Inducing disbelief in free will alters brain correlates of preconscious motor preparation

Supplementary Materials online

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1. Reading materials

All participants were first given a Dutch translation of the following introductory paragraph:

> Francis Crick is the British physicist and biochemist who collaborated with James D. Watson in the discovery of the molecular structure of DNA, for which they received the Nobel Prize in 1962. He is the author of *What Mad Pursuit, Life Itself,* and *Of Molecules and Men*. Dr. Crick lectures widely all over the world to both professional and lay audiences, and is a Distinguished Research Professor at The Salk Institute in La Jolla, CA.
> Dr. Crick's essay (below) comes from *The Astonishing Hypothesis*.

After this introductory paragraph, participants were given a text according to the condition they were assigned.

No-free will group

> "You," your joys and your sorrows, your memories and your ambitions, your sense of personal identity and free will, are in fact no more than the behavior of a vast assembly of nerve cells and their associated molecules. Who you are is nothing but a pack of neurons.
> Most religions hold that some kind of spirit exists that persists after one's bodily death and, to some degree, embodies the essence of that human being. Religions may not have all the same beliefs, but they do have a broad agreement that people have souls.
> Yet the common belief of today has a totally different view. It is inclined to believe that the idea of a soul, distinct from the body and not subject to our known scientific laws, is a myth. It is quite understandable how this myth arose without today's scientific knowledge of nature of matter and radiation, and of biological evolution. Such myths, of having a soul, seem only too plausible. For example, four thousand years ago almost everyone believed the earth was flat. Only with modern science has it occurred to us that in fact the earth is round.
> From modern science we now know that all living things, from bacteria to ourselves, are closely related at the biochemical level. We now know that many species of plants and animals have evolved over time. We can watch the basic processes of evolution happening today, both in the field and in our test tubes and therefore, there is no need for the religious concept of a soul to explain the behavior of humans and other animals. In addition to scientists, many educated people also share the belief that the soul is a metaphor and that there is no personal life either before conception or after death.
> Most people take free will for granted, since they feel that usually they are free to act as they please. Three assumptions can be made about free will. The first assumption is that part of one's brain is concerned with making plans for future actions, without necessarily carrying them out. The second assumption is that one is not conscious of the "computations" done by this part of the brain but only of the "decisions" it makes – that is, its plans, depending of course on its current inputs from other parts of the brain. The third assumption is that the decision to act on one's plan or another is also subject to the same limitations in that one has immediate recall of what is decided, but not of the computations that went into the decision.
> So, although we appear to have free will, in fact, our choices have already been predetermined for us and we cannot change that. The actual cause of the decision may be clear cut or it may be determined by chaos, that is, a very small perturbation may make a big difference to the

end result. This would give the appearance of the Will being “free” since it would make the outcome essentially unpredictable. Of course, conscious activities may also influence the decision mechanism.

One’s self can attempt to explain why it made a certain choice. Sometimes we may reach the correct conclusion. At other times, we will either not know or, more likely, will confabulate, because there is no conscious knowledge of the ‘reason’ for the choice. This implies that there must be a mechanism for confabulation, meaning that given a certain amount of evidence, which may or may not be misleading, part of the brain will jump to the simplest conclusion.

Control group

Psychologists have shown that common sense ideas about the working of the mind can be misleading. When psychology began as an experimental science, in the latter part of the nineteenth century, there was much interest in consciousness. It was hoped that psychology might become more scientific by refining introspection until it became a reliable technique.

Since the problem of consciousness is such a central one, and since consciousness appears so mysterious, one might have expected that psychologists and neuroscientists would now direct major efforts toward understanding it. This, however, is far from being the case. The majority of modern psychologists omit any mention of the problem, although much of what they study enters into consciousness. Most modern neuroscientists ignore it.

The American psychologist, William James, discussed consciousness in his work ‘The Principles of Psychology’ (1898), and described five properties of what he called “thought”. Every thought, he wrote, tends to be part of personal consciousness. Thought is always changing, is sensibly continuous, and appears to deal with objects independent of itself. In addition, thought focuses on some objects to the exclusion of others. In other words, it involves attention. Of attention he wrote, “It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. It implies withdrawal from some things in order to deal effectively with others.”

Many psychologists believed that some processes are subliminal or subconscious. For example perception was similar in its logical structure to what we normally mean by inference, but that it was largely unconscious. Three basic ideas of consciousness were developed. Firstly, not all the operations of the brain correspond to consciousness. Secondly, consciousness involves some form of memory, probably a very short term one. Thirdly, consciousness is closely associated with attention.

Unfortunately, a movement arose in academic psychology that denied the usefulness of consciousness as a psychological concept. This was partly because experiments involving introspection (which involves thinking about what one is thinking) did not appear to be leading anywhere and partly because it was hoped that psychology could become more scientific by studying behavior that could be observed unambiguously by the experimenter. This was called the Behaviorist movement. It became taboo to talk about mental events. All behavior had to be explained in terms of the stimulus and the response.

How can we approach the study of consciousness in a scientific manner? Consciousness takes many forms, but as I have already explained, for an initial scientific attack it usually pays to concentrate on the form that appears easiest to study. Christof Koch and I chose visual awareness rather than other forms of consciousness, such as pain or self-awareness, because humans are very visual animals and our visual input is especially vivid and rich in information. In addition, its input is often highly structured yet easy to control. For these reasons much experimental work has already been done on it.

2. Action monitoring processes

Besides the influence of disbelief in free will on the RP, we were also interested in the question whether the free will manipulation affects post-action influences on conscious intentions (Lau et al., 2007; Kühn & Brass, 2009; Banks & Isham, 2009; Rigoni et al., 2010). More precisely, it has been shown that people are influenced by false external action feedback when they have to report when they had the intention to act. For instance, false feedbacks signaling a response different or later than the actual one modify individuals' estimates of *when* they wanted to act (Banks & Isham, 2009; Rigoni et al., 2010); this indicates that people rely also on external feedbacks (e.g. tones signaling the response, somatosensory and tactile cues) when estimating internal events such as the intention to execute an action. We wanted to test whether the influence of external feedback becomes amplified in the no-free will group. To answer this question we manipulated the feedbacks following the individual response. Each button press was associated with either a simultaneous or a delayed auditory feedback and then participants were asked to report the time they had the first intention to press the button (Fig. 1 in the manuscript).

A two-way mixed ANOVA was performed with the factors *group* (control, no-free will) and *feedback delay* [0, 20, 40, 60 ms] and the reported W as dependent variable. The averaged reported Ws at delays of 0, 20, 40, and 60 ms were -237, -220, -199, and -225 ms, respectively, relative to time of response. However, the analysis revealed that this effect was not significant [$F(3, 81)=2.13$, $p=.1$]. There was neither an effect of *group* [$p=.64$] nor an interaction effect [$p=.43$]. This result indicate that the free will manipulation did not influence action monitoring processes related to the reported time of conscious intentions.

3. Specificity of the effect for motor preparation

In order to assess whether the effect found in the no-free will group was specific for brain processes related to motor preparation, we investigated whether sensory evoked potentials (i.e. processes that were non-related to motor preparation) were influenced by the same experimental manipulation. According to our hypothesis, the free will manipulation only influenced brain processes related to action preparation. Therefore we should not find a difference between the two groups in brain activities unrelated to volition or to motor preparation, such as sensory evoked potentials. More precisely, we expect not to find increased activity in sensory evoked potentials in the control group as compared to the no-free will group. To address this issue, we time-locked the ERP traces to the auditory tone with a time window from 200 ms prior and 300 ms after the auditory tone. We used the 200 ms pre-stimulus interval as baseline. By using this time window, we were reasonably confident that the activity related to the motor preparation to report the W (i.e. by using the mouse) was not included.

The auditory tone elicited three clearly visible components (see Fig. S1), namely P50, N100 and P200, peaking at around 70, 150 and 250 ms, respectively, after the auditory tone. For each component, an ANOVA was performed using a 2 × 4 design: *group* (control, no-free will), and *site* (Fz, FCz, Cz, CPz). The dependent variable was the peak amplitude of the component (i.e. peak amplitude between 0 and 100 ms, 100 and 200 ms and 200 and 300 ms, for P50, N100 and P200, respectively) relative to the pre-stimulus baseline.

P50

The analysis revealed a main effect of *site* [$F(3,81) = 24.749$, $p < .0001$, $\eta_p^2 = .478$], with P50 being larger over CZ, followed by CPz, FCz, and Fz. Neither the *group* factor ($p > .11$) nor the *group* × *site* interaction ($p > .9$) were significant. Although there is almost a statistical trend for the P50, the direction is opposite from what one would expect if the no free will manipulation would lead to a general attenuation of brain activity.

N100

The analysis showed a main effect of *site* [F(3,81) =24.749, $p < .0001$, $\eta_p^2 = .663$], with N100 being larger over frontal areas (i.e. Fz, followed by FCz, Cz, and CPz). Neither the *group* factor (p>.63) nor the *group* × *site* interaction (p>.61) were significant.

P200

The analysis showed a main effect of *site* [F(3,81) =24.749, $p < .0001$, $\eta_p^2 = .58$], with P200 being larger over Cz, followed by CPz, FCz, and Fz). Neither the *group* factor (p>.6) nor the *group* × *site* interaction (p>.7) were significant.

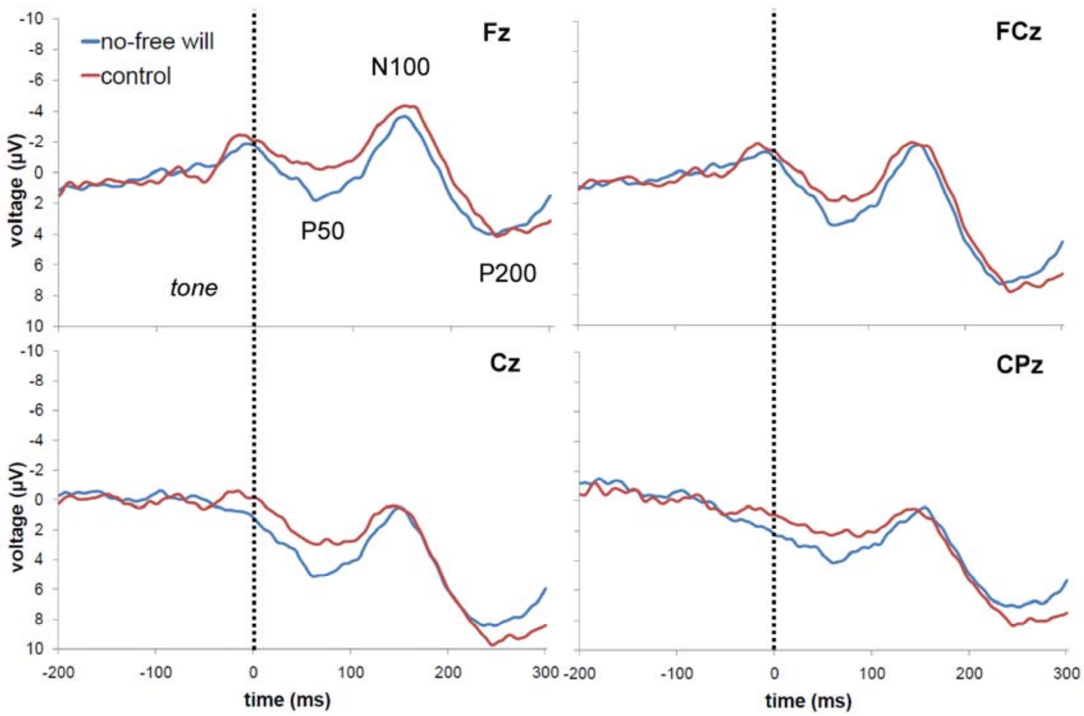

Figure S1 Grand-averaged post-action ERPs. ERPs are time-locked to the auditory stimulus, which was presented after the response. Sensory evoked potentials (i.e. P50, N100, and P200) did not differ between the two groups.

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