Project Proposal[1]: dynamics of conscious will

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Abstract

Libet (1983) [2] showed that the onset of the readiness potential (RP) precedes the time of conscious intention (W) reported by the participants when performing a simple task of pressing a button at their time of choice. This result, if not denying the role of consciousness in voluntary action, points to its secondary nature. Blanke et al.[4] suggested that: the regular cycle of breathing is part of the mechanism that leads to conscious decision-making and acts of free will. They found out there is a coupling between the respiratory phase and the readiness potential (RP) amplitude in the Libet task. We aim to investigate the existence of such couplings between the phase of an oscillatory auditory or visual stimulus and the readiness potential onset time and amplitude.

1 Introduction[1]

Actions are guided by a combination of external cues, internal intentions and stored knowledge. From a pure reflex to a highly voluntary decision there's a continuum of intermediate actions. Reflex is immediate and its form is determined by the form of stimulus, i.e. it's a purely stimulus-driven action. On the other hand, voluntary actions are free from immediacy and are possibly only indirectly determined by the form of stimulus.

Libet asked the following questions: Are voluntary acts initiated by a conscious decision to act? More recently, it was suggested that the RP could be an artefact of measurement, potentially putting free will back into our command. But if we take on the view that our conscious decisions arise from a cascade of firing neurons, then the origin of the RP may actually provide insight into the mechanisms that lead to voluntary action and free will.

In the following sections we present the subjective experiences associated with volition, measurement of conscious intention and criticisms thereon, the neural substrates of voluntary action and reflexes, and finally viewing voluntary action as decision making.

1.1 Subjective experiences of volition

There are two subjective experiences necessary for an action to be volitional (edit);

The experience of **intention**: planing to do or beain about to do something.

The experience of **agency**: confirmation that the action made by the individual has caused the external event.

Here we focus on the former since assessing the latter is rather out of reach. e.g. it can be studied via external stimulation of the brain that might cause an action and a false feeling of agency. Although some non-invasive studies have been carried out in the last decade (Haggard 2017, Sense of agency in the human brain).

1.2 Measuring volition

Previous studies have usually recorded and studies voluntary actions in one of the following ways:

1. Fixed action at arbitrary time
2. Optional action from a set of tasks at specified time
3. Optional action from a set of tasks at arbitrary time
4. Do/Don't action at specified time

Furthermore, the participant is instructed to report the moment at which they first felt the urge to act which we denote by W. Libet et al (1983) showed that the onset of the RP (denoted by RPO) precedes W about 350-450 ms which has been interpreted as the lack of conscious causation of a voluntary act.

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criticisms on recording voluntary actions

- A radical view dismisses "voluntariness" as a socially constructed artefact of the experimental situation rather than a genuine cognitive process, Participants reflect their understanding of 'free will'. They monitor their own performance and selectively vary it to make it seem random. These criticisms apply to repeated choice, not the concept of generating information for an occasional individual action.
- No motivation. Instruction to act voluntarily is a bit paradoxical!
- Subjective estimates of when conscious experiences occur are unreliable. Results might vary according to how the participant divides attention between the clock and their own motor preparation[3].

1.3 Brain circuits

Brain circuits (cortical networks) contributing to voluntary action. There is a fundamental distinction in the cortical organization of voluntary and stimulus driven action, in other words reflexes and voluntary actions have distinct neural substrates:

Voluntary actions (Self-paced):

$$\text{Basal ganglia} \rightarrow \text{ preSMA } \rightarrow \text{ SMA } \rightarrow \text{M1(motor)}$$

Stimulus-driven actions (Externally triggered): - Object-oriented actions such as grasping

$$\text{S1 (sensory) } \rightarrow \text{ Parietal } \rightarrow \text{ Premotor } \rightarrow \text{M1}$$

Both circuits converge on the primary motor cortex (M1), which executes motor commands by transmitting them to the spinal cord and muscles.

$$\text{M1} \rightarrow \text{ Spinal Chord } \rightarrow \text{ Muscle}$$

Methodological and theoretical difficulties concerning cortical networks

1. RP is measured relative to a neutral baseline period.
   - in stimulus-locked recording, baseline is taken just before the stimulus delivery.
   - what could be the correct baseline before a voluntary action? when do the neural precursors of action begin?
2. What causes the preparatory activity of the preSMA? (possibly basal ganglia)
   - The brain circuits for voluntary action might consist of loops rather than linear chains that run back to an unspecified and uncaused cause (the 'will').
   - Output from BG to preSMA is reduced in Parkinson patients. They show less frequent and slower actions. Signals from BG (recorded with electrodes) precede the RP.
   - BG drives currently appropriate actions. This drive is modulated according to patterns of reward. From this view, voluntary action is better characterized as a flexible and intelligent interaction with the animal's current and historical context than as an uncaused initiation of action.

1.4 Voluntary action as decision making

A voluntary action is complex process which can be broken into the following steps:

- Early 'whether decisions': Needs and desires have a major role. Reasons for voluntary action:
  - routine processing of stimuli can fail to generate sufficient information to determine a response
  - a new reason for action can suddenly emerge.

  - a general drive to perform occasional voluntary actions allow exploration of the behavioral landscape.

- What task:
  - The participant has to choose from a set of options. e.g. left or right.
- What movement:
  - The participant has to choose a movement to indicate their choice. e.g. if the choice is left then the participant may display their choice with reach or saccade.
- Late 'whether' decision (**veto**): There is evidence that even in the cases where an RP is generated, the decision can be cancelled in the final moments. Some accounts suspect that this is where the consciousness has a direct role.
- When: Several studies have compared brain activity between self-paced conditions, in which the participant themselves decides when to make an action, and externally triggered conditions, in which the participant makes a similar action in response to a stimulus. Activity in both the preSMA and the dorsolateral prefrontal cortex has been identified by this comparison. Studies that focused on voluntary action alone confirmed that the timing of an action can be prdicted from preparatory activity in the preSMA.

Breathing cycle

Blanke et al. investigated the potential role of interoceptive signals in voluntary action and the RP. Evidence show that there is a relation between the phase in respiratory cycle, voluntary action, and the RP amplitude. Results report that (1) participants initiate voluntary actions more frequently during expiration, (2) this respiration-action coupling is absent during externally triggered actions, and (3) the RP amplitude is modulated depending on the respiratory phase.

voluntary action control, the ability to initiate an action based on one's own will, is an essential component of self-consciousness. Most of the previous studies report that a slow negative drift of brain activity, the so-called readiness potential, precedes the onset of voluntary action by ~ 1 second.An important source of continuously changing neural signals —at the cortical, subcortical, and peripheral level-is interoceptive signals, for example respiratory or cardiac signals
Voluntary acts may be defined as acts that are felt by the subject to have been deter-mined by himself or herself and to have been caused by a conscious decision. This definition depends explicitly on the first-person perspective. From the third-person perspective, one can also regard an act by someone else as voluntary, based on its appearance. In this case, one believes the person in question will also have the feeling that he or she determined the act by a conscious decision. Suppose someone is under-going brain surgery, in an awake state. He suddenly raises his arm. Someone who is looking on will probably take this to be a voluntary act, because raising one's arm usually is. But she asks the patient: 'Why did you raise your arm?', and he answers: 'I didn't. My arm moved by itself.' And in fact the movement has been caused by the surgeon's having applied an electrical stimulus on the patient's motor cortex. The patient was not conscious of any decision by himself to perform the movement, so he does not experience it as a voluntary act.

Acts of free will and inner states of the body

The prevailing view in neuroscience is that consciousness is an emergent phenomenon of the brain. Firing of the brain's neurons leads to consciousness and the feeling of free will or voluntary action. By belonging to the physical universe, the brain's electrical activity within the constraints of anatomy, is subject to the laws of physics. In this sense, brain signals encoding the body, lungs and heart might naturally affect the brain's cognitive states too and therefore influence acts of free will.
To test whether the RP depends on the body's inner state and the brain's representation thereof, Blanke and colleagues asked 52 subjects to press a button at will at Campus Biotech in Geneva. EEGs monitored brain activity, a belt around the chest measured breathing activity and cardiac activity was recorded.The results related to the phase in respiratory cycle were tested using permutation test to measure the statistical accuracy of the results.

Tasks and Experiments:

- Task 1: Testing Whether the onset of voluntary movement is associated with spontaneous breathing signals For this we compute the phase of respiration at the onset of button presses, using the Hilbert transform. previous results show that the mean respiration phase at the moment of button press was observed for 19 out of 20 participants during the expiration phase, that is between 0 and π.

  During an externally triggered action task participants were asked to press the response button as soon as they perceived a green dot at the center of the clock face. These results show that the reported coupling between the respiration phase and the movement onset is specifically observed for voluntary actions, but not during externally triggered actions in an otherwise identical experimental setup. Behavioral results show that the spontaneous breathing phase, but not the cardiac phase, is coupled with the onset of voluntary action, as tested in two classical voluntary motor tasks, and this respiration-action coupling is absent during externally triggered actions.

- Task 2: Testing Whether respiration signals could affect the RP, based on the observed behavioral coupling between respiration and voluntary action   For this analysis, the phase of the ECG signal was calculated based on a peak detection algorithm.behavioral results show that the spontaneous breathing phase, but not the cardiac phase, is coupled with the onset of voluntary action.The results show that the RP amplitude was smaller during the expiration periods compared with the inspiration periods

- Task 3: Investigating whether the phase of respiration is related to the modulation of resting state EEG amplitude, to exclude the possibility that the observed coupling might reflect mere artefact influence of respiration on EEG signals   For that Blanke and his team computed the resting state EEG amplitude that was time-locked to the respiration peak.

1.5 Readiness Potential

The Readiness Potential (RP) is a slow negative EEG potential found in the seconds preceding voluntary actions. The cognitive significance of RP is controversial. Some accounts link the RP to the fact that timing of voluntary actions is generated endogenously, without external constraints, and perhaps even randomly. This aspect of the RP is what we intend to look further into. Other accounts take the RP as reflecting the unique role of planning, therefore of temporal expectation, in voluntary actions.
A recent study[5] has asked whether RP is found only at time of voluntary action, or if it also occurs when no action is produced. They found RP-like events in background EEG. Most EEG epochs contained a number of events that were similar to the true RP, but did not lead directly to any voluntary action. However, these RP-like events were equally common in epochs that eventually terminated in voluntary actions as in those where voluntary actions were not permitted. Events matching the temporal profile of the RP were also a poor match for the spatial profile, and vice versa. In conclusion, these events are false positives, and do not reflect the same mechanism as the RP itself.

2 Research Problem

When there is no short-scale temporal motivation for an instructed action of the first type (see 1.2), are the action times truly random? Does the brain manage to generate the necessary information for a motor action completely endogenously. Blanke et al (2020) showed that breathing is coupled with self-paced voluntary action and the cortical readiness potential [4]. We aim to investigate the effects of subliminal and supraliminal cues on the shape and onset time of RP.
Brain function involves oscillations at various frequencies. This could imply that perception and cognition operate periodically, as a succession of cycles mirroring the underlying oscillations[6].

- Can we observe a coupling between RPO and periodic auditory or visual sub/supraliminal stimuli and their frequency?

- Distribution of RPO and action time with respect to phase of the stimulus. Does the distribution's shape depend on the amplitude of the oscillatory stimulus?

- If the existence of underlying brain rhythms entails periodicity in perception, then will we observe a distinctive behaviour around specific frequencies, near which the coupling intensifies?

Wonderings

- If our commitment to decision is being made before we are aware of it, then what mechanism is making the decision?
- Does the brain's processing of internal bodily signals interfere with the ability to act freely?
- In the case that periodic stimuli couples with the onset time of RP, does this coupling and the coupling between respiratory cycle and RP share the same underlying mechanism? If so, then could one suspect that the breathing-RP coupling might not stem from interoceptive signals from a shared source such as the brainstem?

3 Methods

Preparation

First, the participant's just noticeable difference (JND) in intensity and frequency should be determined. During each task, the participant is exposed to an auditory signal with base intensity and frequency denoted by I_0 and ω_0 respectively. The intensity of the signal varies as: $I(t) = I_0 + \Delta I H_\lambda(t)$ where $H_\lambda(t) =$ is a periodic indicator function of a time interval of length $\lambda * T$ where T is the period. This form of function is chosen because we guess abrupt changes might have a more dramatic effect. The amplitude ΔI is chosen below and above the JND in the case of a subliminar and supraliminar stimulus respectively.

Task

The participant is instructed to voluntarily press a key at time of their choice with their right index finger. Whether to confirm the press or not and the means of confirmation is not decided yet.
For each type of stimulus, auditory and visual, the task is divided into three blocks with a duration of five minutes. During each block the participant is exposed to a periodic stimulus with a constant amplitude, base intensity and frequency. The cases of subliminar base intensity, supraliminar base intensity with subliminar amplitude, and supraliminar base intensity with supraliminar amplitude is to be studied in these three blocks.

4 Expected Results and Implications

One of the following results might turn out to be true:

- No coupling is observed: This indicates that the applied stimulus has not affected the self-paced voluntary action.
- RPO is coupled with supraliminar but not with subliminar stimuli. This result may be interpreted as evidence against the epiphenomenal nature of consciousness.
- RPO is coupled with all types of stimuli and the intensity of the coupling changes in a continuous manner with respect to the amplitude of the oscillatory stimuli. This shows that in this task conscious perception of stimuli is irrelevant to generation of self-initiated action. This is in line with the idea of epiphenomenality of consciousness.
- RPO is coupled but a discontinuity is observed in the intensity of the coupling in the transition from subliminar to supraliminar sitmuli. This result shows that consciousness affects the generation of voluntary action, and thus cannot be merely of an epiphenomenal nature.

Another imaginable possibility is that somehow the

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