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Relationship Between Readiness Potential and Reasoning-initiated Movements

Bochen Li
Bard College

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Bochen Li

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Abstract

In 1983, Benjamin Libet conducted a groundbreaking research, in which he found that readiness potential, a slow negativity shift in the brain, might already determine an action before a person consciously intended to. Although the study has attracted vast scholar attention in the past four decades, all the debates, criticisms, and advancements in methodology have been limited in the sense that only impulse-driven studies were examined, while reasoning-initiated movements are completely neglected. This paper argues that the comparison of RP before reasoning and impulse-initiated movements can not only produce a more thorough relationship between action planning, subjective intension, and their underlying neural mechanisms, but also can generate significant philosophical implications about the efficacy of consciousness. Thus, this paper proposes a study that compares impulse-driven movements under Libet-style task and reasoning-initiated movements prompted by a novel response-to-syllogism task. The hypotheses are 1) the mean amplitude of the EEG would be lower in the RP of reasoning-initiated movements; 2) the time of intention would be earlier or simultaneous with the onset of RP of reasoning-initiated movements; 3) Only late components of the stereotypical RP would be observed and the onset of RP will be significantly closer to movement onset in the reasoning-initiated condition.

Introduction

In the Athenian tragedy Oedipus Tyrannus, a prophetic oracle foretells that the protagonist Oedipus will inevitably kill his father and marry his mother. Despite Oedipus's determined efforts to avoid this fate, he ultimately fails to escape the destiny predicted by the oracle decades before these actions transpire. While the notion of a prophecy influencing a person's actions in this narrative may seem purely fictional, recent neuroscientific research over the last century has introduced a comparable concept by examining a specific brain signal at the scalp—known as the readiness potential (RP)—using electroencephalogram (EEG). The RP is a slow negative potential shift predominantly observed in the motor cortex before the initiation of movements. It was first associated with the subjective decision to act in a 1983 study conducted by Libet et al. In this experiment, participants were instructed to perform self-paced finger or wrist flexions, signaling the movement whenever they "felt like it," while observing a rotating clock. They reported the time they first desired to act, and scalp EEG was recorded during the task. The results indicated that RP emerged before the reported awareness of the decision to act, suggesting that the brain may decide or prepare to initiate an action before conscious awareness of such a decision takes place (Libet et al., 1983).

Criticisms and advancements

The intriguing findings of the Libet study imminently attracted vast scholarly attention. Numerous follow-up studies were conducted to address issues and to improve the original paradigm.

Determining a way to measure intention time

The first significant challenge in the original experiment revolved around the operationalization of W—the moment when the subjective intention to move first becomes apparent. In Libet et al.'s (1983) original study, W was determined by asking participants to recall the position on a rotating clock when they initially sensed the urge to move. However, subsequent research demonstrated that this method exhibited low construct validity. Notably, the study by Pockett and Miller (2007) revealed a substantial difference in reported W-times when participants initiated the finger movement compared to when they completed it. Another study by Banks and Isham (2009) demonstrated that W could be influenced by both visual and auditory cues in the environment. When sound and a visual image of the hand were presented with a delay after the actual movement, participants' reported W-times were significantly affected, indicating that W did not accurately reflect the time of the conscious decision but was retrospectively inferred with the assistance of external cues (Banks & Isham, 2009).

The introduction of interruption cues during self-paced movement tasks to ascertain intention time was pioneered by Matsuhashi and Hallet (2008). In this task, participants were instructed to perform self-paced movements similar to the original

Libet study. However, an occasional beep required participants to inhibit the action if they already felt the urge to move, waiting at least 5 seconds before resuming movements. Assuming that canceling "consciously intended" movements would cause a dip in the initially uniform distribution of tones, the study estimated the time of intention (T) to be 1.42 seconds before movement onset, generally later than the early components of RP (Matsuhashi & Hallet, 2008). This innovative task, incorporating interruption cues, successfully circumvented potential inaccuracies arising from subjects self-reporting the time of intention.

However, a significant issue in this design was the possibility that subjects might remain inactive for more than 5 seconds simply because they did not feel any urge to move. The analysis, however, would interpret the lack of movement as a result of movement inhibition. In a subsequent study by Parés-Pujolràs et al. (2019), participants observed a letter stream, and an orange letter was randomly presented. In contrast to Matsuhashi and Hallet's (2008) design, participants were instructed to proceed with their self-paced movements only if they felt prepared to move upon seeing the cue. This modification addressed the issue that not all movements examined in previous studies were preceded by awareness of conscious intention. If participants were not consciously aware of their intention to move before making a movement, the reporting of decision time would necessarily rely on external cues or subjective estimation, rendering it less valid. By instructing participants to move only when consciously aware of the intention upon seeing a cue, this method successfully isolated movements for which participants had conscious access to their preparation. Consequently, the reporting of time of intention before these movements is less likely to be inferred retrospectively.

The letter stream method, initially introduced by Soon et al. (2008), emerged as a valuable improvement. In this approach, participants were presented with a random letter string comprising 8 consonants. After pressing a button, the screen transitioned to a response-mapping page featuring the last three consonants presented and a “#” sign. Participants were required to identify which letter they saw when deciding to move among the three displayed letters, or choose the “#” sign if the decision occurred with an earlier letter or if they were not paying attention (Soon et al., 2008). This method significantly enhanced the construct validity of decision time. Unlike a rotating clock, the letter stream's random and discrete order prevented subjects from retrospectively inferring an earlier letter based on the current one. Consequently, the reported letter more accurately reflected the timing of their subjective decision. This methodology has been adopted and refined by subsequent studies. For instance, the study by Parés-Pujolràs et al. (2019) increased the number of random letters in each block to 20.

The addition of interruption cues during self-paced movement tasks to determine intention time was first used by Matsuhashi and Hallet (2008). In the task, participants were instructed to do self-paced movements like in the original Libet study, but, differently, a beep was played occasionally. Upon hearing the sound, they were instructed to inhibit the action if they already felt the urge to do so, and waited for at least 5 seconds to initiate movements again. Based on the assumption that the cancellation of “consciously intended” movements would cause a dip in the originally uniform distribution of tones, the study estimated the time of intention (T) to be 1.42s before movement onset and generally later than the early components of RP(Matsuhashi & Hallet, 2008). In this novel task with the addition of interruption cues, the potential inaccuracy given rise by subjects self-reporting time of intention was successfully avoided.

Nevertheless, a major problem in this design is that subjects might be inactive for more than 5 seconds simply because they did not feel any urge to move, while the analysis would still consider the lack of movement a result of movement inhibition. In a later study (Parés-Pujolràs et al., 2019), participants watched a letter stream, and an orange letter was randomly presented. By contrast to the design of Matsuhashi and Hallet (2008), participants were told to only proceed with their self-paced movements if they felt prepared to move when seeing the cue. This study addressed the problem that not all movements examined in previous studies were preceded by awareness to conscious intention. If participants are not consciously aware of their intention to move before making a movement, the reporting of decision time necessarily relies on external cues or subjective estimation, and is, correspondingly, less valid. By asking the participants to only move when they were consciously aware of the intention upon seeing a cue, this method successfully isolated movements that participants had conscious access to their preparation. Thus, the reporting of time of intention before these movements are less likely to be inferred retrospectively.

The relationship between RP and actions

The debate surrounding the relationship between readiness potential (RP) and subsequent movement initiation has been a topic of contention, particularly in response to the original Libet study. Libet posited RP as a specific and causal indicator of actions, supported by two main reasons.

Firstly, Libet argued that both early and late effects of RP were maximal at the vertex, with the supplementary motor cortex (SMA) in the mesial neocortex identified as the prominent site of RP's effect (Libet et al., 1982, 1983). He suggested that the SMA's relevance to movement planning substantiated RP's role in action development. However, Soon et al. contested this view, asserting that SMA is primarily involved in the late stages of action planning (Soon et al., 2008). They argued that if RP represents the process of action development, it should be linked to earlier stages of movement preparation in other cortical areas, including those responsible for action planning and execution.

To address these concerns, subsequent studies employed fMRI with higher spatial resolution to measure neural activation during Libet-style tasks. Soon et al. found that the earlier parts of a decision to move could be encoded in the prefrontal and parietal cortex up to 10 seconds before movements (Soon et al., 2008). Furthermore, studies successfully differentiated the sites of early and late RP occurrences, with early RP prominent in SMA and premotor cortex, and late RP distinguished in the primary motor cortex (M1) (Shibasaki & Hallet, 2006; Schurger et al., 2021). These findings align with our understanding of the motor cortex's functions, where SMA is related to mental rehearsal, the premotor cortex is responsible for action preparation, and M1 sends out movement commands and controls muscle contractions (Knierim, 2020). Consequently, RP appears to reflect the process of movement preparation, with its spatial shift consistent with the order of brain-initiated movement sequences.

The second reason for Libet's claim that RP indicates movement initiation was based on its reliable temporal precedent of subsequent spontaneous movements. However, two potential issues were identified. First, if RP appears before one is aware of an intention, it is plausible that RP may also emerge when subjects inhibit a movement after a conscious intention is perceived. Second, the method employed by Libet focused solely on EEG data preceding the action, potentially overlooking RP-like activities at other times (Parés-Pujolràs et al., 2019). This raises the possibility that RP may not be a unique antecedent to action and that similar activities could occur at different times.

In a 2008 study by Trevena and Miller, participants were tasked with deciding whether to press a key upon hearing a cue. The findings initially cast doubt on the role of readiness potential (RP) in inhibiting movements. Specifically, when participants chose to inhibit movements, the electroencephalogram (EEG) patterns recorded did not show significant differences compared to trials where participants decided to press (Trevena & Miller, 2008). However, this conclusion was limited by the method used to calculate RP, as it involved the lateralized readiness potential (LRP). LRP traditionally focuses on right-hand movements, calculated as C3 - C4, reflecting the difference in neural activation between the left and right hemispheres. The study by Trevena and

Miller, in contrast, used a more complex formula (C3l - C4l + C4r - C3r) / 2, which averaged differences for both left and right-hand movements. This method, as pointed out by Filevich et al. (2013), introduced biases as left-hand movement RPs are not normally distributed like those for right-hand movements. Furthermore, the study did not control for participants' handedness, contributing to potential inaccuracies in LRP calculation.

A subsequent study addressing a similar task and examining the contingent negative variance (CNV), a negativity shift anticipating movement inhibition, found significant differences in EEG amplitude at the electrode Cz (located at the center of the scalp). The EEG amplitude was notably more active when a movement was executed than when it was transiently inhibited with a delay rather than immediate. This study also revealed an inverse relationship between EEG amplitude and reaction time (RT), strongly suggesting that the decision to inhibit or act can be predicted by the RP pattern (Filevich et al., 2013). These findings contribute to a more nuanced understanding of RP in movement inhibition scenarios, emphasizing the importance of accurate measurement methods and considering the lateralization bias in RP calculations.

This implication is further backed up by the results of the study done by Parés-Pujolràs et al. (2019). As mentioned, the study specifically studied the actions following the explicit conscious feeling of urge to move. The results showed that these actions are preceded by significantly stronger RPs than the RPs before regular self-paced actions studied using the classic Libet’s paradigm. Combining this discovery with the finding of Filevich et al. (2013), a stronger RP is observed to be correlated with a stronger and more apparent urge to move, while a weaker RP is correlated with the inhibition of movement. Thus, it is almost certain that RP can serve as an indicator of urge-initiated actions.

The second possible challenge to the connection between RP and movement preparation established by Libet was that, as mentioned, RP might also occur when there were neither actions nor overt inhibitions. According to results from various studies, RP-like activity does occur regularly even when movements are absent(Schurger et al., 2012; Schurger, 2018; Travers et al., 2019). Nevertheless, the findings did not disprove the RP's connection to action planning, as computational neuroscientific models provide two alternative interpretations for these RP-like activities. The stochastic decision model (SDM) postulates that there are constant random neural fluctuations in the motor cortex that result in a movement when exceeding a threshold. The model advocates for a late-decision account, the idea that RP reflects the neural process of arriving at a decision to move (Schurger et al., 2021). An alternative possibility, as Travers et al. (2019) pointed out, is that the RP-like negativity shifts observed in the lack of movements are false positives resulting from trial averaging, as supported by the finding that the temporal and spatial resemblance of these activities to RP are unrelated to each other. This possibility supports the early-decision account, which is consistent with Libet's stance, that readiness potential is "a specific, causal precursor to voluntary actions(Travers et al., p.7)".

Gaps

Does RP disprove free will?

Despite the dispute between the time that a decision is made, evidence accumulated by previous RP research seems to yield consensus on two following conclusions: 1) the onset and early parts of RP reliably precedes conscious awareness of intention; 2) both SDM and the classic early-decision account support that RP is relevant to movement preparations (although SDM argue that RP is not a sufficient condition for the initiation of a movement, it would agree that the threshold crossing of RP is the cause of movement execution). Combining the two premises, an inference frequently made is that our brain already starts to prepare for a movement before we subjectively feel an intention to move. This inference is significant mainly because it has been frequently utilized as a counterargument against the existence of free will. However, I would argue the idea that RP has anything to tell about free will is more intuitive than logical. Supported by a philosophical evaluation of definitions surrounding free will, I would argue that research into RP is irrelevant to the free will debate. According to Derk Pereboom, the term free will is used in four different senses in various philosophical debates over the course of history. Among the four types of free will he summarized, we can imminently exclude free will MR (for “moral responsibility” (Pereboom, 2002, p.2)), the concept that free will is “an agent’s ability to exercise the control in acting required to be morally responsible for an action(p.2)”, from being relevant to the research about RP, as RP apparently cannot generate conclusions about morality and the human society. In the meantime, as Pereboom says, there is barely any disagreements regarding the existence of free will RR (for “reasons-responsive (p.2)”), the ability to act rationally and to act in a way that is responsive to reasons , in the first place,as most people would agree that people can act according to reasons (p.3).

The type of free will that is thought to be most relevant to RP research has been free will ND (for “not determined”(p.1)), defined as “an agent’s ability to act without being determined so to act by causes beyond her control(p.1).” The logic of how data about RP refutes this kind of free will is as follows:

1) RP reflect the neural activity that already determines our actions before “we” decide to act

Thus, 2) our actions are determined by neural activities

3) our actions are not determined by “us”

Thus, 4) we do not possess the ability to act without being determined.

Although the logic is valid itself, premise 1 is, in fact, self-contradictory. If we define an agent as one’s biological self, then her brain is also a component of this agent. As a result, the activities of the brain should be considered equivalent to her body movements in this sense. Hence, the fact that neural activity decides one’s bodily actions does not negate her ability to act without being determined, but only outlines how a part of hers’ activity causes another part of hers to vary.

Some might argue that the “we” in premise 1 is not defined using biological criteria, but is our subjective consciousness. However, as evident from ample neurological studies on unconscious patients with brain damage, consciousness has to be an outcome of neural activities. Even if RP does not precede our conscious will to act, our conscious will has to be given rise by other activities in the brain. Therefore, it would be tautological to study RP consciousness to prove that there exists neural activities before our conscious intention to act, considering consciousness is by definition a result of neural activities.

A second type of free will that has been related to RP was the free will AP (for “alternative possibilities”(p.1)). By definition, it is “an agent’s ability, at a given time, either to act or to refrain: that is, if an agent acts with free will, then she instead could have refrained at that time from acting as she did”. As mentioned earlier, the paradigm of choosing between action and inhibition was examined by multiple studies (Trevena & Miller, 2018; Filevich et al., 2013, Schultze-Kraft et al., 2015). Nevertheless, it has to be noted that, assuming that RP indeed outlines the preparation of movements, RP can only produce implication about free will AP under the following two circumstances: 1) if a movement cannot be inhibited once RP occurs, then free will AP is disproved; 2) if a intention to move can be canceled any time after RP onset, then free will AP is proved. However, studies have reliably shown that decision to act can be inhibited after the emergence of RP (Trevena & Miller, 2018; Filevich et al., 2013). Meanwhile, studies also revealed a point-of-no-return, the time after which people can no longer inhibit a movement. The point-of-no-return appears after the RP (at around 200 ms before movement onset) and is not relevant to any specific pattern of RP. Therefore, RP also cannot provide evidence either supporting or disqualifying free will AP.

In summary, apart from free will MR and RR that are not conceived to be related to RP in the first place, both free will ND and AP, which have been frequently considered as the important philosophical implications generated by RP research, are actually unrelated to RP. First, depending on the different definitions, it is either self-contradictory or tautological to apply RP as an evidence against free will ND. Second, previous research on movement inhibition tasks has shown that RP does not provide any meaningful information about free will AP either. Thus, the philosophical significance of previous RP research has largely deteriorated.

Is the relationship between RP/intention/action reliable?

Besides problems associated with RP's philosophical inference, the relationship that previous studies have claimed to reveal between the timing of conscious intention, actions, and RP is also flawed.

Problems with intention

The instruction that is consistently utilized among most RP studies asks participants to move when they feel the urge to, and then the time when they perceive the urge is recorded as the time of intention. However, I would argue that this paradigm has an extremely poor construct validity, as it barely reflects the time that most components of an intention are formed. First, regarding timing, the decision to move has already been made, at least to a great extent, when participants decide to obey the instructions told by the experimenters. Meanwhile, the specific content of the movement is also defined by the instructions significantly earlier than the so-called time of intention, for example, a quick flexion of the right index finger. If we examine the formation of intention in these tasks according to the three-hierarchy-model of intention, most components in the abstract plans(completing the study), general action plans(moving fingers), and detailed motor commands(moving the right index finger abruptly after hearing a trial starting cue)(Parés-Pujolràs & Haggard, 2022) have already settled at the very beginning of the experiment. The only component that participants had to decide in the progress of the experiment is the timing of when to perform these actions. Nevertheless, the study paradigms further prohibits participants from consciously deciding a time to move, making it even questionable if “the feeling of the urge to move” can be related to an intention at all. If we consider the example of yawning, it is the same as the Libet-style movements because it is followed by an urge to yawn and people do not predetermine a time to yawn, but can we state that a person intends to yawn? I would strongly disagree because, according to our empirical knowledge, an intention is a conscious deliberation of determining a specific action in the future. Therefore, to establish a valid relationship between RP and conscious intention, an experiment should investigate intentions that are explicit and active conscious phenomena (e.g. an internal dialogue “I need to move my right index finger now because…” instead of the abstract feeling of an urge). Ideally, the participants also would not know whether they should move until the intention occurs.

Problems with action type

Previous studies claim that RP is the distinct pattern before voluntary actions, “those caused by internal processes within the agent themselves and not an external stimulus (Travers et al., p. 1)”, However, does the Libet-style task really measure actions that are generated by internal processes? As mentioned, the specific content of actions that participants conduct are determined by the instructions from the experimenter. Meanwhile, the general time frame of these actions are also determined by the starting cue and finishing cue of each trial. As a result, it is biased to consider the movements studied in Libet-style tasks to be free from external determinants. In fact, it is highly unlikely to find any action that is completely separated from external influence, especially under lab settings, where participants are asked to perform certain actions in a specific time frame. Therefore, it is doubtful whether the definition of voluntary movement is a meaningful one, since it can barely be applied to describe any movement in real life at all.

A more reliable description of these movements, in my point of view, is “spontaneous movements” that are “capricious in origin”(Libet., 1983). In other words, these movements are impulse-driven. In this case, the movements examined by Libet’s paradigm have a limited ecological validity, as a lot of our daily movements are not driven by impulses, but are initiated by reasoning and rational thinking. For example, while the feeling of anxiety and pressure might prompt a student to start writing an essay, the reasoning about the consequences of missing the deadlines and the causal relationship between starting to write now and the ability to submit the paper on time might also be a likely cause for her to start working. Therefore, the existing account of

RP study could be benefited from a study that examines the relationship between RP and reasoning-initiated movements. By comparing the patterns of RP before reasoning-initiated movements and those before spontaneous movements, we could obtain a better understanding about the relationship between RP and action preparation in real life.

Current study

To contribute to a more thorough understanding about the relationship between conscious intention, movement initiation, and their underlying neural activities, while addressing the issues incorporating the low construct validity of intention measurement and the overlooking of reasoning-initiated movements in previous studies, I propose the current study to investigate the relationship between RP and actions initiated by deductive reasoning.

Deductive reasoning was specifically selected for this study because its premises guarantee its conclusions by definition. Therefore, unlike other forms of reasoning, it is possible to justify an intention on its own. Using an example of deductive reasoning, if I know the premise that an apple has vitamin C/ all things with Vitamin C are good for health, then I know for sure that apples are good for health. As a result, if I want to become healthier, this piece of deductive reasoning can be the sole cause for me to eat an apple. By contrast, if I use inductive reasoning, the empirical knowledge that I have eaten apples for various times and the observation that I become healthier, cannot guarantee the conclusion that apples make people healthier. Therefore, other mental influencers are needed in order for me to make the decision to eat an apple to become healthier. That is said, the causal relationship between other forms of reasoning and movements are not controllable under laboratory settings, so deductive reasoning was selected to represent reasoning before actions.

In the proposed experiment with a within-subject design, participants will be instructed to complete two tasks in counterbalanced orders. While task 1 will ask participants to conduct impulse-driven movements by instructing them to conduct button presses whenever they feel the urge to. As earlier sections have illustrated, the letter stream method and the addition of interruption cues significantly eliminate the negative effects of self-reporting decision time. The paradigm designed by Parés-Pujolràs et al. (2019) includes both letter stream method and the interruption cue, and more helpfully, isolates movements preceded by stronger feeling of urge to move. Therefore, task 1 in this proposal will be a replication of the task conducted by Parés-Pujolràs et al. (2019).

Task 2 will be adding a manipulation to task 1, asking the participants to conduct button presses responding to prompts of syllogisms, the type of deductive reasoning that consists of two premises and a conclusion. In the task, participants will first hear the two premises played auditorily (not presented visually to reduce large eye movements, which would lead to greater noise in the EEG data), followed by a movement instruction combined with a conclusion generated based on the two premises. For example, the two premises “Tom is a cat” and “all cats have four legs” followed by the movement instruction “press the button if Tom has four legs”. Upon hearing the movement cue, participants will evaluate whether the conclusion is guaranteed by the two premises, or in other words, if the conclusion is necessarily true when the two premises are true. After performing the reasoning in their mind, it is assumed that they will generate a consciously accessible intention to move or to inhibit movement based on the validity of the syllogism, and they will be asked to conduct button-press immediately when they finish evaluating the movement message. In this case, the intention to move should only be accessible right before a movement is conducted. This measurement, thus, increases the construct validity of time of intention, as the intention to move is no longer available at earlier stages of the study.

The independent variable in our study would be the type of movement (impulse-initiated or reasoning-initiated), while the dependent variable would be the difference in the RPs preceding the two types of movements. The hypothesized relationship between the two RP patterns is outlined by the study's potential implications in the efficacy of conscious thoughts. The efficacy of consciousness is the philosophical concept that characterizes our conscious events' ability to induce causal effect on the physical events in the brain. In our comparison, reasoning is an important conscious event represented by thoughts and internal dialogues, while the impulse-driven action, using a Libet-style paradigm, is prompted by instructions that disallow any conscious thinking about the movement or timing. Due to lack of empirical evidence in this area, the study hypothesizes that conscious thoughts are efficacious based on the subjective experience that the conscious phenomenon of reasoning can lead to the initiation of subsequent decisions and movements. Subsequently, we propose three hypotheses about the difference in RP pattern that precedes the two types of movements. 1) the mean amplitude of the EEG would be lower in the RP of reasoning-initiated movements. If RP is causally related to movements as various previous literature suggested, then it would describe the neural input from the motor cortex that is needed to stimulate a movement. Therefore, if reasoning is efficacious, we would observe a reduction from the original input. If described using evidence from our subjective experience, this effect should be responsible for the feeling that when we use reasoning to determine an action, the feeling of impulse or desire to act is lessened. 2) the time of intention would be earlier or simultaneous with the onset of RP of reasoning-initiated movements (while still be after the onset of RP of impulse-initiated movements as previous research suggests). If the reasoning indeed gives rise to the intention to move, then there is no way that the movement would already be in preparation before the reasoning has generated an outcome. 3) Only late components of the stereotypical RP would be observed and the onset of RP will be significantly closer to movement onset in the reasoning-initiated condition. While the activity about movement execution in M1 is hypothesized to stay the same, earlier activities in SMA and premotor cortex are hypothesized to be substituted by activities in the deductive reasoning network, which are shown to be clearly separated from motor cortex (Prado et al., 2011).

Due to the novelty of the task, a pilot study with a small sample size is conducted with the emphasis on the following questions: first, would participants manage the deductive reasoning deductive reasoning task? Second, Would participants report the existence of conscious thoughts before reasoning-initiated activity and the lack of conscious thoughts before impulse-initiated activity as I hypothesize? EEG data and preliminary analyses were made to show examples of what the analyses would look like in the proposed study.

Pilot study

Introduction

The design of the pilot study slightly deviated from the proposed design due to the lack of equipment to synchronize EEG data recording and stimuli presentation. First, the letter stream is substituted by a built-in timer of the software, Labscribe, that EEG data was recorded into, and subjects were to report their intention time as the time they see on the timer. Although the timer can be read to milliseconds, it is impossible for people to visually perceive and memorize the millisecond units while the timer is in motion. Therefore, the time of intention is only reported to seconds. As eeg events are described in milliseconds, the time of intention measurement is considered imprecise and was not analyzed. Meanwhile, the interruption cue was also compromised also due to the technical inability to synchronize data and stimuli.

Methods

Participants

3 participants were recruited from Bard College and the surrounding community. All participants were between 18-35 years old, right handed, fluent in English, have unimpaired vision (or vision correctable by glasses and contacts) and hearing, and report no attention deficit, learning disability, or any neurological disorders. One

participant reported not understanding the task in the middle of the experiment, and the participant's data was excluded.

Stimuli

80 syllogism prompts were first extracted from the dataset Avicenna, a dataset of syllogisms that consists of natural languages, then manually changed by adding "press the button if" in front of the conclusions. The validity of the syllogisms were balanced (40 trials, 40 trials). Syllogisms were manipulated that participants can only tell the validity of it at the end of the presentation of stimuli. For instance, an original prompt was:

Arsenal finished the Premier League season with zero loss.
Being unbeaten in the Premier League grants a winner with golden trophy instead of silver.
Press the button if Arsenal wins a golden trophy instead of silver.

As participants might determine that the prompt is valid when they hear the word "trophy" in the concluding sentence, the last three words "instead of silver" were removed. In this case, participants will not know the answer or press the button before a stimulus is fully presented.

To eliminate the possibility that participants use real life knowledge instead of logic to examine the conclusions, all the conclusions of invalid trials were manipulated to be true (in real life). Therefore, a manipulation check can be later by specifically calculating the accuracy rate of invalid trials.

EEG recording

EEG activities were recorded at the C3 and C4 electrodes in the international 10/20 system, with a ground electrode at the left ear lobe. Linked mastoids were used as the reference.

Procedures

Spontaneous movement task

Participants sat stable with their eyes about 50 centimeters away from a laptop screen, and were asked to fixate at and pay attention to a timer on the screen. At the start of each trial, they heard a hightone, which was the cue for blinking inhibition, they were asked to refrain from any blinking and eye movements until hearing a low tone, the cue for a blinking break, after 10 seconds. Then they heard a movement instruction cue “press the button when you feel the urge to do so”. They were instructed to conduct self-paced presses on the event marker spontaneously between the hightone and the low tone. They were asked not to pre-decide on a time to respond to. To prevent movements caused by the difficulty to refrain from blinking, subjects were told if they felt that they could not inhibit blinkings anymore, simply blink and tell the experimenter. Meanwhile, the experimenter also sits at the right side of the participant to observe unreported blinkings and overt bodily movements. If blinkings or large movements were observed during a trial, then the trial is rejected from EEG analysis.

10 seconds after the start of a trial, a low tone was played that indicated that a blink break had started. During the blinking break, participants were allowed to close their eyes or blink as many times as they liked to rest their eyes. During the blinking break, a cue for reporting the time of intention was played, “When did you first decide to press?”. Participants were instructed to verbally report the time they remembered seeing on the timer when they first felt the urge to move using the format “x minute x second”.

The first 5 trials were used as practice trials, during which participants could stop any time and ask the experimenter questions. After the 4 practice trials, 35 real trials were conducted for each participant.

Deductive reasoning task

Participants sat stable with their eyes about 50 centimeters away from a laptop screen, and were asked to fixate at and pay attention to a timer on the screen. Due to the relative difficulty of the task, the participants were first introduced to the different concepts of true conclusions and valid conclusions before the start of this task. The instructions specifically emphasized that participants should only press the button when a conclusion is guaranteed by its conclusions, even though it might be contradictory to empirical knowledge in real life.

At the start of each trial, they first heard two premises of a syllogism with an 1-second-interval between the two. They were asked to pay attention to the two premises, but blinkings or eye movements were allowed during the phase. After the two premises were presented, they heard a hightone, which was the cue for blinking inhibition, and they were asked to refrain from any blinking and eye movements until hearing a low tone, the cue for a blinking break, after 10 seconds. Then they heard a movement instruction cue “press the button if ‘a conclusion generated from the two premises’”. They were instructed to press the event marker between the presentation of the high tone and the low tone if they considered the conclusion to be guaranteed by the two premises. If not, they were told to not conduct any movements during the trial. To prevent movements caused by the difficulty to refrain from blinking, subjects were told if they felt that they could not inhibit blinkings anymore, simply blink and tell the experimenter. Meanwhile, the experimenter also sits at the right side of the participant to observe unreported blinkings and overt bodily movements. If blinkings or large movements were observed during a trial, then the trial is rejected from EEG analysis.

10 seconds after the high tone, a low tone was played that indicated that a blink break had started. During the blinking break, participants were allowed to close their eyes or blink as many times as they liked to rest their eyes. During the blinking break, a cue for reporting the time of intention was played, “When did you first decide to press?”. Participants were instructed to verbally report the time they remembered seeing on the timer when they first decided that using the format “x minute x second”.

The first 4 trials (2 valid and 2 invalid) were used as practice trials, during which participants could stop any time and ask the experimenter questions. After the 4 practice trials, 76 real trials (38 valid and 38 invalid) were conducted for each participant. Due to the long duration of the task, participants were given a 3-minute-break at the midpoint of the task (after 38 real trials).

Behavioral results

Accuracy of deductive reasoning trials

The accuracy of response to valid conclusions is calculated for the two data retained. Subject 1 had an accuracy of 93.4% while subject 2 had an accuracy of 79.0%.

The accuracy was also calculated respectively for the first 38 trials and the last 38 trials as divided by the break. Subject 1 had an accuracy of 97.4% during the 1st half and an accuracy of 89.5% during the 2nd half; subject 2 had an accuracy 81.6% during the 1st half and an accuracy of 76.3% during the second half. The decrease in performance in the 2nd half possibly suggested a fatigue effect.

As all the conclusions in the invalid trials were manipulated to be true, the accuracy for invalid trials was specifically calculated. Subject 1 had a 92.1% successful rate in differentiating between true and valid conclusions; subject 2 had 76.3% accuracy rate in differentiating between true and valid conclusions. The accuracies are high and almost equivalent to the general accuracies, which likely suggests that both participants were evaluating the conclusions based on logic.

Time of intention

As the time of intention was only accurate to seconds while normal EEG events are accurate to milliseconds, the mean time of intention was not calculated for this task due to the significantly large measurement error. However, the mean time of intention will be calculated in the proposed study and compared with the onset of RP.

Qualitative results

After the studies are finished, subjects 1 and 2 were both interviewed regarding different aspects of the deductive reasoning task to generate potential areas of improvements. Interviews, instead of questionnaires, were used in the hope that subjects would raise points that were not initially thought of by the experimenter when designing the task, and would elaborate on the details that might help improve the experimental design.

While being asked about the difficulty of the task and general experience conducting it, both subjects reported fatigueness of the eye and the decrease of cognitive ability mostly during the second half of the experiment. This can provide support for the fatigue effect observed in their accuracy of response. Regarding the feeling of fatigueness, subject 1 thought that the break in the middle of the task interrupted his concentration and that he experienced a decreased attention immediately after the break. Meanwhile, subject 2 said that while the syllogism tasks are not difficult in themselves, he felt sleepy after repeatedly hearing the computer-generated voice.

While being asked whether there existed conscious thoughts before conducting movements, both participants reported that conscious thoughts and internal dialogues were abundant before reasoning-initiated movements, and were absent before impulse-initiated movements.

While being asked about the difficulty to determine the time of intention, both participants confirmed that intention time was easier to be determined before reasoning-initiated actions. According to subject 1, the preparatory process of movements in the spontaneous action task was more “random”, and therefore, sometimes it is hard to determine a specific time that an intention emerges, especially when compared with the preparation of reasoning-initiated actions.

EEG data processing

All EEG data were processed using EEGLAB(Delorme and Makeig, 2004 and ERPLAB (Lopez-Calderon & Luck , 2014).

The preprocessing method of EEG data is consistent as used in the study conducted by Parés-Pujolràs et al. (2019), as the proposed study will include a replication of the task in that study. First, data was re-referenced to the average of the two mastoids and then applied with a 30 Hz low-pass filter. They are then time-locked to either impulse-initiated or reasoning-initiated movements, and epochs were created in the interval of - 2.5 s to 1 s. A baseline correction was performed at -2.5 s to -2 s (Parés-Pujolràs et al, 2019).

Different to Parés-Pujolràs et al.'s study of calculating RP by averaging activities at FCz, Cz, and C3, however, LRP instead of RP was measured and was calculated using the classical method of subtracting activities at C4 from those at C3 in this study. The rationale for using LRP in this study was that as there was only one small EEG cap that was available to the study, I could not adjust the size of EEG cap according to the size of participants' head size, so that electrodes might not be accurately positioned at the true positions. In this case, a difference between the general activities in the left-hemisphere and right-hemisphere is thought to be more clear and valid.

EEG Results

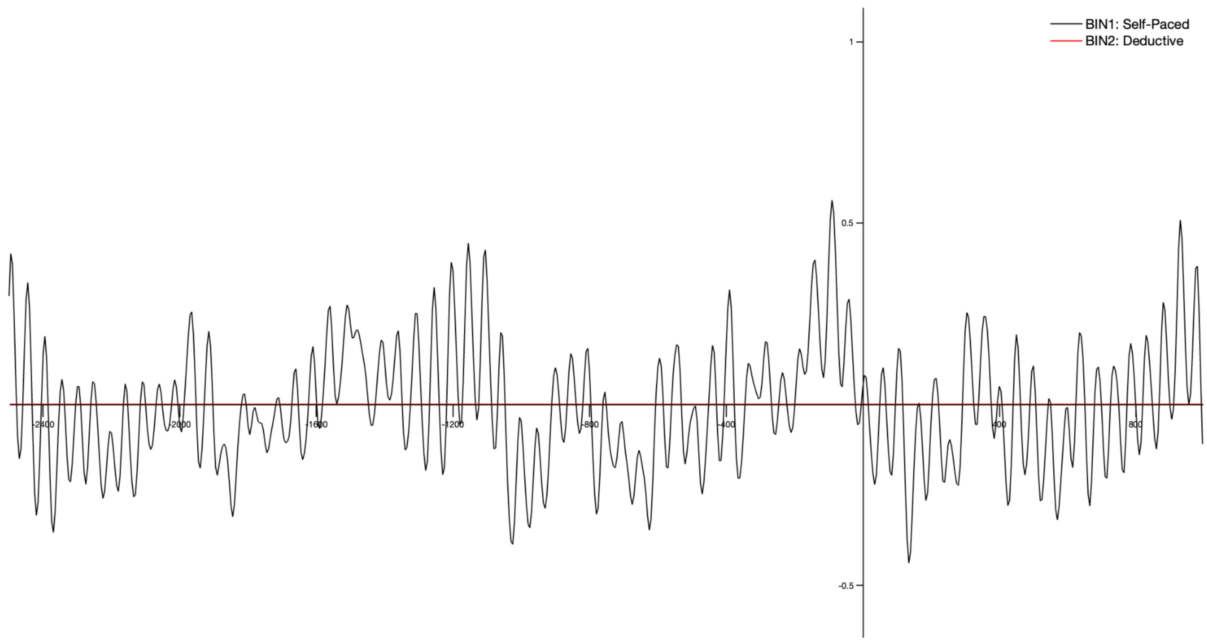

Figure 1. LRP in self-paced trials

As figure 1 shows, the LRP waveform of readiness potential shows an RP-like pattern that generally matches the stereotypical timeframe of RP, as observed from the increase in amplitude starting from -400 ms before movement onset and the only peak in amplitude that exceeds 0.5 μV. Nevertheless, according to the criterion method, the onset of an RP can only be identified when it exceeds some arbitrary values (e.g. 30 % of the maximus amplitude or 0.6 μV)(Mordkoff & Gianaros, 2010). Nevertheless, due to the large noise, an onset of RP cannot be reliably determined by either criterion. However, based on numerous previous research on spontaneous movement, it is highly likely that the pattern reflects an RP to a certain extent but is overshadowed by the noise.

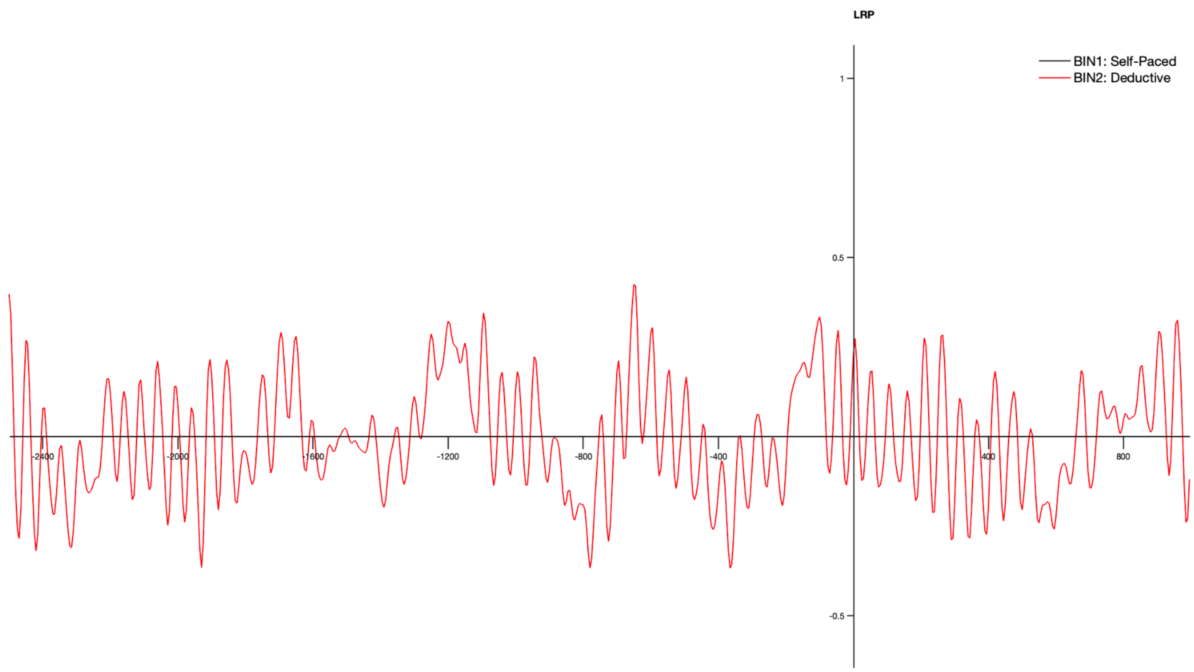

Figure 2., LRP in deductive reasoning trials

As figure 2 shows, no RP-like pattern was found in the LRP waveform of reasoning-initiated movements. Unlike observed in self-paced movement LRP, the increase in amplitude before movement onset is smaller than the noises.

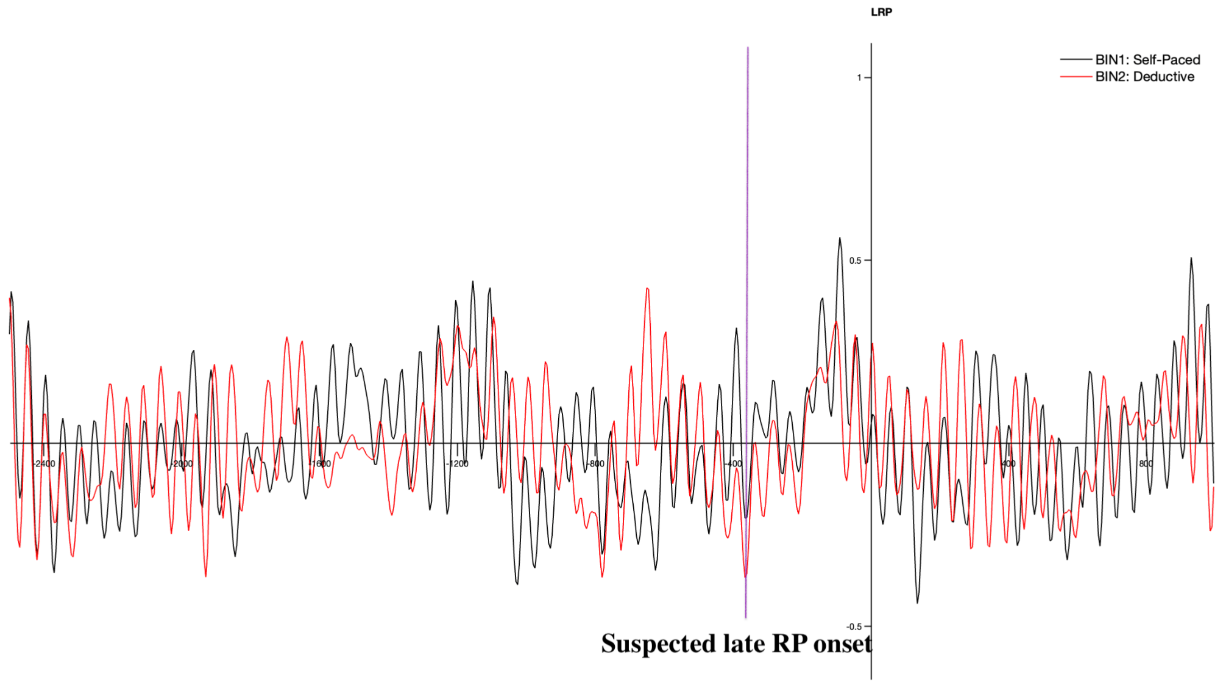

Figure 3., LRP waveforms in both reasoning and spontaneous condition with a suspected point of late RP onset

Figure 3 directly compares the LRP waveforms of reasoning-initiated and impulse-initiated movements. Although the two patterns are messy and entirely unrelated at earlier sections, after 400 ms before movement onset, as the line in the graph signifies, the two forms starts two very similar patterns while LRP of reasoning-initiated movements reliably lower in amplitude than the LRP of impulse-initiated movements. According to Schurger et al. (2021), 400 ms is exactly the point that divides the early components of RP from late RP. As late RP is directly related to movement execution in M1 and has the strongest effect, and that the two conditions study the exact same movement, button-pressing using the right thumb, it is possible that the patterns after 400 ms before movement onset actually reflect late RPs. If that is the case, then two hypotheses that I proposed might be supported by the data pattern observed. First, reasoning-initiated movements RP would have a lower amplitude than impulse-initiated movements RP; second, the late components of RP would both be observed in spontaneous and reasoning-initiated movements. However, these inferences are only educated guesses now and cannot be considered valid until the effect is replicated and amplified by larger studies with more precise equipment.

Inferential results

Due to the extremely small sample size in the pilot study, no inferential statistics were calculated. Nevertheless, inferential tests will be used in the proposed study.

Discussion

The pilot study is evidently limited by the technological limitations. The equipment used for EEG data acquisition was iWorx-TA-220 toolbox, an equipment that is designed for educational purposes and is significantly less precise than equipment generally used in EEG research. The study was also not conducted in a faraday cage, which made the EEG data prone to the electromagnetic effects in the environment. Meanwhile, due to the exploratory nature of the study and the relative difficulty of tasks involved, an extremely small sample size was sought. As a result, there was a substantial amount of noise in the EEG data.

Besides, another limitation is that the timing of intention to act was not studied due to lack of ways to synchronize data and stimuli presentation. As no previous research had studied the intention time of reasoning-initiated action, it has to be calculated

The main goals for this pilot study was to verify the effectiveness of manipulation proposed by the novel deductive reasoning task, and to seek for participants' feedback that can help improve the task, and both goals were achieved.

By analyzing the accuracy of response to syllogism prompts, especially the response to invalid trials, it was supported that the participants were using reason rather than empirical knowledge to complete the task. Moreover, both subjects reported to experience conscious thinking while evaluating the conclusions of syllogisms, which supported the effectiveness of the manipulation.

An area that can apparently be improved is the length of the experiment, especially the deductive reasoning task. As participants reported fatigueness prominently in the second half of the experiment and a fatigue effect is seen to affect participants' performance, a future study will reduce the number of trials in both conditions.

Surprisingly, despite the large noise, a brief pattern that was found by comparing reasoning-initiated movement RP and impulse-driven movement RP might yield implications that support two hypotheses I proposed. Namely, the two RPs simultaneously initiated a mutually-related increasing trend at about 400 ms before movement onset, the point that is confirmed by previous research to be the pivotal point of early and late stages of RP, while the RP of reasoning-initiated movement was reliably lower in amplitude. This pattern might support my hypotheses that RP of reasoning-initiated movements are lower in amplitude than that of spontaneous movements because of the added involvement of deductive reasoning networks into the decision making process. Meanwhile, the hypothesis that the late stages of RP, which characterizes movement execution, would both be seen in the two types of RP is also supported. Nevertheless, for these inferences to be made, the effects have to be replicated and amplified in future research with significantly more trials and less noise.

Proposed study

Introduction

The proposed study aims to amend the limitations appeared in the pilot study.

A first limitation was the overlooking of intention time due to the inability to synchronize data presentation and stimuli presentation. However, time of intention is crucial because 1) no previous study had estimated the time of a intention occurred in a reasoning process precedes movement onset, 2) nor had they investigated if there is any significant difference regarding the time that one is aware of these explicit conscious intentions with the the time that people are aware of irrational urge. More importantly, 3) the intention time is essential to test the main hypothesis that the onset of reasoning-initiated action RP occurs simultaneously with intention. Envisioning that the technical deficiency is solved when the proposed study is conducted, the letter stream task and interruption cue as used by Parés-Pujolràs et al. (2019) will be used to determine the time of intention. As explained in the introduction section, these two methods significantly advance the accuracy of intention time because they effectively prevent participants from using external cues to report decision time.

Second, the pilot study was limited by the large noise partly due to a small sample size. To determine a sufficient number of participants, a power analysis is conducted. Previously, some studies have compared the ERP amplitude precedes spontaneous movements and precedes movements after certain cues or stimuli, and my study design has a similar goal. The Schurger et al. 2012 study found a large effect size of .9, while the Parés-Pujolràs et al. 2019 study also used the .9 effect size in a priori power analysis and yielded significant results. Therefore, .9 is set to be the minimally-interesting effect size in the proposed study. With the goal to obtain .9 power, an effect size of .9 at the standard .05 alpha error probability, the calculated sample size is 16.

Explicit criteria for data exclusion is also added. In the plot study, a third participant's data was excluded because of a very rare event that participants telling the experimenter that he does not understand the instruction in the middle of a task. If he had remained silence, a lack of data exclusion rationale would lead to the inclusion of invalid data and harms the internal validity. As the study requires the participants to correctly perform reasoning and constantly paying attention to letters on the screen, participants who are lower outlier in accuracy in deductive reasoning task, as calculated by subtracting the 1st quartile with 1.5 interquartile range, or higher outlier in blinking trials, as calculated by adding 1.5 interquartile range to the 3rd quartile, will be excluded from further data analyses.

To further increase internal validity, the order of the two tasks is counterbalanced. Meanwhile, block randomization is used where each participant will be randomly assigned to one of the eight blocks consisting of two condition orders that are randomly determined. The study will also use simple randomization to randomize the order of the stimuli (syllogism prompts) for each participant.

A third limitation in the pilot study was the fatigueness evident both in subject's performance in the deductive reasoning task and in their qualitative feedback. Therefore, the trial number is decreased from (35 (self-paced) + 76(deductive)) to 30 + 60).

As the data of the pilot study showed that the participants were using reason rather than empirical knowledge to complete the deductive-reasoning task, and that participants reported to experience conscious thinking while evaluating the conclusions of syllogisms, the assumption that the response–to-syllogism task prompts reasoning-initiated movements is supported. Therefore, the same task was used in the proposed study except the substitution of timer for letter stream and the addition of interruption cue.

As the data obtained from the pilot study generate any findings that could challenge the three hypotheses previously made, the proposed study also have the same hypotheses: 1) the mean amplitude of the EEG would be lower in the RP of reasoning-initiated movements. 2) the time of intention would be earlier or simultaneous with the onset of RP of reasoning-initiated movements 3) Only late components of the stereotypical RP would be observed and the onset of RP will be significantly closer to movement onset in the reasoning-initiated condition.

Methods

Participants

20 participants will be recruited. All participants were between 18-35 years old, right handed, fluent in English, have unimpaired vision (or vision correctable by glasses and contacts) and hearing, and report no attention deficit, learning disability, or any neurological disorders.

Stimuli

10 participants will be invited to rate the difficulty of 64 syllogism prompts generated from syllogisms contained in the dataset Avicenna. The difficulty, then, is controlled between the valid and invalid trials. While the number of valid and invalid trials remains balanced (32 - 32), the number of true and false conclusions are also balanced across valid and invalid trials. As a result, manipulation can be checked directly by calculating the general accuracy of response.

EEG recording

EEG activities were recorded at the Fcz, Cz, and C3 electrodes in the international 10/20 system because they can individually reveal spatial activity in corresponding brain sites(Fcz to SMA, Cz to M1, C3 to premotor cortex), with a ground electrode at the left ear lobe. Linked mastoids were used as the reference.

Procedures

Spontaneous movement task

Participants sat stable with their eyes about 50 centimeters away from a laptop screen, and were asked to fixate at and pay attention to a timer on the screen. Some low-case consonant letter streams will appear on the screen in a pseudorandom order. Letters are either black or orange. Black letters were presented for 216 ms, and orange letters for 266 ms. Each stream contained multiple orange letters, which appeared at random intervals of 3 s–20s after stream onset or after the preceding orange letter. Participants will be asked to fixate at and pay attention to the letters and make self-paced presses on the spacebar whenever they feel the urge to do so. They will be asked not to pre-decide on a letter to respond to, and after each press, the letter stream will terminate and a prompt appears on the screen and ask: "which letter was on the screen when you first decided to press?" By pressing the corresponding key on the keyboard, participants answer the question and the letter stream proceeds. When an orange letter is displayed on the screen, the participants will be instructed to only press the key if they already feel an urge to move when the letter appears, and actions occurring within 2 seconds after the presentation of an orange letter will be labeled as movements with awareness to intention. Participants will be allowed blinking breaks when the letter stream terminates by prompts and for 10 seconds after 5 blocks of letter streams ends. They will be given blink breaks when the prompt terminates the letterstream to close their eyes or blink as many times as they want, and will be instructed to reduce eyeball movements and blinkings to their best during the rest of the experiment.

Deductive reasoning task

Participants sat stable with their eyes about 50 centimeters away from a laptop screen, and were asked to fixate at and pay attention to a timer on the screen. Some low-case consonant letter streams will appear on the screen in a pseudorandom order. Letters are either black or orange. Black letters were presented for 216 ms, and orange letters for 266 ms. Each stream contained multiple orange letters, which appeared at random intervals of 3 s–20s after stream onset or after the preceding orange letter. As the letter strings play on the screen, syllogisms that consist of two premises and one conclusion will be played using computer speakers. After hearing the two premises, participants will then hear the instruction of movement combined with a conclusion generated by the two premises, which also lasts for 1 block of letter string. They are instructed to evaluate the conclusion based on the premises and then press/ not press the spacebar immediately after they have finished evaluating the conclusion according to the instruction given. For each letter string, only one sentence of the prompt will be played. Two blocks of letter strings will be played after the instruction is played for participants to reason and respond. Participants are asked to fixate and attend to the letters throughout the 5 blocks of letter string as in task 1, but will only be doing keypresses responding to the deductive reasoning instructions. Each action will terminate the letter string and a prompt appears on the screen and ask: “Which letter was on the screen when you first decided to press?” By pressing the corresponding key on the keyboard, participants answer the question and the letter stream proceeds. Orange letters appear in the same interval as in the spontaneous movement tasks. Participants will be asked to not respond to the current deductive reasoning prompt if they have not finished evaluating the conclusion upon seeing the orange letter. They will be given blink breaks when the prompt terminates the letterstream to close their eyes or blink as many times as they want, and will be instructed to reduce eyeball movements and blinkings to their best during the rest of the experiment.

EEG processing

Data is re-referenced to linked mastoids and filtered with a 30 Hz low pass filter. Epoch's are extracted from the time window from -2.5 s to 1s relevant to movement onset, and baseline corrected at -2.5 s to -2 s. RP is calculated as the mean of activities at the sites Cz, C3, and FCz.

EEG results

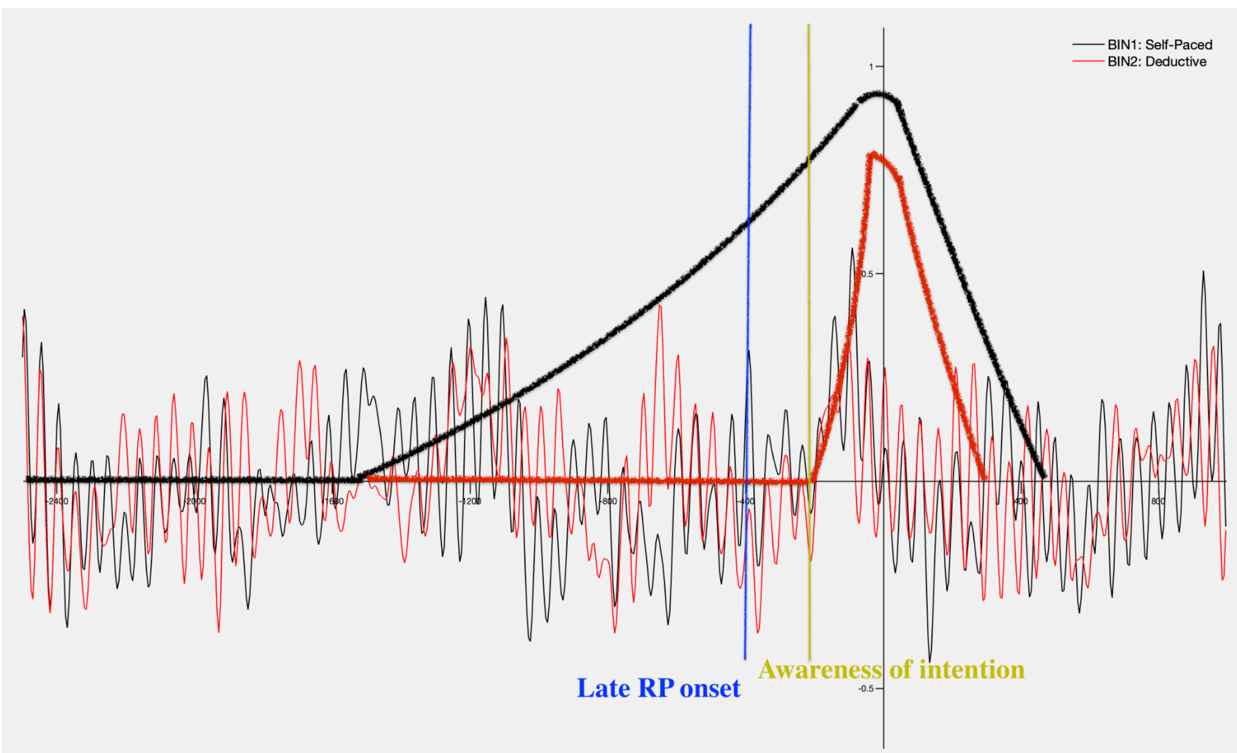

Figure 4. Hypothetical data

Figure 4 shows the hypothetical data drawn on top of data found by the pilot study. The first observable difference would be the neutralization of noise at the start of epoch, Then, early RP of spontaneous movement would first start to develop.followed by its entering late RP at about -400 s, which precedes conscious awareness to intention. Subsequently, if the three hypotheses are supported, then the onset of RP of reasoning-initiated movement will be significantly closer to movement onset and simultaneous with the emergence of intention as shown in figure 4. What is notable is that, the intention generated during reasoning and before spontaneous movements might not occur at the same time, the figure only includes the time, - 200s, that spontaneous movement is shown to emerge because there is no data about the timing of the intention of reasoning-initiated actions. Last but not least, the amplitude of RP before reasoning-initiated movements, as shown by figure 4, would be reliably lower than RP of spontaneous movements.

Time of intention

Time of intention of $RP_{reasoning}$and $RP_{spontaneous}$ is calculated as the mean of all the reported decision time immediately after the presentation of interruption cue.

Inferential statistics

As previous sections articulated, the intention before spontaneous movements is different from the intention of a reasoning-prompted movement in that the latter is more active and explicit, and I wonder if that could be reflected by a difference in timing.

Therefore, a paired-sample t-test will be run to test if there is a significant difference between the mean of the two decision time.

Another question that can be investigated by inferential statistics is about the false positives in the deductive reasoning task. Since these button-pressing are failed attempts to apply reason, it is reasonable to postulate that they are affected by greater “urge” to press. Thus, it is possible that false-positives have lower amplitude than spontaneous movements RP but higher amplitude than reasoning-initiated movements. Therefore, an one-way ANOVA is run among the amplitude of false positives and that of the two experimental conditions, followed by pairwise comparison to test if the proposed relationship exists.

Discussion

If the hypothesized relationship is observed in the actual EEG data of the proposed study, then efficacy of conscious thoughts will be strongly suggested, as the addition of conscious thoughts largely modify the neural input before a decision to move.

Nevertheless, the proposed study has two main limitations. First, the ecological validity of the deductive reasoning task might be low. The content of the reasoning examined in the task is not logically related to the movement, but are forcibly put together. However, in real life, reasonings lead to action because they have logical relationship to the action. Thus, it remains questionable to what extent can the deductive reasoning task can yield truth about reasoning-initiated movements in the real world.

Second, as mentioned earlier, a complete intention would include timing of action, whether to act, and the content of actions. However, in the proposed study, the content of actions in deductive reasoning trials are still predefined. Therefore, a future study might improve this limitation by designing an online task that participants define the content of movements according to their reasoning.

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Appendix. A OSF preregistration

Metadata

Title*

The relationship between readiness potential and movements after deductive reasoning

Description*

The study compares the readiness potential, a slow buildup of brain signal measured at the scalp by electroencephalogram (EEG), before self-paced movements and reason-initiated movements.

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Subject*

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Study Information

Hypotheses*

List specific, concise, and testable hypotheses. Please state if the hypotheses are directional or non-directional. If directional, state the direction. A predicted effect is also appropriate here. If a specific interaction or moderation is important to your research, you can list that as a separate hypothesis.
Example: If taste affects preference, then mean preference indices will be higher with higher concentrations of sugar.

The hypotheses of this study is that instead of a classically defined readiness potential (a gradual buildup of brain negativity before the awareness of movement preparation), the onset of the electrical activity found before reasoning-initiated movements would be: 1) simultaneous with or after the awareness of the intention to move; 2) significantly closer to the movement onset; 3) significantly lower in amplitude

Design Plan

In this section, you will be asked to describe the overall design of your study. Remember that this research plan is designed to register a single study, so if you have multiple experimental designs, please complete a separate preregistration.

Study type*

Please select one of the following statements.

- Experiment - A researcher randomly assigns treatments to study subjects, this includes field or lab experiments. This is also known as an intervention experiment and includes randomized controlled trials.
- Observational Study - Data is collected from study subjects that are not randomly assigned to a treatment. This includes surveys, “natural experiments,” and regression discontinuity designs.
- Meta-Analysis - A systematic review of published studies.
- Other

Blinding*

Blinding describes who is aware of the experimental manipulations within a study. Mark all that apply.

- ☐ No blinding is involved in this study.
- ☑ ~~For studies that involve human subjects, they will not know the treatment group to which they have been assigned.~~
- ☐ Personnel who interact directly with the study subjects (either human or non-human subjects) will not be aware of the assigned treatments. (Commonly known as “double blind”)
- ☐ Personnel who analyze the data collected from the study are not aware of the treatment applied to any given group.

Is there any additional blinding in this study?

N/A

Study design*

Describe your study design. The key is to be as detailed as is necessary given the specific parameters of the design. There may be some overlap between this question and the following questions. That is OK, as long as sufficient detail is given in one of the areas to provide all of the requested information. Examples include two-group, factorial, randomized block, and repeated measures. Is it a between (unpaired), within-subject (paired), or mixed design? Describe any counterbalancing required.

Example: We have a between subjects design with 1 factor (sugar by mass) with 4 levels.

More info: This question has a variety of possible answers. The key is for a researcher to be as detailed as is necessary given the specifics of their design. Be careful to determine if every parameter has been specified in the description of the study design. There may be some overlap between this question and the following questions. That is OK, as long as sufficient detail is given in one of the areas to provide all of the requested information. For example, if the study design describes a complete factorial, 2 X 3 design and the treatments and levels are specified previously, you do not have to repeat that information.

> The study will use a within-subjects design with 1 factor (type of movement) with two levels (reasoning-initiated movement and self-paced movement). Each participant will go through two tasks in counterbalanced order.

Randomization

If you are doing a randomized study, state how you will randomize, and at what level. Typical randomization techniques include: simple, block, stratified, and adaptive covariate randomization. If randomization is required for the study, the method should be specified here, not simply the source of random numbers.

Example: We will use block randomization, where each participant will be randomly assigned to one of the four equally sized, predetermined blocks. The random number list used to create these four blocks will be created using the web applications available at http://random.org.

More info: Typical randomization techniques include: simple, block, stratified, and adaptive covariate randomization. If randomization is required for the study, the method should be specified here, not simply the source of random numbers.

> The study will use block randomization, where each participant will be randomly assigned to one of the ten blocks consisting of two condition orders that are randomly determined. The study will also use simple randomization to randomize the order of the stimuli (syllogism prompts) for each participant. The random number list used to create the block and the stimuli order will be created using the web applications available at http://random.org.

Sampling Plan

In this section we’ll ask you to describe how you plan to collect samples, as well as the number of samples you plan to collect and your rationale for this decision. Please keep in mind that the data described in this section should be the actual data used for analysis, so if you are using a subset of a larger dataset, please describe the subset that will actually be used in your study.

Existing data*

Preregistration is designed to make clear the distinction between confirmatory tests, specified prior to seeing the data, and exploratory analyses conducted after observing the data. Therefore, creating a research plan in which existing data will be used presents unique challenges. Please select the description that best describes your situation. See https://cos.io/prereg for more information.

- Registration prior to creation of data: As of the date of submission of this research plan for preregistration, the data have not yet been collected, created, or realized.
- Registration prior to any human observation of the data: As of the date of submission, the data exist but have not yet been quantified, constructed, observed, or reported by anyone - including individuals that are not associated with the proposed study. Examples include museum specimens that have not been measured and data that have been collected by non-human collectors and are inaccessible.
- Registration prior to accessing the data: As of the date of submission, the data exist, but have not been accessed by you or your collaborators. Commonly, this includes data that has been collected by another researcher or institution.
- Registration prior to analysis of the data: As of the date of submission, the data exist and you have accessed it, though no analysis has been conducted related to the research plan (including calculation of summary statistics). A common situation for this scenario when a large dataset exists that is used for many different studies over time, or when a data set is randomly split into a sample for exploratory analyses, and the other section of data is reserved for later confirmatory data analysis.
- Registration following analysis of the data: As of the date of submission, you have accessed and analyzed some of the data relevant to the research plan. This includes preliminary analysis of variables, calculation of descriptive statistics, and observation of data distributions. Please see cos.io/prereg for more information.

Explanation of existing data

If you indicate that you will be using some data that already exist in this study, please describe the steps you have taken to assure that you are unaware of any patterns or summary statistics in the data. This may include an explanation of how access to the data has been limited, who has observed the data, or how you have avoided observing any analysis of the specific data you will use in your study.

Example: An appropriate instance of using existing data would be collecting a sample size much larger than is required for the study, using a small portion of it to conduct exploratory analysis, and then registering one particular analysis that showed promising results. After registration, conduct the specified analysis on that part of the dataset that had not been investigated by the researcher up to that point.

More info: An appropriate instance of using existing data would be collecting a sample size much larger than is required for the study, using a small portion of it to conduct exploratory analysis, and then registering one particular analysis that showed promising results. After registration, conduct the specified analysis on that part of the dataset that had not been investigated by the researcher up to that point.

N/A

Data collection procedures*

Please describe the process by which you will collect your data and your inclusion and exclusion criteria. If you are using human subjects, this should include the population from which you obtain subjects, recruitment efforts, payment for participation, how subjects will be selected for eligibility from the initial pool, and your study timeline. For studies that don't include human subjects, include information about how you will collect samples, duration of data gathering efforts, source or location of samples, or batch numbers you will use.
Example: Participants will be recruited through advertisements at local pastry shops. Participants will be paid $10 for agreeing to participate (raised to $30 if our sample size is not reached within 15 days of beginning recruitment). Participants must be at least 18 years old and be able to eat the ingredients of the pastries.
More information: The answer to this question requires a specific set of instructions so that another person could repeat the data collection procedures and recreate the study population. Alternatively, if the study population would be unable to be reproduced because it relies on a specific set of circumstances unlikely to be recreated (e.g., a community of people from a specific time and location), the criteria and methods for creating the group and the rationale for this unique set of subjects should be clear.

Participants will be recruited from Bard college and surrounding communities using posters and flyers. An email will then be sent out to participants who are interested to restate the eligibility criteria and schedule time of the experiment. The eligibility criteria ask participants to be:

a. 18-35 years old
b. Right-handed
c. Fluent in English (due to the nature of the stimuli)
d. Unimpaired vision (could be corrected by glasses and contacts) and hearing, not color-blind
e. Not having a diagnosed attention deficit, learning disability, or neurological condition.

f. Not mind having harmless recording sensors attached to participants' scalp.
g. Ability to sit relatively still for about an hour

Sample size*

Describe the sample size of your study. How many units will be analyzed in the study? This could be the number of people, birds, classrooms, plots, or countries included. If the units are not individuals, then describe the size requirements for each unit. If you are using a clustered or multilevel design, describe how many units are you collecting at each level of the analysis. This might be the number of samples or a range, minimum, or maximum.
Example: Our target sample size is 280 participants. We will attempt to recruit up to 320, assuming that not all will complete the total task.
More information: For some studies, this will simply be the number of samples or the number of clusters. For others, this could be an expected range, minimum, or maximum number.

The target sample size is 16 and the maximum sample size is 20 participants.

Sample size rationale

This could include a power analysis or an arbitrary constraint such as time, money, or personnel.
Example: We used the software program G*Power to conduct a power analysis. Our goal was to obtain .95 power to detect a medium effect size of .25 at the standard .05 alpha error probability.
More information: This gives you an opportunity to specifically state how the sample size will be determined. A wide range of possible answers is acceptable; remember that transparency is more important than principled justifications. If you state any reason for a sample size upfront, it is better than stating no reason and leaving the reader to "fill in the blanks." Acceptable rationales include: a power analysis, an arbitrary number of subjects, or a number based on time or monetary constraints.

The software program Jamovi was used to conduct a power analysis. The goal is to obtain .9 power to detect an effect size of .9 at the standard .05 alpha error probability, and the calculated sample size is 16.

Stopping rule

If your data collection procedures do not give you full control over your exact sample size, specify how you will decide when to terminate your data collection. If you are using sequential analysis, include your pre-specified thresholds.
Example: We will post participant sign-up slots by week on the preceding Friday night, with 20 spots posted per week. We will post 20 new slots each week if, on that Friday night, we are below 320 participants.
More information: You may specify a stopping rule based on p-values only in the specific case of sequential analyses with pre-specified checkpoints, alphas levels, and stopping rules. Unacceptable rationales include stopping based on p-values if checkpoints and stopping rules are not specified. If you have control over your sample size, then including a stopping rule is not necessary, though it must be clear in this question or a previous question how an exact sample size is attained.

The recruitment will be stopped once the participant number reaches 20. Although it is expected that some participants might not finish the tasks, the sample size is limited by budget and will not exceed the number of 20.

Variables

In this section you can describe all variables (both manipulated and measured variables) that will later be used in your confirmatory analysis plan. In your analysis plan, you will have the opportunity to describe how each variable will be used. If you have variables which you are measuring for exploratory analyses, you are not required to list them, though you are permitted to do so.

Manipulated variables

Precisely define all variables you plan to manipulate and the levels or treatment arms of each variable. This is not applicable to any observational study.
Example: We manipulated the percentage of sugar by mass added to brownies. The four levels of this categorical variable are: 15%, 20%, 25%, or 40% cane sugar by mass.
More information: For any experimental manipulation, you should give a precise definition of each manipulated variable. This must include a precise description of the levels at which each variable will be set, or a specific definition for each categorical treatment. For example, “loud or quiet,” should instead give either a precise decibel level or a means of recreating each level. 'Presence/absence' or 'positive/negative' is an acceptable description if the variable is precisely described.

The study manipulates the type of the movement that the participants conduct. The two levels are 1) self-paced movements, which are button-presses whenever participants feel the urge to do so; 2) reason-initiated movements, which are button-presses according to the conclusion of the deductive reasoning.

Measured variables *

Precisely define each variable that you will measure. This will include outcome measures, as well as any measured predictors or covariates.

Example: The single outcome variable will be the perceived tastiness of the single brownie each participant will eat. We will measure this by asking participants 'How much did you enjoy eating the brownie' (on a scale of 1-7, 1 being 'not at all', 7 being 'a great deal') and 'How good did the brownie taste' (on a scale of 1-7, 1 being 'very bad', 7 being 'very good').

More information: Observational studies and meta-analyses will include only measured variables. As with the previous questions, the answers here must be precise. For example, 'intelligence,' 'accuracy,' 'aggression,' and 'color' are too vague. Acceptable alternatives could be 'IQ as measured by Wechsler Adult Intelligence Scale' 'percent correct,' 'number of threat displays,' and 'percent reflectance at 400 nm.'

The main measured outcome variables will be

a. The onset of readiness potential (RP). First, the RP is computed by averaging activities at electrodes Cz, FCz, C3. Then, the onset is identified as the first point in time that the RP exceeds some arbitrary value according to two standards: 1)the latency at which the component starts to deviate significantly from zero and 2) the latency at which a certain proportion of its maximum amplitude is attained (Smulders, Kenemans, & Kok, 1996).
b. The time of the intention to move, measured by participants self-reporting the time off the timer on the screen that they are first aware of the intention to move.
c. The movement onset, measured by an event-marker, which sends a signal to the software Labscribe and marks the EEG data every time the participants press the button.
d. The time at which the peak of the EEG amplitude occurs, directly measured by the software Labscribe.

Indices

If applicable, please define how measures will be combined into an index (or even a mean) and what measures will be used. Include either a formula or a precise description of the method. If you are using a more complicated statistical method to combine measures (e.g. a factor analysis), please note that here but describe the exact method in the analysis plan section.

Example: We will take the mean of the two questions above to create a single measure of 'brownie enjoyment.'
More information: If you are using multiple pieces of data to construct a single variable, how will this occur? Both the data that are included and the formula or weights for each measure must be specified. Standard summary statistics, such as "means" do not require a formula, though more complicated indices require either the exact formula or, if it is an established index in the field, the index must be unambiguously defined. For example, "biodiversity index" is too broad, whereas "Shannon's biodiversity index" is appropriate.

The indices are

a. The difference between the onset of readiness potential and the time of the intention to move, calculated by subtracting the latter from the former.
b. The difference between the onset of readiness potential and the onset of movement, calculated by subtracting the latter from the former.
c. The difference between the mean amplitudes of two readiness potentials

Analysis Plan

In this section, you will describe one or more confirmatory analysis. Please remember that all analyses specified below must be reported in the final article, and any additional analyses must be noted as exploratory or hypothesis-generating. A confirmatory analysis plan must state up front which variables are predictors (independent) and which are the outcomes (dependent).

Statistical models *

What statistical model will you use to test each hypothesis? Please include the type of model (e.g. ANOVA, RMANOVA, MANOVA, multiple regression, SEM, etc) and the specification of the model. This includes each variable that will be included, all interactions, subgroup analyses, pairwise or complex contrasts, and any follow-up tests from omnibus tests. If you plan on using any positive controls, negative controls, or manipulation checks you may mention that here. Provide enough detail so that another person could run the same analysis with the information provided. Remember that in your final article any test not included here must be noted as exploratory and that you must report the results of all tests.
Example: We will use a 2 X 3 repeated measures ANOVA (RMANOVA) with both factors within subjects to analyze our results. This is perhaps the most important and most complicated question within the preregistration. Ask yourself: is enough detail provided to run the same analysis again with the information provided by the user? Be aware for instances where the statistical models appear specific, but actually leave openings for the precise test.
More information: This is perhaps the most important and most complicated question within the preregistration. As with all of the other questions, the key is to provide a specific recipe for

analyzing the collected data. Ask yourself: is enough detail provided to run the same analysis again with the information provided by the user? Be aware for instances where the statistical models appear specific, but actually leave openings for the precise test. See the following examples:

- If someone specifies a 2x3 ANOVA with both factors within subjects, there is still flexibility with the various types of ANOVAs that could be run. Either a repeated measures ANOVA (RMANOVA) or a multivariate ANOVA (MANOVA) could be used for that design, which are two different tests.
- If you are going to perform a sequential analysis and check after 50, 100, and 150 samples, you must also specify the p-values you'll test against at those three points.

A paired-sample t-test will be used to compare the difference in the three indices between the two conditions of the independent variable.
An one-way ANOVA is run among the amplitude of false positives in response of deductive reasoning tasksand that of the two experimental conditions, followed by pairwise comparison to test if the proposed relationship exists.
a paired-sample t-test will be run to test if there is a significant difference between the mean of the two decision time.

Transformations

If you plan on transforming, centering, recoding the data, or will require a coding scheme for categorical variables, please describe that process.
Example: The "Effect of sugar on brownie tastiness" does not require any additional transformations. However, if it were using a regression analysis and each level of sweet had been categorically described (e.g. not sweet, somewhat sweet, sweet, and very sweet), 'sweet' could be dummy coded with 'not sweet' as the reference category. If any categorical predictors are included in a regression, indicate how those variables will be coded (e.g. dummy coding, summation coding, etc.) and what the reference category will be.
More information: If any categorical predictors are included in a regression, indicate how those variables will be coded (e.g. dummy coding, summation coding, etc.) and what the reference category will be.

N/A

Inference criteria

What criteria will you use to make inferences? Please describe the information you'll use (e.g. specify the p-values, Bayes factors, specific model fit indices), as well as cut-off criterion, where appropriate. Will you be using one or two tailed tests for each of your analyses? If you are comparing multiple conditions or testing multiple hypotheses, will you account for this?

Example: We will use the standard $p<.05$ criteria for determining if the ANOVA and the post hoc test suggest that the results are significantly different from those expected if the null hypothesis were correct. The post-hoc Tukey-Kramer test adjusts for multiple comparisons.

More information: P-values, confidence intervals, and effect sizes are standard means for making an inference, and any level is acceptable, though some criteria must be specified in this or previous fields. Bayesian analyses should specify a Bayes factor or a credible interval. If you are selecting models, then how will you determine the relative quality of each? In regards to multiple comparisons, this is a question with few "wrong" answers. In other words, transparency is more important than any specific method of controlling the false discovery rate or false error rate. One may state an intention to report all tests conducted or one may conduct a specific correction procedure; either strategy is acceptable.

I will use the standard $p<.05$ criteria to determine if the t-tests suggest that the results are significantly different from those expected if the null hypothesis is supported.

Data exclusion

How will you determine what data or samples, if any, to exclude from your analyses? How will outliers be handled? Will you use any awareness check?

Example: We will verify that each subject answered each of the three tastiness indices. Outliers will be included in the analysis.

More information: Any rule for excluding a particular set of data is acceptable. One may describe rules for excluding a participant or for identifying outlier data.

Data will be excluded if 1) the participant's response accuracy to the validity of the syllogism conclusion is considered a lower outlier, as calculated by subtracting the 1st quartile with 1.5 interquartile range OR 2) the participant does not finish the whole experiment for any reason.

Missing data

How will you deal with incomplete or missing data?

Example: If a subject does not complete any of the three indices of tastiness, that subject will not be included in the analysis.

More information: Any relevant explanation is acceptable. As a final reminder, remember that the final analysis must follow the specified plan, and deviations must be either strongly justified or included as a separate, exploratory analysis.

If a subject does not complete any of the two tasks, the subject's data will not be included in the analysis.

Exploratory analysis

If you plan to explore your data to look for unspecified differences or relationships, you may include those plans here. If you list an exploratory test here, you are not obligated to report its results. But if you do report it you are obligated to describe it as an exploratory result.
Example: We expect that certain demographic traits may be related to taste preferences. Therefore, we will look for relationships between demographic variables (age, gender, income, and marital status) and the primary outcome measures of taste preferences.

N/A

Other

Other

If there is any additional information that you feel needs to be included in your preregistration, please enter it here. Literature cited, disclosures of any related work such as replications or work that uses the same data, or other context that will be helpful for future readers would be appropriate here.

N/A

APPENDIX B: CONSENT FORM

INFORMED CONSENT AGREEMENT

Study title: Readiness Potential and movements after deductive reasoning
Principal investigator: Bochen Li

Advisor: Professor Justin Hulbert

You are being asked to take part in a research experiment at Bard College that seeks to learn more about a type of brain signal that precedes our movements, which is called readiness potential. To decide whether or not you wish to participate, you should know enough about its risks and benefits to make an informed judgment. This consent form gives you information about the research study, and the experimenter will provide you with additional information about the specific tasks that you will be performing. Once you are ready, you will be asked if you wish to participate and, if so, you will sign the consent form. You can choose not to participate, and you can choose to end your participation at any time
during the study.

Background: In our study, we hope to learn more about how a type of brain signal, readiness potential, is related to movements initiated by deductive reasoning.

What you will do in this study:
The study takes approximately 1 hour in total.

As this study requires the measurement of your brain activity, an electroencephalogram (EEG) device will be set up on the head. You will need to wear a cap that is attached to a body harness placed under the armpits and around the chest to help hold the cap. Small and clean electrodes will be put on your scalp, your earlobe, and your mastoids (the bones behind both years) with the help of adhesive gel. The electrodes do not discharge any electricity, meaning that it is impossible for them to shock you. The gel applied is not irritative, but there is a slight chance of irritation for very dry scalp or skin.

After the EEG device is set up, you will be asked to conduct two tasks. The first task involves doing movements, specifically button presses while paying attention to a timer on the computer screen, which you may later be asked to report the time. The second task involves the same task except that you will be asked to do the button presses according to some deductive reasoning prompts you will be hearing.

Risks and benefits: There are no health risks associated with this study. Experiment sessions are kept as short as possible, and every attempt is made to ensure that you would be kept as comfortable as possible throughout. Should you become fatigued or in any way uncomfortable during the experiment, you may ask for a break or withdraw at any time without penalty.

After the experiment, participants who had sensors attached to them may prefer, for appearance reasons, to wash off remnants of the completely harmless electrolyte gel with the provided soap and warm water. There is a potential risk of mild discomfort during the application of the sensors, but you should inform the investigator if you feel any discomfort so that the procedure can be adapted or discontinued. Some of the sensors used in the experiment are made from steel with gold plating.

There is a possible link between the use of certain drying face products, such as Retin-A, and subsequent skin irritation, so as a precaution you are asked to inform the experimenter not to apply electrodes to skin areas that are excessively dry or easily irritated. Although not directly affected by the measurement device, participants with pacemakers are advised not to participate out of a similar abundance of caution.

The words and sounds you might encounter during the experiment are intended to be neutral, non-threatening, and inoffensive. Still, certain individuals may find some of the materials presented. If you find yourself getting disturbed or upset and you want to quit the experiment at any point, you have the right to do so. Just tell your experimenter, “I want to stop,” and you will be free to leave without penalty.

If you are a student at Bard College and find that any aspect of the experiment caused you distress, you are encouraged to contact the Bard Counseling Center at 845-758-7433 during normal business hours or at 845-758-7777 after hours or on weekends.

While this research experiment is not expected to provide participants with any direct benefits, the data collected from this study may help improve the scientific understanding of how to effectively control the focus of attention and the results of doing so. Moreover, the researchers hope that participants gain insight into the research process at Bard College through their involvement with this work.

Compensation: In exchange for participating in this experiment, you will receive a base rate of $14.20/hour..

Your rights as a participant: If you have read this form and have decided to participate in this project, please understand that your participation is voluntary and you have the right to withdraw your consent or discontinue participation at any time by telling your experimenter without penalty. The alternative is not to participate. The results of this research study may be presented at scientific or professional meetings or published in scientific journals. Your individual privacy will be maintained in all published and written data resulting from the study. The experimenter will tell you more about the study and our hypotheses at the end of the session. If you wish, you can send an email message to the principal investigator, Bochen Li (bl3870@bard.edu), and he will send you a copy of any manuscripts based on the research (or a summary of the results).

Confidentiality: Your raw data will be stored in an unidentifiable way and in a password-protected file which only can be accessed by the researcher. Research records will be stored securely in a locked cabinet and/or on password-protected computers.
If you have questions about this study, please ask researcher Bochen Li, bl3870@bard.edu or contact project advisor Dr. Justin Hulbert, jhulbert@bard.edu. If you have questions about your rights as a research participant, please contact the Bard College Institutional Review Board at irb@bard.edu.

STATEMENT OF CONSENT:
"The purpose of this study, procedures to be followed, and the risks and benefits have been explained to me. I have been given an opportunity to ask questions, and my questions have been answered to my satisfaction. I have been told whom to contact if I have additional questions. I have read this consent form and agree to be in this study, with the understanding that I may withdraw at any time."

By signing below, I agree with the above statement of consent and further certify that I I am at least 18 years of age.

__________________________________ ____________

Participant signature Date

____

Participant name (printed)

____

Experimenter signature

APPENDIX.C ELIGIBILITY EMAIL

Hi,

Thank you for your interest in participating in the study. Please find below a brief description of the procedure that you should expect when participating in the experiment:

This study will take approximately 1 hour to complete and you will get a $14.20 compensation. After entering the study, you will be asked to put on an EEG cap and conduct two tasks while we record your brain activity. The first task involves doing movements, specifically button presses while paying attention to a timer on the computer screen, which you may later be asked to report the time. The second task involves the same task except that you will be asked to do the button presses according to some deductive reasoning prompts you will be hearing.

Please see below to double-check your eligibility criteria:

a. 18-35 years old
b. Right-handed
c. Fluent in English (due to the nature of the stimuli)
d. Unimpaired vision (could be corrected by glasses and contacts) and hearing, not color-blind
e. Not having a diagnosed attention deficit, learning disability, or neurological condition.
f. Not mind having harmless recording sensors attached to participants' scalp. Note that the sensors require the application of a gel that may leave a residue after the experiment. If you're planning on doing something immediately after the experiment, you may want to consider leaving yourself enough time to get a shower first. Single-use hair dye will damage our recording equipment, so we cannot allow anyone to participate with single-use dye in their hair. Participants must also be willing and able to remove any facial jewelry/earrings for the experiment
g. ability to sit relatively still for about an hour

If you are still interested and find yourself eligible, please reply to this email with name, email address, and schedule a time for the experiment with me. Thank you!

APPENDIX D:DEBRIEFING

APPENDIX D. DEBRIEFING

Study title: Readiness Potential and movements after deductive reasoning
Principal investigator: Bochen Li
Advisor: Professor Justin Hulbert

Thank you for participating in this experiment!

This research is designed to learn more about a type of brain signal called readiness potential. Previous research finds that before we make a movement like pressing a button or extending a finger, a readiness potential is already found to be building up in our brain even before we are aware of the intention to move. However, previous research has largely been confined to examinations of self-paced movements (i.e., simple movements like pressing a button or tapping a finger conducted whenever participants “feel the urge to”). Meanwhile, there are abundant movements in real life that are not preceded by the feeling of an urge to move, but reasoning, and these movements are more often associated with the concepts of free will and free action. To address this issue, the current project aims to study whether reasoning-initiated movements are still preceded by a readiness potential that is detectable prior to the participants' awareness of having made a decision, and the hypothesis is that instead of a classically defined readiness potential , the electrical activity found before movements after deductive reasoning would be: 1) simultaneous with or after the awareness of the intention to move; 2) significantly closer to the movement onset; 3) significantly less “gradual,” as marked by the averaged brain signal reaching a similar ERP amplitude in significantly shorter time.

Regardless, if you have any questions or concerns afterwards, you may contact me (by phone at 646-736-8982 or via email at bl3870@bard.edu). Again, I thank you for your participation.

APPENDIX.E IRB APPROVAL

Bard College Institutional Review Board

Date: 10/30/2023
To: Bochen Li
Cc: Justin Hulbert; Nazir Nazari
From: Ziad M. Abu-Rish, IRB Chair
Re: Readiness Potential and Actions Following Deductive Reasoning

DECISION: AMENDMENT APPROVAL

Dear Bochen Li

The Bard IRB committee has reviewed your proposed amendments submitted on 10/5/2023. Your requested has been approved through October 3, 2024. Your case number remains 2023OCT4-LI.

Please notify the IRB if your methodology changes or unexpected events arise. We

wish you the best of luck with your research.

Ziad M. Abu-Rish, Ph.D.
IRB Chair
Associate Professor of Human Rights and Middle Eastern Studies
Bard College
zaburish@bard.edu

APPENDIX. F PROPOSED DATA

Budget table

Item	Participant compensation	Adhesive gel	Rubber gloves	Ivory detergent	Total
Budget	270	10	15	40	335

The study time is 1 hour so approximately 19 participants will be compensated $14.20 each. The adhesive gel is used to attach the electrodes to the scalp; the rubber glove is worn throughout the experiment and the detergent is used to clean the EEG cap.