

Abstract 1

Title: The neuroscience of volition: history, methods, findings, and open questions

Authors: Tomáš Dominik¹, Alfred Mele², Aaron Schurger^{1*}, Uri Maoz^{1*}

¹ Brain Institute, Chapman University, CA, USA

² Department of Philosophy, Florida State University, FL, USA

* These senior authors contributed equally to the project

Abstract: You are reading a book in your favorite armchair and, at some point, you reach for a cup of tea. You probably do not pause and ponder why you decided to reach for the cup of tea at that particular moment. However, a series of neural events occurred leading to your action, in a fashion that tells us something important about how the brain produces voluntary movements. In 1965, Kornhuber and Deecke asked participants to spontaneously move at irregular intervals. They found that the movement was preceded by a negative deflection in the averaged EEG signal—the readiness potential (RP). In the 1980s, Benjamin Libet and colleagues explored when in the course of movement preparation the participants become aware of their intention to move (*W*). Based on their results, they argued that *W* emerged only long after the RP onset. Many took this to mean that the actions in Libet’s experiment were initiated unconsciously. There are many issues with Libet’s experiment, and today its results are interpreted much more cautiously. Despite that, Libet’s experiment laid the groundwork for a field now known as the neuroscience of volition.

Here we aim to comprehensively summarize the history and empirical findings of the neuroscience of volition. From an initial list of approximately 2300 publications, we selected over 400 papers and books, constituting the core knowledge base of the neuroscience of volition. In doing so, we summarized previous research on delays in conscious experience production that directly inspired Libet’s 1980s study. We provide a comprehensive overview of Libet’s experiment, including its lesser known but important features, such as trials with movements occurring non-spontaneously. We show that Libet’s results were replicated in many follow-up studies. However, we also point to objections to Libet’s experiment, such as caveats in his method of obtaining introspective reports, problematic points in his interpretation of the RP, and conceptual issues, such as Libet’s dualistic assumptions. Additionally, we show that the literature contains many suggestions for overcoming these issues.

Advances in the neuroscience of volition naturally go beyond criticism of Libet’s experiment. New methods for recording volition-related brain activity were proposed:

machine-learning-based EEG and fMRI decoding, frequency-domain EEG methods, intracranial recordings, and many others. Contemporary methodologies study meaningful actions on top of arbitrary ones, explore genuinely spontaneous behavior, or use neuroscientific knowledge to predict which choice the participant makes when presented with various alternatives.

We conclude with some of the contemporary open questions in the field. Are intentions discrete states or are they dynamical processes? Is consciousness itself causal in volitional processes? How early can we truly predict a self-initiated action, and which of its aspects are or are not predictable?

Keywords: neuroscience of volition, Libet's experiment, free will, readiness potential