems would be totally determined by their atoms, genes, or neurons. It is more difficult to grasp and accept that higher levels could also influence or determine lower levels. This form of “downward causation” would be required for conscious will to affect matter, such as when consciousness influences muscle cells to produce physical actions. (For a more extensive discussion on downward causation in biology, see Noble (2008), or Murphy *et al.* (2009)).

2.1 Relationship between free will, determinism, and causality

Before proceeding further with the problems we are discussing here, let us first try to sort out the relationship between determinism, causality, and free will, according to some general notions (see e.g. *Stanford Encyclopedia of Philosophy*).

Determinism is the idea that all events, including human actions, are determined by preceding causes. Given the state of the universe at one time and the laws of nature, only one future is possible. Determinism implies a causal structure where every event is the result of previous events. *Causality* refers to the relationship between causes and effects. In a deterministic framework, causality implies that every event is necessitated by preceding events in accordance with the (deterministic) laws of nature. *Free will* is the ability of individuals to make choices that are *not* determined by prior causes. The central question is whether humans *can* be genuinely free to make their own decisions if determinism holds.

Two main positions regarding this last issue could be considered. 1) *Compatibilism*, which holds that free will is compatible with determinism. Even if our actions are determined by prior causes, we can still be considered free, as long as we act according to our desires and intentions

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without external compulsion. 2) *Incompatibilism* states that free will and determinism cannot exist together. The argument is that in a deterministic world, individuals have no real control over their actions and hence cannot have free will.

Incompatibilists can be *libertarians*, who believe the world is indeterministic and humans have free will. Alternatively, they can be *hard determinists*, who argue that all events in the world, including human actions are determined by natural laws, and hence free will cannot exist. It could perhaps be appropriate to distinguish between events and actions, where actions require conscious agents. *Agent causation* holds that agents themselves can be the originators of causal chains that are not determined by prior events, and hence could allow for free will.

2.2 Free will and consciousness

Although we may believe we act out of free will in our daily lives, a widely held view in both popular scientific and philosophical literature is that free will is merely an illusion. This view is partly based on the notion that the world is deterministic (at least on a macroscopic level), which excludes the possibility of a truly free will. In addition, many psychophysical experiments suggest that a decision, such as moving a finger, is preceded by specific brain activity occurring up to several seconds before we become consciously aware of making "our" decision.

One reason for the growing interest in free will is its significant implications for our worldview and how we, as humans, perceive ourselves within it. The issue of free will is also closely tied to numerous other topics discussed in science, philosophy, and religion. For instance, it is deeply connected to the problem of consciousness, where factors like memory, mood, and perception influence our thoughts, intentions, and decisions. Naturally, free will is also strongly associated with concepts such as morality, conscience, and responsibility.

In the following sections, we will explore some of these issues related to free will in greater depth. They have also been dealt with in a recent book, *Free Will: Philosophers and Neuroscientists in Conversation*, edited by Uri Maoz and Walter Sinnott-Armstrong (2022) and resulting from an international Templeton/Fetzer funded collaboration, *Neurophilosophy of Free Will*.

3. Problems with physics

When examining the challenges that physics presents for free will, the core issue is that the only possible causes for events in the world are either natural laws, which are typically viewed as deterministic, or chance events, which are indeterministic. Neither of these options appears to leave room for the existence of any free will.

As stated in the previous section, compatibilists, such as Daniel Dennett (1984) or Jenann Ismael (2016), believe the laws of physics are deterministic, although there could still be some kind of free will. In Ismael's case, free will could exist at a "local level", but quantum indeterminism does not help here, because it does not allow for control of our actions (Ismael, 2016). She suggests that causation does not work at the level of the entire universe, which supposedly is a closed system, but just in smaller subsystems of it. In smaller subsystems, like human beings which obviously are open, free will can arise. From the causation in local systems, free will may emerge through deliberation, where we decide how to act. At the same time, she argues that if we knew all the initial conditions of a subsystem and all the forces that affect it, we could calculate the future of the system, which is typical traditional determinism.

3.1 A deterministic worldview

Compatibilists, such as Ismael and others (notably John Stuart Mill in the mid-19th century, and many philosophers since), are able to reconcile free will with determinism. However, I struggle to see how we, as conscious agents, can truly make changes (by our own choice) in a world that is

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fully determined and, in principle, predictable. It is difficult to understand how causation and free will can operate only at a local level without affecting the world as a whole (even if our decisions or actions might not impact the universe on a cosmic scale). To me, the "freedom" described by compatibilists doesn't seem truly free.

Among physicists and philosophers, there is a general assumption that the world at large is governed by deterministic laws of nature. But what are the reasons for this assumption? The main reason, I believe, comes from classical physics and the success in calculating and predicting the motion of physical objects, primarily using Newtonian mechanics, which operates on deterministic principles. According to these laws, if the state of a system is known, its state at any future time can be precisely predicted. The French mathematician and physicist, Pierre-Simon Laplace stated this principle very clearly, saying that if a “demon” knew the precise location and momentum of every atom in the universe, it could predict the future of the universe with absolute certainty.

Isaac Newton was deeply religious and was, like most scientists in those days, a deist, believing that God had created the world as a perfect clockwork, where everything is governed by immutable deterministic laws. When he was able to demonstrate that the motion of physical objects could be calculated and the trajectories predicted with great precision, this was believed to be a proof of the deterministic nature of the laws of God and Nature.

However, the possibility to use Newton’s calculus to calculate and predict was just for simple systems. When a system consisted of three or more interacting objects, the problem became too complicated to calculate with any accuracy. This was a fact that much later became associated with deterministic chaos, which eventually could be simulated with computers.

Another argument for determinism is the *principle of causal closure*, which suggests that every physical event has a physical cause. It is also related to the first law of thermodynamics, saying that energy is conserved in closed systems, which the Universe is supposed to be. Hence it is believed that free will, as supposedly a non-physical process, could not cause any events in the physical world (Pylkkänen, 2007).

While determinism is a very dominant view today, there is a number of arguments against it, at least as a general principle for how the Universe works. Actually, the deterministic worldview was challenged already in the middle of the 19th century, when chance events, or randomness were introduced in scientific theories, both in physics and in biology.

3.2 Indeterminism

In physics, Ludwig Boltzmann introduced randomness through statistical mechanics to describe the motion of atoms and molecules. Around the same time, Charles Darwin proposed chance events as one of the mechanisms, along with natural selection, driving the evolution of species.
Later on, chance events and randomness became an important aspect of quantum mechanics (QM). In particular, the *Copenhagen interpretation* of QM suggests that nature is inherently probabilistic at the microscopic level of atoms and subatomic particles. A typical example was the decay of radioactive atoms, but also when determining the position of wave-particles, such as electrons. The *Heisenberg uncertainty principle* even states that position and momentum of a particle *cannot* both be determined simultaneously. Hence, there is a fundamental indeterminism and unpredictability, at least at this level of matter.

Actually, Werner Heisenberg, as one of the founders of QM, challenged the classical conceptions of natural laws and offered a nuanced understanding on how they might work. He argued that, since the laws of QM do not predict exact outcomes but rather the probabilities of different outcomes of experiments, there should be an epistemological shift from deterministic predictability to probabilistic descriptions of the world. This indeterminacy should be seen as a fundamental feature of nature, not just a limitation of our measurement techniques, but rather a limitation to human knowledge in describing reality. Heisenberg also highlighted the role of the observer in quantum measurements. The act of measurement affects the system being observed, meaning that the laws of nature must account for this interaction. This view complicates the notion of objective reality existing independently of observation. Heisenberg suggests that scientific theories are only tools for organizing and predicting phenomena, and laws of nature should be regarded just as models that help us understand and interact with the world (Heisenberg, 1971).

However, it should be noted that there are other interpretations of QM. For example, David Bohm suggested that hidden variables could explain the seemingly indeterministic phenomena in QM, while the world is in fact deterministic, even at the micro level (Bohm, 1952; 1957).

In addition, *chaos theory*, although based on deterministic equations, also challenges the idea that deterministic systems are also predictable. The outcome of a chaotic complex system is so sensitively dependent on initial conditions, that it becomes unpredictable at longer time scales. Small differences in initial conditions can hence lead to vastly different outcomes (Lorenz, 1963; Gleick, 1987).

An extended view on quantum indeterminism is given by Karl Popper, in particular in the book "*The Open Universe*" (Popper & Bartley, 1982), where the concept of *propensities* is discussed. Popper proposes that nature operates based on propensities, i.e. tendencies or dispositions of physical systems to produce certain outcomes in given conditions. There is an inherent uncertainty in predicting specific events, and this uncertainty exists independently of our knowledge or measurement. This view could represent a middle ground between strict determinism and pure indeterminism, which implies some level of indeterminism in all natural laws. Hence, the future is open and not predetermined by the present or by preceding causes. In an open universe, new, unpredictable properties, structures, and phenomena can emerge, which implies that the universe is inherently creative and capable of producing novel outcomes.

Popper connects the concept of an open universe with human freedom and creativity. He argues that humans possess the ability to make decisions and act freely, making real choices that influence the future in unpredictable ways. The idea of an open universe aligns with Popper's general philosophy, especially his focus on falsifiability and the provisional status of scientific theories. Because the future is uncertain and open, scientific knowledge remains tentative and subject to change as new evidence and discoveries emerge.

Understanding propensities allows for a more nuanced view of prediction and explanation in science. With this understanding, we can study the tendencies of systems to behave in certain ways under specific conditions, even if precise outcomes cannot be predicted with certainty. Propensities offer a way to understand causation in a probabilistic framework. Rather than viewing causation as a deterministic process where specific causes always lead to specific effects, propensities imply that causes increase the likelihood of certain effects, which reflects the probabilistic nature of the world.

An alternative way of looking at propensities is given by the idea of *dispositionalism*, which is gaining increasing interest in modern philosophy and science. Dispositionalism is a philosophical theory, partly developed by philosopher Stephen Mumford, that explains various phenomena in terms of the dispositions or tendencies of objects and entities (Mumford, 2004; Anjum & Mumford, 2018). The theory suggests that the properties of objects are dispositional, meaning they possess inherent capacities to behave in particular ways under specific conditions. These dispositional properties are dynamic, referring to potential actions or reactions, where the active role

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of objects in producing effects is emphasized, rather than seeing them as passive elements in causal relationships. Dispositionalism also suggests that laws of nature are descriptions of the dispositions of objects rather than external, governing rules. Instead of viewing such laws as mere regularities, it is argued that they reflect the real dispositions of entities.

Hence, according to the views of Heisenberg, Popper, Mumford and others, natural laws should not be considered deterministic, but rather seen in terms of propensities or dispositions. It is an indeterministic, probabilistic view of the world, not only at the level of atoms and subatomic particles, but rather dominating all levels and aspects of the Universe. If this view holds, physics should not be used as a basis for arguments against free will, but how about neuroscience?

4. Problems with neuroscience

4.1 Free will as an illusion

As mentioned in Section 2, it is generally believed that neuroscience has demonstrated that free will is an illusion. It is primarily a number of psychophysical experiments, by Libet and others, (Libet *et al.*, 1982, 1983; Keller & Heckhausen, 1990; Haggard & Eimer, 1999; Soon *et al.*, 2008; Haynes, 2011) that have been used to support this notion. In such experiments with electroencephalography (EEG), there is a so-called “readiness potential” (RP), which appears when averaging over a large number of trials, and seems to precede a conscious volitional movement. The RP starts approximately 1050 ms before the action in experiments where the subject acknowledges prior planning, and around 550 ms before the action when no prior planning is reported. Since it takes about 200 ms for the muscles to activate after a decision to act, the RP appears to precede a volitional act by about 850 ms with pre-planning and by 350 ms without pre-planning. This difference shows that the timing of the RP critically depends on pre-planning.

However, only a portion of our conscious processes can be verbally reported, and subjects often cannot recall or acknowledge pre-planning. Yet, they are fully aware that they are expected to act (e.g. to move a finger) within the next 10-100 seconds, as instructed by the experimenter. It is possible that the observed 350 ms effect may be attributed to residual (unconscious) preplanning, and that the RP for truly unplanned actions aligns with the perceived moment of intention. The shortest observed time between RP and action in Libet's experiments (Libet *et al.*, 1983) were on average only 270 ms, which can essentially be considered as RP occurring simultaneously with the perceived act of will (Trevena & Miller, 2002).

While EEG (and MEG, magnetoencephalography) can capture the timing of volitional acts on the scale of seconds or less, brain imaging techniques, such as functional magnetic resonance imaging (fMRI), offer more precise spatial information about the specific brain regions involved. However, the temporal resolution here is not so good, with timescales from several seconds to minutes. This technique measures changes in blood oxygen levels with high resolution, allowing for the tracking of local brain activity patterns. Such studies have demonstrated that the prefrontal cortex (PFC) plays a key role in the planning and selection of volitional actions, while the supplementary motor area (SMA), parietal cortex, and basal ganglia also appear to contribute. (Frith *et al.*, 1991; Spence & Frith, 1999; Schultz, 1999).

John-Dylan Haynes and colleagues (Soon *et al.*, 2008; Haynes, 2011) have used fMRI to examine the temporal relationship between subjective decisions and brain activity. In their study, subjects were instructed to press one of two buttons, using either the left or right hand, at any time they chose. While doing so, they watched a sequence of letters on a screen, and the timing of their subjective decision to press a button was recorded by having them indicate the letter they were focusing on when the decision occurred. When subjects reported exercising their free will, fMRI scans were conducted on several cortical regions, including the SMA and PFC. It turned out that

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fMRI images from the PFC taken ten seconds before the button press contained information that led to an average of 60% correct prediction of which hand (left or right) would press the button. Although a result of 50% would correspond to a random prediction, a pure guess, the reported results have been taken as evidence that free will is an illusion.

The second key finding from the experiments by Soon *et al.* (2008) is that the timing of the button press can be predicted with 60% accuracy based on fMRI data from the SMA. While the exact role of the SMA is not fully understood, it is commonly believed to be involved in planning learned sequences of movements. The RP is predominantly observed in the SMA.

Direct manipulation of the brain, through methods like electrical stimulation (Fried *et al.*, 1991; Desmurget *et al.*, 2009) or transcranial magnetic stimulation (TMS), can evoke various experiences, including the sensation of free will (Brasil-Neto *et al.*, 1992; Haggard, 2009). These artificially induced feelings of free will may sometimes lead to purposeful movements or hallucinations of imagined actions.

For example, electrical stimulation of the SMA can evoke a sense of free will linked to either real or imagined movements (Fried *et al.*, 1991). With lower-intensity stimulation, subjects reported feeling a strong urge to move a specific part of their body. When the stimulation at the same SMA point was increased, the corresponding muscle actually contracted. This finding is supported by other experiments and anatomical studies, which indicate that the SMA is part of the direct neural pathway from decision to action. The urge to act appears to be functionally connected to actual movement preparation, suggesting that this sensation may be an illusory, delayed effect of decisions made elsewhere (Wegner, 2003).

Desmurget *et al.* (2009) used electrical stimulation of parietal and premotor cortical areas during surgery to investigate their roles in conscious intention and motor awareness. They discovered that stimulating parietal areas could induce a strong sense of intention or desire to move a body part (such as a hand, foot, or mouth), and with more intense stimulation, it could even create the sensation that a movement had actually occurred. Stimulation of the premotor areas caused actual movements of the mouth and limbs, though the subjects often denied having moved. This indicates that the unusual and artificial context of open brain stimulation in areas related to planning can provoke temporary hallucinations of volitional movements. This should, however, not be taken as conclusive evidence that free will is illusory in normal, healthy, and conscious individuals.

4.2 Alternative interpretations

There is a number of alternative interpretations of the experimental results such as the ones discussed above. Some of these alternatives, as summarized below, could instead lead to the assumption that free, conscious will is real and can have a causal impact on matter. In the following, I will use the term "conscious will" instead of "free will," since the discussion on freedom may obscure the main point.

The conventional interpretation of experiments like those by Libet or Haynes and colleagues is based on a simplified view of the subjects' conscious processes. It presumes that the subject's consciousness is initially blank, or at least unrelated to the experiment, until they suddenly experience an urge to act. This assumption is critical for interpreting the results of these experiments. If it were found that subjects had subconsciously pre-planned all their actions, the conclusions drawn from these experiments would be significantly different.

However, the subject's consciousness is not blank, neither during examination nor in the experiments. Although subjects were instructed not to pre-plan and to “act spontaneously,” there was an implicit expectation that they would produce certain pre-specified, random “free-will actions.” While subjects may have consciously intended to act spontaneously, they might have subconsciously pre-planned their actions to some extent.

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A more cautious interpretation of the same data suggests that there is a weak correlation between the brain's activity state seconds before the action and at the moment of action. This correlation could be understood as the result of unreported pre-planning, a connection between the memory of the previous action and the upcoming one, or a weak link between unconscious neural processes and a consciously experienced volitional act.

It is also conceivable that the intentional process results in a gradual increase in consciousness, perhaps originating in a totally unconscious intention. The transition could be incremental and does not need to constitute a sharp threshold. In any case, the results from all such experiments might have been affected by an unknown degree of pre-planning, which could erroneously lead to the conclusion that conscious will is illusory.

If one electrically stimulates the "neural correlates of conscious will", as in the experiments by Desmurget *et al.* (2009), it can create a sensation of intention, without sending a functional signal to the brain's premotor area, and without triggering any action. This does not contradict the idea that conscious will typically has a causal influence on actions. In fact, stimulating the premotor area can cause mouth or limb movements without a corresponding sense of intention, and subjects may even deny that any movement occurred. These experiments suggest that movements alone are not enough for motor awareness. Rather, activity in "the neural correlates of conscious will" seems to be essential for this awareness, whether or not a movement actually follows.

Another issue with experiments on conscious will is that subjects are asked to make deliberate decisions repeatedly, allowing investigators to gather enough data. This means that subjects carry memories of previous rounds, which influence their subsequent choices. (In fact, humans have problems to generate truly random sequences, as shown by Uri Maoz and colleagues (Wong *et al.*, 2021). Most people are likely to choose "left" as their next "conscious will" action if they have already chosen "right" several times in a row.) Thus, the next choice is often correlated with previous ones. When Haynes and colleagues found a 60% correlation between the next decision and the state of the PFC ten seconds before the action, it could actually reflect a correlation between the memory of past choices and the current decision. It is possible that the next choice in a series of keystrokes could have a 60% correlation with the accumulated history of prior selections.

Perhaps the major criticism of interpreting experimental results as evidence that free will is an illusion is that these experiments do not actually test free, conscious will. The experiments are often overly simplistic, typically involving only two "choices" (e.g., pressing one of two buttons), with outcomes that have no real significance for the participant. The simplicity of these laboratory setups is meant to exclude the complexities of a real environment and its impact on brain activity and behavior. The goal is to eliminate factors that might influence the experiment's outcome but cannot be controlled. Since it is extremely difficult to track brain signals associated with specific mental activities or experiences, efforts are made to filter out anything that could cause interference. Even in these basic scenarios, the correlation between specific neural activity and the experience of an act of will is achieved with only around 60% accuracy (Soon *et al.*, 2008). However, this misses an important point that it may be in complex, real-world ("ecological") situations — where we must consider many factors, including moral responsibility — that our conscious will is fully expressed.

Experiments by Uri Maoz and colleagues (2019) use more sophisticated decision-making scenarios, rather than the simple two-button options, where the different choices carry varying values for the participants. This setup requires an evaluation process, involving a longer period of deliberation within the brain and consciousness to reach a decision. In such cases, the RP observed in Libet's and other experiments has not been detected. It is possible that the RP represents a spontaneous brain impulse signaling that a motor action (e.g., pressing a button) should be performed. The motor signal to the muscles might then be the result of a random event in the brain's neural activity, unrelated to an act of free will (Schurger *et al.*, 2012; Schurger, 2018),

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though this hypothesis has been disputed (Travers *et al.*, 2020), and many details regarding the exact role of the RP remains unclear (Parés-Pujolràs *et al.*, 2023).

In summary, experiments where one attempts to correlate neural processes with mental processes are bound to be difficult to interpret, because of the complexity involved. In the particular case of volition, there is a large number of "external" factors that may influence, without deterministically controlling or determining, our decisions to act. Such factors could be physical, chemical, or biological, which may occur before the conscious volitional act. There is also a lot of "internal", partly unconscious influences that matters for our decisions. This can be various neural or mental factors such as mood, memories, thoughts, feelings, etc. Additionally, we can be influenced directly or indirectly by other individuals. Such influence on the decision-making process, however, is not the same as the decision itself.

In a complex system like the human brain, the constant interaction with the environment and all the internal and external feedback circuits involved make it difficult, if not impossible, to pinpoint causal chains and distinguish cause from effect. This is further compounded by the brain's different organizational structures, which include not only connections between various brain regions but also between different neural levels. As a result, it is unclear whether a neural event precedes a mental event, follows it, or occurs simultaneously. Simplified statements or hypotheses — whether asserting that free will exists or is an illusion — can never fully capture the brain-mind complexity.

Despite the problems with complexity, hypotheses and assumptions about relations between neural and mental processes are necessary for designing experiments and interpreting and analyzing the data. When it comes to volition, it is particularly intriguing to trace the neural pathways involved, from the formation of an intention to act, to the decision to carry out the action, and finally, to the execution of that action. In the next sections, I will discuss various steps in the decision making process and how this problem can be approached with neurocomputational models, which necessarily implies tremendous simplifications. Such modeling can be regarded as a complement to experimental approaches when trying to clarify causal relationships in willful actions and interpreting the results.

5. Decision-Making

All decisions can be considered resulting from a (gradually increasing) conscious process. In cases where it might appear as we make decisions unconsciously, for example turning right at the next traffic light while thinking about making dinner at home, may result from the initial conscious decision to drive home. Also, even if every single part of that drive from work to home has become automatic, they had to be conscious at the time we learnt that route.

So, if decisions are conscious, how about intentions? Our intentions are crucial for our decisions, but many internal and external factors may also influence our decisions, as discussed above. In the following, we will first look at the process of decision-making (DM) and later on explore the relations between intentions and decisions, as part of volition.

There are many theories about how we make decisions, how our emotions and thoughts play a role, and how context and attitudes affect us, but the focus here is on current knowledge about brain areas and processes involved in individual decision-making. In particular, how computer models can help us better understand how these different parts and processes could interact in the brain.

Psychologically, the DM process can be divided into three phases: 1) Emotional evaluation and prioritization of different possible options based on emotional responses. 2) cognitive/rational assessment of the options, leading to the execution of an appropriate action (depending on needs). 3) Post-action evaluation of the effect of the action, and comparing it with the expected value of the decision/action (Enste & Paulus, 2005).

DM is, however, rarely as rational as we would like to believe, which was demonstrated by Kahneman and colleagues (1979, 2011) in a series of notable experiments. According to their hypothesis, DM results from an interaction between an intuitive/emotional system and a rational/cognitive system, referred to as System I and System II, respectively. The hypothesis suggests that there is an integration between a "bottom-up", intuitive, fast, implicit, and emotional system (System I) and a "top-down", deliberate, slow, explicit, and cognitive system (System II), (Kahneman, 2011).

5.1 Modelling of decision-making

In order to understand how the different parts of the brain interact and collectively contribute to DM and volition, we have constructed neurocomputational models which can be used to simulate various experimental situations (Hassannejad Nazir & Liljenström, 2015, 2016; Hassannejad Nazir *et al.*, 2023). Several brain areas may be involved in DM, but for our DM model we focus on the lateral prefrontal cortex (LPFC), orbitofrontal cortex (OFC), and amygdala, which all have been demonstrated to play important roles.

For the problem of intentionality, on the other hand, we model different subregions of LPFC (Broadman areas 9, 10, and 46) and the anterior cingulate cortex (ACC), as dominant structures involved in the intentional control (IC) process. ACC plays an important role in modulating the neurodynamics of LPFC through projecting its subregions during different attentional control phases. Both of these models (DM and IC) are computationally developed from a cortical neural network model originally developed for (olfactory) perception and associative memory (Liljenström, 1991, 1995).

Our computer model of DM is based on Kahneman's hypothesis of two systems, as briefly described above (Hassannejad Nazir & Liljenström, 2015). In our model, the evaluation of the consequences of an action, following a decision, can be described using a value function, which corresponds to the expected value of an optional choice. This value function is a product of the magnitude of the expected value, delay, and probability of occurrence. It is therefore reasonable to choose an action that leads to the greatest overall value of the consequences of the chosen outcome. When an individual learns from experience, it is important to identify which specific action that caused a given outcome. In the model, different alternative options are represented by dynamic neuron groups (cell assemblies), which oscillate synchronously with frequencies in the gamma range (30-80 Hz), corresponding to EEG signals from the associated brain areas.

There may be many different external and internal factors influencing our DM, such as needs, desires, and risks, as well as knowledge and uncertainty about the environment. For example, the expectation of a large reward may motivate an individual to pursue an action despite a high cost. Uncertainty about the consequences of an action may lead to greater risk-taking and exploratory choices, while predictable situations could lead to considering long-term rewards more seriously.

One of the most important parameters when assessing the value of different rewards is *time*. In intertemporal DM, where the relative value of a reward at different time points must be considered, the value of the reward (normally) decreases inversely proportional to time (Doya, 2008). As a result, people are more tempted by short-term rewards than long-term ones, even though this generally leads to a net loss, meaning we typically ignore high-value/long-term benefits in favor of low-value/immediate rewards. For instance, decisions related to climate change must be made long before the effects become noticeable, and hence is often down-prioritized. Presumably, short-term goals involve neural structures primarily engaged in emotions, while long-term rewards are primarily evaluated by rational cognition.

Successful DM is an adaptive process based on both individual experiences and social factors. It also depends on our attitudes, preferences, moods, etc. Attitudes are relatively stable and typically do not change on shorter time scales but can change over long term as a result of knowledge, experience, and insights gained personally and through interactions with others. We also address

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these issues in our modeling. (For more details on our DM model and its results, see Hassannejad Nazir & Liljenström (2015, 2016)).

6. Intentionality

Decisions to act seem very much related to the RP in Libet type experiments, and although its significance in volition has been questioned (Schurger *et al.*, 2012; Schurger, 2018), the general notion is that all our actions are preceded by an RP (Travers *et al.*, 2020; Schultze-Kraft *et al.*, 2020). As mentioned in the previous section, we hypothesize that a decision is resulting from a competition between cell assemblies in System I (Amygdala/OFC) and System II (LPFC). Somehow, the "winning" signal is transmitted to pre-SMA and SMA before going to motor areas and signals to various muscles. However, the causal pathways leading to the RP, which is measured in the (pre-)SMA, is not quite clear. In order to investigate how the RP emerges from activities in other brain areas, we have constructed a modified model of the DM model described above, where we focus on the intentional control (IC) process preceding a decision (Hassannejad Nazir *et al.*, 2023). In this IC model, we only consider signals originating in the LPFC, which is associated with primarily cognitive/rational decisions.

There are reasons to regard intentionality as a *driving force* to act purposefully, in order to achieve a specific goal (Freeman, 1999; Liljenström, 2011, 2018). Intentional processes are prerequisite for a volitional act and could be more or less conscious. An action can be considered an act of free will if the individual is aware of the intention to carry it out. Volitional acts, or more generally, behavior is grounded in perception and previous experiences/memories.

In principle, we could have many conscious and perhaps unconscious intentions competing, but just a few of them may lead to a decision to act. Further, intentions may be *distal* or *proximal*, depending on their longer or shorter temporal relation to a decision (see e.g. Mele (2019) and Parés-Pujolràs & Haggard (2021)). For example, I may have had a distal intention to travel to Prague for a long time, but deciding what to see and do there could be based on proximal intentions while walking around in the city. Intentions could also have emotional or cognitive origin, and hence be associated with different parts of the brain, including the limbic system. (Another type of intentions are *motor* intentions, concerning which muscles should be activated in more detail, but this is not in focus here. See further discussions in Maoz & Sinnott-Armstrong (2022)).

Much of human behavior is still influenced by our limbic system, so unconscious intentions may originate from there, perhaps leading to actions without decisions. However, many intentions have a cognitive origin and could supposedly be consciously formed in neocortex, e.g. in PFC (Haggard & Parés-Pujolràs, 2021). Typically, unconscious (often proximal) intentions would have emotional origin, perhaps in the limbic system, while distal intentions would typically be cognitive and conscious and would precede a decision to act. Proximal intentions are usually quite close in time for an action. In some cases, when immediate actions are called for, intentions and decisions could be more or less simultaneous. This is in line with the ideas of the DM process described in the previous section.

6.1 Modelling of intentional control

Volitional DM is about weighting and selecting an option among potential alternatives, which involves a conscious control process. It is conceivable that this process could be correlated with a rather complex, perhaps chaotic neurodynamics, before it reaches a decision, which supposedly would entail a more ordered, perhaps oscillatory dynamics.

In our modeling, we use attractor network dynamics to describe the intentional process leading to a decision to act (Hassannejad Nazir et al, 2023). More precisely, we use our IC model to investigate transitions between different attractor states of cortical networks and the processes of intentional control (IC), as the preparatory phase of voluntary action. Attractors are recurrent neural activity patterns of different kinds which could be characteristic for various states of cortical networks. Such states could, for example, be related to memories, concepts, percepts, intentions, or decisions (Freeman, 2000; Albantakis & Deco, 2011; Hutt & beim Graben, 2017; Schoemann & Scherbaum, 2020).

For our modeling, we treat the brain as a complex nonlinear system, capable of producing both oscillatory and high-dimensional chaotic neural activity patterns (attractors). We hypothesize that a decision is associated with a transition from a chaotic to a stabilized oscillatory attractor brain state, by means of an IC process. Presumably, there is a difference in the neurodynamics dependning on whether the decisions are made during arbitrary or deliberate choices, where experiments indicate that an RP does not appear in the latter case (Maoz *et al.*, 2019; Mudrik *et al.*, 2020).

We use our IC model of LPFC and ACC to test this transition hypothesis by investigating the time evolution of the neural activity patterns in these cortical structures. We specifically simulate the attractor network dynamics during the preparatory phase of IC, leading up to a decision to act. The results may shed light on the relation between the governing mechanisms and certain characteristics of the attractor dynamics in this process.

We propose that the EEG-like signals generated by our IC model can help clarify some properties related to the oscillatory activity in the involved brain regions. For instance, we have simulated the observed shift in the oscillatory activity, from beta to gamma frequency in PFC. Our model has also been used to explore the temporal evolution of different attractor states, demonstrating that the emergence of intention can be influenced by the hierarchical processing of both external and internal information, as well as by retrieved goals and associated actions. The neural attractor states in our IC model are regulated by feedback loops at each stage.

Our findings, including the demonstration of neural state transitions, provide a possible explanation for certain experimental observations during volition, which we believe represent only part of the process of IC. Based on our study, we contend that existing experimental data alone cannot be considered sufficient evidence against the existence of free will. On the contrary, our modelling suggests how decisions may result from an intentional process which gradually becomes more and more conscious. (For more details on our IC model and its results, see Hassannejad Nazir *et al.*, (2023)).

7. Discussion

In our model of decision-making (DM), as outlined in Section 5, decisions are simulated based on a weighted evaluation of various emotional and cognitive assessments of the consequences of associated actions. However, it is not certain that a decision mechanically follows this calculated evaluation. There is a certain degree of uncertainty, or indeterminacy in the simulations. In the model, any decision is made with a certain probability, provided by a random number generator (Hassannejad Nazir & Liljenström, 2015). In reality, it could be our more or less free will that prevents us from slavishly following what the brain has calculated as the best decision in each individual case, which could be considered the most rational one.

Further, with our model of intentional control (IC), we have demonstrated how the feedback-based connectivity between ACC and different LPFC subregions may give rise to a hierarchical process (Hassannejad Nazir *et al.*, 2023). To describe the neural processes involved in decision-making, intention and volition, it appears necessary to explore and understand changes in the neurodynamic patterns in the associated brain areas. For example, the convergence of chaotic to limit cycle attractors, as well as the observed frequency transition from beta to gamma oscillations, are suggested to represent the intentional process leading to a decision. It indicates the importance of feedback pathways in the intentional preparation of voluntary actions. While current experimental observations can only partially explain the process of voluntary actions, no conclusions can be made about free will. Yet, by using neurocomputational models like ours, it is possible to provide a more comprehensive view on this process, which could lead to further experimental predictions on how to pinpoint brain processes important for conscious (free) will.

But are the decisions we make simply a weighting of intuitive/emotional and rational/cognitive factors, each corresponding to different neural systems and processes? And are our intentions only a matter of some increasing activity in certain brain areas, perhaps resulting in a transition from chaotic to oscillatory attractor states? If so, then our computer models or a robot, where these corresponding systems and processes are implemented, should also be able to make the same (smart) decisions. In that case, there seems to be little influence of a truly free will, which humans presumably could possess. Alternatively, we might assume that even the computer/robot could be considered to have similar free will. From the behavior, from the "outside", we currently cannot determine whether an individual, or a robot, performs an action out of free will, by chance, or by an intricate interplay of deterministic laws and events.

In our grossly simplified models, as well as in reality, it is clear that many internal and external factors constantly influence the (simulated) intentions and decisions. In the brain's intricate neural network, where numerous parts interact through countless feedback loops, it is nearly impossible to identify the primary cause or the initial "independent" signal that triggers the process leading to a decision and, ultimately, to an action. This complexity is further heightened by the external world, where we are embedded in a network of social relationships and other external factors that influence our choices. Similarly, it becomes challenging to determine which event or influence from others will have the greatest effect on our decisions. Nevertheless, there seems to be a strong connection between free will and consciousness, but since it is not clear how to adequately model consciousness computationally, we just assume it could be correlated with certain complex neurodynamics, as done for our models.

In any case, it is obvious that consciousness is central to higher cognitive functions, in that conscious cognition can provide prediction, expectation, willful actions, plans, goals, hopes, etc., beyond immediate perception. This has implications for how a partner is chosen, how to ensure good living conditions for offspring, etc., which certainly would have an evolutionary advantage. Conscious cognitive functions should also enable more complex interactions with other individuals and the surrounding environment. (Thus, a robot or an AI system attempting to emulate human cognition should be more limited in their capacity, as long as they are not conscious).

The complex neurodynamics of the brain's neural networks, with oscillations of various frequencies and intermittent chaotic behavior, appear to be significant for cognitive functions and conscious activity. Such activity has been associated with perception, attention, and associative memory, but also with volitional expressions and activity in sensory and motor areas of the brain. Although many details are still unknown, it is clear that the interplay between the neurodynamics of sensory and motor pathways is essential for complex interactions with our environment. In addition, our cognitive and conscious abilities depend on and evolve through purposeful interaction with the complex and changing environment in which we are embedded. The ability to perceive and act likely evolves and improves both over the course of evolution and during an individual's lifetime.

It is reasonable to regard attention and intention as dual aspects of consciousness, with their neural correlates involved in perception and action, respectively, interacting with the environment through the sensory and motor pathways of the nervous system (Liljenström, 2011, 2022). These processes correspond to "inward" and "outward" activities of consciousness, both equally important for exploring the external and internal worlds.

The idea of consciousness as an emergent phenomenon is quite common, though it is not always described in terms of neurodynamics and the relationship between sensory and motor systems, as we have done here. In a typical reductionist description, emergent phenomena are considered unable to causally influence the underlying components (such as particles or cells) that make up the system. Yet, it is evident that individuals interact with their environment through perception and intentional actions. Intentionality, as an active aspect of consciousness, may thus have causal effects on matter (c.f. Murphy *et al.*, 2009). When intentional actions include e.g. partner selection and the care for offspring, it is conceivable that consciousness not only has material effects on an individual level, but can also be seen as a driving force in evolution.

Although it has been over three decades since consciousness first began to be considered a scientific problem (see e.g. Crick & Koch, 1990), science still cannot say much about what consciousness is or how it relates to the brain and its activity. Understanding consciousness remains one of the greatest challenges in science, with many questions unresolved, such as how it is related to decision-making and free will (Maoz & Sinnott-Armstrong, 2022). The fact that many have come to view consciousness and free will as subjects for scientific study does not necessarily mean that all aspects of consciousness, such as qualia or its causal effects on matter, are considered. Instead, consciousness is often reduced to something essentially measurable that fits within the current scientific framework, where it might be equated with e.g. mere neural activity (Dennett, 1991).

The subjective aspect of consciousness, which Thomas Nagel (1974) proposes to be the most important characteristic of consciousness, rules out the possibility for physics (or any science) to deal with it, since physics traditionally only deals with objects, or objective aspects of the world, not subjects or any subjective aspects (van Gulick, 2018). More generally, the theories and laws of physics have been developed for inanimate, comparatively simple objects and their interactions, and not for complex biological systems.

In particular, agency or intentionality has not been part of physical theory, and cannot necessarily be reduced to the theories of simple systems. If we consider intentionality to be a fundamental aspect of consciousness, and if an advanced form of intentionality leads to free will actions, through which our consciousness can influence matter, it is indeed challenging to fit this into the current scientific description of the world. Indeed, consciousness seems to imply a freedom beyond the determinism of classical physics and the indeterminism of quantum physics (Liljenström, 2022). Yet, if we can accept indeterminacy and "non-causality" in the quantum world, why shouldn't we be able to do so in the bio-psychic world of organisms?

8. Concluding remarks

In the end, can science, with its experiments, theories, and models, help us understand our sense of making decisions and acting out of free will? Can we ever determine whether we could have acted differently, made other choices, if we had wanted to?

As discussed above, there are various interpretations of the experiments conducted on the issue of free will, but the dominant view in science today is that the brain makes decisions and that we, as conscious subjects, have no say in the matter. It is obviously easier in scientific contexts to accept an interpretation that confirms the dominant paradigm rather than one that would contradict it.

In physics, there is a general notion that any "laws" or principles found should be universal, should hold everywhere and eternally in the Universe. Yet, this assumption is not necessarily true, but it is simple and reasonable, in lack of any evidence. In science in general, Occam's razor is being used frequently for any model or theory, typically saying that the simplest explanation is usually the best one. Or in Einstein's words: "A model should be a simple as possible, but not simpler". However, it is not always easy to determine what actually the simplest model is.

Simplicity is also guiding the experiments we conduct, and test our hypotheses with. Hence, the "systems" used by Newton to test his laws of motion consisted of at most two interacting objects. With three or more objects interacting, the system was too difficult to predict with the math-

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ematics at hand. Nowadays, we can use computers to simulate large complex systems with millions of components, but it does not mean that we can predict the outcome of such systems in real situations, where the accuracy in the initial values or the existence of unknown or uncontrollable influences may interfere. This is, for example, the case with biological systems.

Yet, even in biology (or medicine), where there are no "natural laws" formulated, one attempts to make experiments as simple as possible, when trying to understand a phenomenon or find causal relationships. In experiments with human subjects who are asked to move a limb when they feel an urge, while measuring their brain activity, it is essential to try to avoid as much of internal or external "noise" as possible. Hence, the experiments become very (too?) simple and artificial, far from the complexity of "ecological", real world situations. To generalize from such simplified and artificial experiments to problems related to free will and consequential actions is indeed quite doubtful.

The scientific aim to simplify is necessary, and all our models are simplifications of reality, but one should be very careful when interpreting simplified experiments and model results, and not believe that they necessarily reveal the true nature of the world. The same goes, of course, for our own neurocomputational models, which were developed in order to trace causal pathways of neural signals involved in intentional control and decision-making. Our results can only be used to simulate real neurodynamics and make plausible explanations for observations during experiments addressing the free will problem. At best, they can be used to rule out certain hypotheses, and suggest possible solutions.

So, if we return to the initial dilemma: how should I travel to Prague and what should I see and do there outside the conference? Let's assume, when we had considered all the different options, my wife and I decided to go to Prague together, but that also changed the conditions for the various decisions to make. For the distal intention to go to Prague, we decided to take the train, because it is best for the environment and for the travel experience, despite the extra time and cost. We also decided to leave the decisions about what to see and do in Prague, until we got there. Then we could let our decisions depend on our different preferences and proximal intentions which would depend on mood, the weather, and other things that could happen there. It appears to me, that all of these decisions were made out of free will, and we could have decided and acted differently.

As we have seen from this example, our decisions and possibility to exert our conscious, free will depend on both distal and proximal intentions, and also considering the intentions of others. Perhaps this is an important insight into free will: that it often involves other people and different aspects of our world, and depends on many different factors within a web of relationships and considerations. Free will is, at least in part, a social phenomenon. Humans become human through their relationships with others — our consciousness and free will depend on the social context in which we exist, as well as on the constraints imposed by nature. Perhaps we are also most free when we act without thinking of ourselves.

An awareness of what influences my decisions and actions should be desirable, but with greater awareness also comes greater responsibility for my actions. The greater the awareness, the greater the responsibility. I am also responsible for ensuring that my actions reflect my understanding, my insights, and my feelings; or in other words, that my actions become a reflection of who I am.

Currently, no scientific method can be used to determine whether free will exists or not, just as we cannot determine whether the world is deterministic or indeterministic, or if the Universe is intentional or not. A belief in one or another worldview is equally reasonable from a purely scientific standpoint, even though many argue that a deterministic world without free will is easier to argue for.

To me, it is quite clear that the "laws of nature" cannot determine our actions, only restrict them. We cannot of course fly (without a device) or unscramble an egg, even if we wanted to. It is only for specific, rather simple systems we can use such laws to calculate future states of these systems to any detail. For complex, living systems, intentional behaviors defy any such lawful predictions, not because our knowledge or methods are insufficient, but because there is a freedom within the boundaries set by nature. For example, Newton's first law of motion says that an object in motion stays in motion with the same speed and in the same direction unless acted upon by an external force. This holds true for an inanimate object, but not for an organism which can stop or move in various directions or at different speed by its own "internal force", or willpower.

I also cannot see any compelling scientific or other reasons to regard free will as an illusion. On the contrary, the very existential experience of existing and being conscious is a more convincing argument for free will being real. Of course, in practice, the exercise of free will is constrained by a multitude of factors, but this does not prevent us from having, at least in principle, the ability to think and act freely. I believe it is essential for science to extend beyond its current alternative explanations of "chance and necessity" in order to encompass consciousness, intentionality, and free will, along with their causal effects on the world

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