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Research Article

A multi-measurement study of the relation between deliberation and volition

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Abstract

Historically, voluntary action and volition more generally have been investigated through the lens of meaningless decisions. Importantly, these findings have been used in the debate about key notions like free will and moral responsibility. However, more recent claims have challenged the possibility of generalizing findings from a meaningless context to a more meaningful one. The current study investigates the markers of volition, specifically comparing meaningful and meaningless decisions. In an effort to maximize their monetary gain, 50 participants repeatedly deliberated between two options, making either rewarded choices—hard-deliberation decisions (where the options differed along two dimensions) or easy-deliberation decisions (where the options differed along a single dimension)—or unrewarded choices, a.k.a. arbitrary decision. This enabled us to contrast rewarded and unrewarded decisions as well as the degree of deliberation between easy- and hard-deliberation choices. We found evidence that rewarded and unrewarded decisions differed along several measures related to volition: participants reported a higher sense of volition, exhibited a stronger Readiness Potential, had increased temporal binding (mostly inconclusive), and demonstrated increased Effort Exerted in the rewarded condition. In contrast, we found evidence for similarity across these measures between easy-deliberation and hard-deliberation conditions. Our results suggest that it is not the complexity of the deliberation process prior to the action that makes it more volitional, but rather that the decision serves a meaningful goal. Our study also introduced a new implicit measure of volition— effort exerted—that well aligned with other measures of volition and should therefore prove useful in future studies.

Keywords: agency; intention; volition

Introduction

Volition might be described as the capacity to exert one's will and could possibly be defined as the capacity to control intentional action—a capacity that is shared by humans and non-human animals (Roskies 2010, Haggard 2019). Historically, the neuroscience of volition has focused on decisions and actions that are unreasoned, meaningless, and purposeless; in other words, arbitrary (Haggard and Eimer 1999, Fried et al. 2011, Soon et al. 2013). And it was assumed that the experimental results found for such arbitrary decisions would generalize to deliberate decisions, i.e. decisions that are reasoned, meaningful, and purposeful (Mudrik et al. 2020). However, this early assumption was quickly challenged on conceptual grounds (Breitmeyer 1985, Bridgeman 1985). Further, more recently, it has also been experimentally observed that the neural correlates of arbitrary and deliberate decisions might be different enough to question the hypothesis that what holds for arbitrary decisions also applies to deliberate decisions (Maoz et al. 2019). Thus, it seems that more research is necessary to understand extent to which results obtained with arbitrary decisions can be generalized to deliberate decisions. This is what we endeavor to address in this article. To do so, we devised a paradigm to manipulate the goal of the decision (i.e. whether the decision aims to achieve a specific goal or not) and the degree of deliberation (i.e. whether the decision is reached using more or less deliberation (Gold and Shadlen 2007).

Studying volition experimentally is challenging, as the process cannot be fully controlled by the experimenter (Haggard 2019). Studying self-generated actions means that participants must at least possess one of the following characteristics: the autonomy to decide what action to carry out, when to perform it, or even whether to perform it (Brass and Haggard 2008). This capacity is associated with a subjective perception of actions as willed,

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which can be referred to as the sense of volition (SoV) (Hallett 2007). Previous work has measured the SoV by asking participants whether they perceived their actions as more or less willed, using explicit self-reported measurements (Moore and Haggard 2010). However, even if self-reported measurements have contributed to our understanding of the mechanisms of volition, they are highly sensitive to different biases (Choi and Pak 2005). An example is the classic social desirability bias (Fisher 1993), in which participants tend to change their behavior and answers so as to please the experimenter. One method that makes it possible to minimize the effects of such biases is to use implicit measures. Two such methods have been reported in the literature. The first consists of using electroencephalography (EEG) to measure the Readiness Potential (RP; Neafsey 2021)—a slow ramping neural activity preceding the act to move. The second consists of measuring "temporal binding" (TB; Haggard 2019). In the following, we briefly examine each in turn.

The RP is a neural marker that appears to reflect the process of preparation of a voluntary action (Kornhuber and Deecke 2016) (for recent reviews: (Neafsey 2021, Schurger et al. 2021). The early part of the RP is thought to be primarily generated by the supplementary and presupplementary motor areas (SMA and pre-SMA), which themselves receive information from the subcortical circuitry of the basal ganglia (Shibasaki and Hallett 2006). The latter part of the RP has been associated with the primary motor cortex, and has been related to another component, the lateralized readiness potential (LRP; Neafsey 2021, Schurger et al. 2021). In the literature, the RP has been largely interpreted as a measure of volition (Haggard 2019, Neafsey 2021, Schurger et al. 2021). In particular it has been suggested that the onset of the RP reflects the decision to move, whereas the RP itself reflects the neural preparation for movement (Libet et al. 1983, Shibasaki and Hallett 2006, Lau 2009, Roskies 2010, Haggard 2019, 2008, Neafsey 2021, Schurger et al. 2021). This classic interpretation of the RP, as reflecting the decision to move, has however been challenged by an alternative account of the RP, as a marker of a stochastic drift-diffusion process toward a threshold (Schurger et al. 2012). According to this view, the decision to move takes place much later, at the threshold crossing, which occurs just before movement onset. Hence, this account offers a different interpretation of the role of the RP in volitional decisions (Neafsey 2021, Schurger et al. 2021, 2012). Understanding what neural processes the RP reflects is thus critical. The LRP, however, although associated with movement preparation (Haggard and Eimer 1999), does not appear to be related to volitional processes (Eimer 1997), and will therefore not be investigated here.

Importantly, experimental studies on the RP have mainly focused on arbitrary decisions that produce meaningless outcomes (Libet et al. 1983, Haggard and Eimer 1999, Fried et al. 2011, Soon et al. 2013, Schultze-Kraft et al. 2021) rather than on deliberate decisions. However, claims have been made that challenge the possibility to generalize findings from arbitrary to deliberate decisions (Mudrik et al. 2020). Addressing this problem, Maoz et al. (2019) investigated the contrast between arbitrary and deliberate decisions on the RP. To do so, the authors designed a task where participants chose which among two Non-Governmental Organizations (NGOs) shown on the screen should receive a donation of $20 (based on a lottery between the selected NGOs for each participant) and an additional $1000 (based on a lottery between all the participants in the study) in the deliberate condition. In the arbitrary condition, no matter what the participants chose, the two NGOs could win $10 each, and the same pair also had a chance to be drawn in the inter-subject lottery and be awarded $500 each. The results of the study revealed that the RP was present before arbitrary decisions but absent, or at least greatly diminished, for deliberate decisions. The authors also compared trials where the degree of deliberation was harder or easier in the deliberate condition, but found no differences. These results seem to indicate that the RP is impacted by the goals of a decision but not by the extent of deliberation.

However, other experimental manipulations produced different results. For instance, Verbaarschot and colleagues (2019) tested both arbitrary and deliberate decisions in a game named "Free Wally." In this study, participants in the deliberate group had the goal to save an animated, fictional whale while participants in the arbitrary group played a control game that did not involve reaching a specific goal. The authors did not observe significant RP differences between the two groups. In another study, Blignaut and colleagues (2022) asked participants for their opinion about moral judgments. In the deliberation condition, participants were (falsely) told that their decisions would be used in real trials in the criminal justice system. In the arbitrary condition, participants were informed that their decisions would not be used, rendering them meaningless. Again, the authors did not observe significant differences in the RP when comparing arbitrary and deliberate decisions. Finally, Nann et al. (2019) investigated differences in the RP associated with the decision to carry out an actual bungee jump into a 192-m-deep abyss, compared to decide to do a 1-m jump (Nann et al. 2019). Here also, no significant differences in the RP between the two types of jumps was found. Thus, the extent to which the amplitude of the RP is different between arbitrary and deliberate decisions remains very much unsettled. Which is of interest as comparing meaningful and meaningless decisions is a distinction that has been described as an important dimension of volition (Roskies 2010, Brass et al. 2013, Haggard 2019),

As for the TB effect, Haggard et al. (2002) discovered that participants experienced a perceptual compression of time when acting voluntarily, but not when the action was passive. This effect, now replicated many times (Haggard 2017, Hoerl et al. 2020, Wen and Imamizu 2022), has been referred to as "intentional binding," "causal binding," or "TB" in the literature, respective to the independent variables manipulated. The TB effect has been used to measure the sense of agency, defined as the feeling of being the author of an action and of being responsible for its outcome (Gallagher 2000). In this regard, the sense of agency has been referred to as the subjective feeling that accompanies volitional behavior (Frith 2013). The feeling of being the author of an action is typically experienced over an action that was willed, rather than, say, over a reflex. In our experiment, participants carry out voluntary actions, hence their sense of agency should be well correlated with their volition over the actions. In our experimental setting, we will therefore use TB as an implicit measure of volition. The effect of deliberation on TB has barely been studied. A single previous study investigated the effect of deliberation on TB by exploring the difference between meaningful and meaningless actions (Di Costa et al. 2018). To do so, the authors designed a random condition, in which participants decisions did not influence the outcome, and a learning condition, in which participants could learn which action leads to greater reward. The results showed shorter estimated intervals (i.e. stronger TB and thus higher SoV) in the meaningful learning condition compared to the meaningless random condition. As far as we know, no other study has explored the effects of the degree of deliberation before an action on TB. However, different studies have found that estimated intervals were shorter in free-choice conditions compared to instructed conditions, with the former typically considered to be more volitional (Kulakova et al. 2017, Barlas et al. 2018, 2017, Caspar et al. 2020, 2018, 2016, Herman and Tsakiris 2020, Pech and Caspar 2021, 2022). It is possible to interpret these results as indicating that more deliberation takes place before action in the free choice condition than in the instructed condition, in which participants do not have to make a choice. But by the same token, it is also possible that the reported TB effects stem from other factors, such as the fact that the free choice condition involves more decision alternatives, an increased perception of responsibility, or maybe merely increased attention.

Insofar as TB is concerned, the measure exhibits substantial variability amongst participants (Saad et al. 2022) as well as incongruent effects across different studies. For instance, while some studies report larger TB in active versus passive conditions (Caspar et al. 2015, Wiesing and Zimmermann 2024) others have not found such differences (Suzuki et al. 2019, Kong et al. 2024). Thus, it remains unclear exactly what TB reflects (Hoerl et al. 2020, Wen and Imamizu 2022, Gutzeit et al. 2023). It is also worth noting that measuring TB presupposes the existence of a time delay between the participant's action and its outcome, as well as an additional response to collect participants' estimates of the interval. Using TB thus creates a somewhat artificial situation for the participants, who need to consciously monitor the temporal interval between their action and an outcome instead of merely passively perceiving the interval.

This concern regarding the TB, in addition to the ones regarding the alternative account of the RP, led us to introduce an exploratory measure. We investigated the potential of a novel implicit marker related to volition, which relates to effort. The underlying construct of this marker is based on work in the social sciences, where there has been an interest in the mental resources thought to be necessary for volitional behavior—"willpower" (Baumeister et al. 2018, Inzlicht and Friese 2019). Here, we used the concept of willpower to refer to the mechanism that exerts control, which is associated with a feeling of effort. It is noteworthy that, as far as we know, little attention has been paid to the relation between volition and the mental resources needed to perform the action. Interestingly, some authors have claimed that volitional actions are more effortful (Pacherie 2008, Lafargue and Franck 2009, Brass et al. 2013). Moreover, previous work has already observed a link (in the opposite direction) from effort (i.e. the use of resources) toward volition. More precisely, participants who are required to exert more effort exhibit a greater RP (de Morree et al. 2012) or a stronger TB (Demanet et al. 2013, Howard et al. 2016). Here, we aimed to explore the relation in the opposite direction, i.e. to investigate whether more effort is allocated to carry out a more volitional action. To explore this relation, we measured "effort exerted" (EE), which we propose as a new measure of volition aimed at capturing the mental resources committed to carry out the action. To do so, we used two handgrips that measured the strength exerted during the decision participants had made (Sakuma et al. 2018, Zhu et al. 2019). The link between physical and mental effort has long been investigated. Over the past two decades, both behavioral and neural findings have increasingly supported the idea that mental effort and physical effort are closely interconnected (Chapman et al. 2010, Wong and Haith 2017). Therefore, we expect the strength exerted on the handgrips during the participants' decision-making to be related to the mental effort involved in making the decision.

Thus, this study focuses on the effect of deliberate versus arbitrary choices on volition. Similarly to previous studies, we contrasted meaningless (i.e. unrewarded arbitrary) and meaningful (i.e. rewarded deliberate) decisions to evaluate the effect of having goals on volition (Maoz et al. 2019, Nann et al. 2019, Verbaarschot et al. 2019, Blignaut and Heever 2022). Further, to investigate the degree of deliberation, we contrasted an "Easy Deliberation" condition and a "Hard Deliberation" condition. Participants were instructed to decide between two alternatives to maximize their monetary reward. The two options varied along one or two dimensions (see Fig. 1) that could be evaluated in the Easy- or Hard-Deliberation conditions. Both options could increase the participant's monetary reward in these deliberation conditions, but one option could increase it more. In contrast, the arbitrary condition was not associated with any monetary gain. We investigated volition through a questionnaire focusing on the SoV, and through three implicit measures: the RP, TB, and EE.

The literature suggests that more meaningful, goal-directed decisions should be more volitional (Roskies 2010, Brass et al. 2013, Kulakova et al. 2017, Barlas et al. 2018, 2017, Haggard 2019, Caspar et al. 2020, 2018, 2016, Herman and Tsakiris 2020, Pech and Caspar 2021, 2022). We therefore hypothesized that both the explicit (SoV) and the implicit (TB and EE) measures of volition should be larger for meaningful decisions (i.e. the Easy and Hard Deliberation conditions) than for meaningless decisions (arbitrary condition; see Table 1 for a summary of the hypotheses. As for neural activity, previous studies either found no evidence of difference in the RP between arbitrary and deliberate decisions (Nann et al. 2019, Verbaarschot et al. 2019, Blignaut and Heever 2022), or found little to no RP in deliberate decisions (Maoz et al. 2019), our hypothesis was thus that the RP would be the same or diminished for both deliberate decisions compared to arbitrary decisions.

We also hypothesized that an increase in deliberation will make the action more volitional as it requires integrating more input and making the decision more complex (Schüür and Haggard 2011, Haggard 2019, Kane 2019, Slors 2019). We thus predicted that both the explicit (SoV) and the implicit (TB and EE) measurements of volition would increase for more difficult decisions (i.e. Easy vs Hard deliberation conditions). For the RP, as Maoz and colleagues (2019) did not find a difference with more difficult decisions (i.e. Easy vs Hard deliberation conditions), and as we did not find other evidence of effect of difficulty, we therefore expected similar RP between the two conditions.

Materials and methods

Participants

We recruited 50 participants (32 female, 18 male) with a mean age of 24.34 (SD = 4.20). After exclusion of outliers, depending on the measures, we had a minimum of 44 participants and a maximum of 49 (see section on "Data exclusion" below). Previous studies investigating deliberation, the RP, and TB generally included 2–29 participants [29 participants in Blignaut and Heever (2022); 20 participants in Maoz et al. (2019); 21 participants in one condition and 20 participants in the other condition in Verbaarschot et al. (2019); 2 participants in Nann et al. (2018); 16 participants in Di Costa et al. (2018)]. However, the SoV and EE we used here have not been investigated before. Hence, we opted for a larger sample size, which had the added benefit of providing a more robust study.

We recruited participants through messages on social media. The inclusion criteria were as follows: being aged between 18 and 85 years old, with normal or corrected-to-normal vision (to be able to view instructions in the experiment), with no gambling addiction (to eliminate any risk of task-induced relapse), and being neither bald nor styled with dreadlocks (either of which often results in poor EEG recordings). Participants were first informed

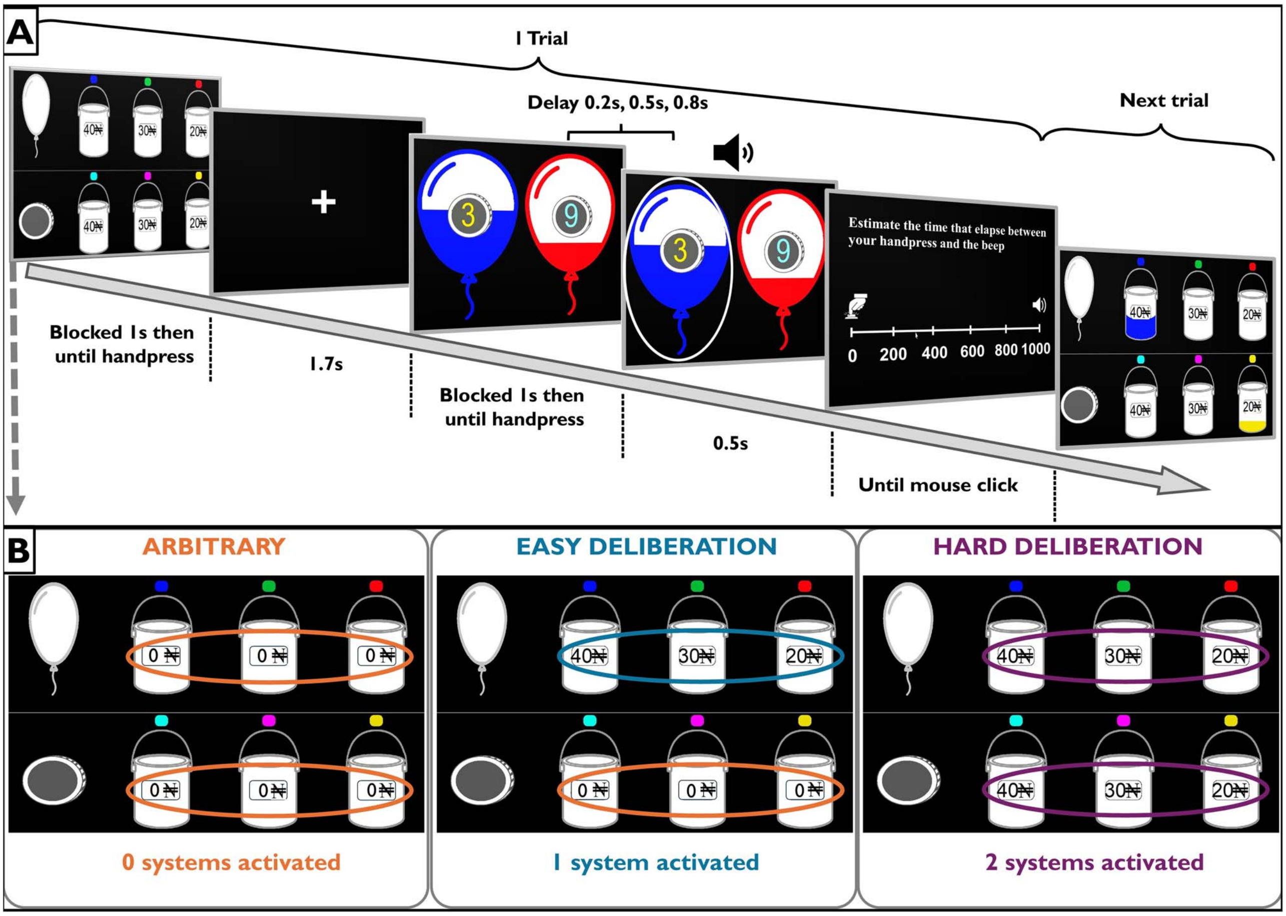

Figure 1. Task design. The participant's task was to maximize the overall number of neuros (₦, a symbolic coin that was linearly translated into a monetary reward) during the experiment. (A) During the task, first the buckets were presented until the participant squeezed the handgrip. The number of neuros associated with the buckets, balloons, and tokens depended on the condition (see B for more details). The handgrip was unresponsive for the first second to make sure the participants took the time to take in the information. The participants were then instructed to focus on the fixation cross for 1.7 s, after which the two pairs of balloons and tokens were presented, each with how much they would increase the fill level of their associated bucket (shown as a proportion for the balloon and as a number (out of a maximum of 17) for the token). They had to select one of them by squeezing the handgrip in their ipsilateral hand. Again, the handgrip was unresponsive for 1 s. After their selection, there was a delay of 200, 500, or 800 ms (uniformly distributed among the three options) before a beep sounded and a white ellipse encircled the selected pair. At that time, participants estimated the time interval between their hand press and the beep using the mouse. Once they clicked the mouse, the next trial started, with the buckets' fill level updated according to the participant's choice. (B) The conditions were differentiated only by the values attached to the buckets (and hence to the balloon and token). In the arbitrary condition, none of the buckets could increase the reward. In the Easy Deliberation condition, only one of the two systems was activated, and in the Hard Deliberation condition, both systems were activated.

Table 1. Summary of "hypotheses."

Hypothesis	**Meaningless versus meaningful** **Arbitrary versus Deliberate (Hard and Easy Deliberation)**	**Low deliberation versus High deliberation** **Easy Deliberation vs Hard Deliberation**
reported Sense of Volition	Lower for Meaningless	Lower for low deliberation
Readiness Potential	Similar or steeper for Meaningless	Similar
Temporal Binding	Higher interval estimates for Meaningless	Higher interval estimates for low deliberation
Effort exerted	Lower for Meaningless	Lower for low deliberation

The first column lays out the comparisons between meaningless and meaningful decisions. The second column provides the comparisons between lower and higher deliberate decisions. Each row represents one of the measures that we investigated during the experiment.

of the experimental task over email (see Instructions section in Supplementary Information S1, Materials). The compensation to take part in the experiment was between €15 and €22, depending on participants' decisions. The study was approved by the ULB-Erasme ethics committee (548/2022).

Procedure and task

When participants arrived in the experimental room, we first calibrated the force of the handgrips (Neulog-237) for both hands to familiarize them with the device (Sakuma et al. 2018, Zhu et al. 2019). They were told that they needed to maintain the same hand position during the entire experiment, so they should find a comfortable position for their hands and fingers. Participants pressed <Enter> to begin the calibration. A red square then appeared in the middle of the screen for 2 s to give participants time to correctly position their hand before recording commenced. The square then turned green for 6 s, during which participants had to achieve their maximal squeeze strength. A visual gauge displayed the amount of the exerted force to provide visual feedback of their squeezing power. Participants could then repeat the calibration (e.g. if they wanted to change their hand positions). After calibration, participants carried out a training session on the task, during which EEG electrodes were placed on their heads. We also used this time to explain to the participants that they had to stay as calm and relaxed as possible, and to minimize eye blinks, saccades, and head and body movements during the trials. Then, the participants performed the task.

The goal of the task was to maximize their own remuneration. To achieve this, participants had to collect (virtual) paint to fill buckets that could be exchanged for "Neuros" (₦). Each participant had six different buckets of different colors, each associated with a different amount of winnable Neuros. Participants were told that every time they filled a bucket with paint, they would accumulate the number of Neuros (N) associated with it. They were further told that Neuros (₦) would be converted into an actual monetary reward (in Euros) at the end of the experiment (see Supplementary Information S2, Methods for details), so they should maximize the number of Neuros to maximize their monetary reward. Once they had filled a bucket with 17 units of paint, they would get the Neuros associated with that bucket (0, 20, 30, or 40 ₦), and the level of paint would reset to 0. To fill the buckets, participants had to choose between two options on the screen using the handgrips (see Fig. 1). Each option consisted of a balloon plus a token. Each balloon/token was associated with a specific color matched to a bucket (i.e. balloon: red, blue, green/token: cyan, magenta, pink) and a specific quantity. For balloons, the amount of paint associated with it (1–17 units) was represented by its fill level. The balloon's color indicated which bucket it would fill (e.g. the blue balloon filled just over half with paint would fill the bucket associated with the blue color with 8 units of paint). For tokens, the amount of paint was indicated precisely using the number on the token, and its associated bucket was represented by the color of the font of the coin (e.g. the coin with the 11 in yellow font would fill the bucket associated with the yellow color by 11 units). The colors and quantities associated with the packages served as indicators of which bucket of colored paint would be filled and by how much. To fill the top and bottom buckets, participants had to collect balloons and tokens, respectively.

The experiment involved three conditions that differed only in the activation of values associated with the buckets, which required varying degrees of deliberation from participants: Arbitrary, Easy Deliberation, and Hard Deliberation. When the values were not activated, participants could disregard the stimuli linked to these buckets when making their decisions. Since participants' goal was to increase their remuneration by collecting buckets with values, removing the values from the buckets made filling them unrewarding and meaningless. Three of the buckets were associated with balloons, and activating them prompted participants to evaluate the color and quantity of paint in the balloon to make their decision. Similarly, for the three buckets associated with tokens, activating them required participants to evaluate the color and consider the quantity of paint to guide their choices. When both systems were activated, participants had to assess both the balloon and the token to make their decision, which thus made the decision more difficult. When only one system was activated, participants had to focus solely on the balloon or the token, thus making the decision easier. However, when both systems were deactivated, participants no longer needed to pay attention to either the balloon or the token, thus resulting in a more arbitrary decision. Hence, the stimuli were similar across all of the conditions (see Fig. 1). The only difference was in the amount associated with the buckets in the different conditions.

More precisely, in the Arbitrary condition, no reward was associated with any of the buckets for the balloon and token (Fig. 1B left). In other words, all six buckets were thus associated with 0 ₦. Hence, the participant's choice could not increase their reward. In the Easy Deliberation condition, only the balloon or the token (but not both) was associated with a reward for the entire experimental session (Fig. 1B middle gives an example where only the balloon is associated with a reward). In this condition, either the balloons system or the tokens system was matched with buckets of different value among 20, 30, or 40 ₦ (i.e. activated). The inactivated system was associated with buckets of 0 ₦. We counterbalanced which system was activated in which condition across participants. In the Hard Deliberation condition, both the balloon and the token were associated with a reward (Fig. 1B right). Hence, overall, each bucket could be associated with one of three colors (blue, green, and red for the balloon; and cyan, magenta, and yellow for the token) and with 0, 20, 30, or 40 ₦, depending on the condition.

Thus, in every trial, participants had to select which of the two options (i.e. balloon-token pairs) would maximize their reward. Participants indicated their selection of the left or right pair by squeezing the left or right handgrip, respectively. To encourage participants to pay attention to the information about the buckets and the association of the balloons and tokens with units of their respective paint, we made the handgrips unresponsive for the first 1 s for those two screens. Subsequently, they were required to squeeze one of the two handgrips to proceed to the next trial. Participants were notified about this 1-s period of unresponsiveness and instructed to look at the stimuli during this time.

Once the participant selected a balloon-token pair, there was a delay of 200, 500, or 800 ms followed by a tone. When the tone was emitted, the selected balloon-token pair was highlighted with a white ellipse that served as visual feedback for the selection. Participants then had to estimate the interval that had elapsed between the hand press and the tone, and were informed that this time interval could vary between 0 and 1000 ms. To express their estimation, participants clicked on a scale ranging from 0 to 1000 ms. The scale was displayed 0.5 s after the tone.

In this study, we carefully controlled the visual stimuli across all experimental conditions during the selection of the packages to ensure uniformity. This methodological choice was crucial because varying visual stimuli can introduce confounding variables that may influence participants' decision-making processes. One limitation is that the consequence of the action evaluated for TB was not the bucket filling, which is the ultimate purpose of the decision, but the selection of the package.

We used a blocked design. Each condition consisted of 72 trials, separated into three blocks of 24 trials each. Hence, there were nine blocks for a total of 216 trials. The order of conditions across blocks was pseudo-randomized so as to avoid both an order effect and the possibility that the same condition occurred twice in a row.

After each block, participants answered the eleven questions included in the SoV questionnaire that we adapted from the sense of agency scale (Tapal et al. 2017; see the Supplementary Information S2, Methods for the list of questions). The 11 questions were therefore repeated three times per condition. Participants had to click on a scale ranging from 0 ("totally disagree") to 100 ("totally agree"). While collecting data and considering potential interpretations, we realized it would be valuable to ask participants how much they deliberated to help with interpreting our results. Starting with the 28th participant, we added an additional question at the end of the experiment, asking participants to rate how much they deliberated during each condition on a scale from 0 ("not at all") to 100 ("very much"), hereafter termed Reported Deliberation. Since this question was not included for the first 27 participants, we decided to introduce it at the very end of the experiment to avoid contaminating other measurements.

The most complex condition among the three was Hard Deliberation. Hence, participants were first trained on this condition because they could then easily understand the other conditions. The training was 10 trials long. If necessary, additional training trials were provided until the participants were confident that they understood all the experimental conditions. The training trials were identical to the experimental trials.

Handgrips

The EE was sampled from the two handgrips (Neulog-237) at a sampling frequency of 10 Hz (Sakuma et al. 2018, Zhu et al. 2019). We opted for a value of 2 newtons as the threshold for a purposeful squeeze of the handgrip. The EE value for each trial was the maximum grip force recorded between the first value recorded and the presentation of the estimation interval scale (resulting in a time window of ~500 ms).

EEG recordings

EEG data were acquired at a sampling rate of 2048 Hz from 32 channels, placed according the international 10–20 system, using the Biosemi system (see http://www.biosemi.com for hardware details). Four additional electrodes were used to acquire horizontal eye movement and mastoid signals. All data were recorded by the Actiview software.

EEG processing

Data were processed using MNE-Python (Gramfort et al. 2013). We downsampled the data to 512 Hz using the default Fast Fourier Transform method of the resample() function in MNE-python. We then applied a bandpass filter between 0.1 and 40 Hz, with the Finite Impulse Response method, a zero-phase delay, and the Hamming window [in line with other literature that measured the RP (Maoz et al. 2019, Nann et al. 2019, Verbaarschot et al. 2019, Travers et al. 2021, Travers and Haggard 2021)]. We detected and interpolated bad channels automatically using the find_all_bads() function of the pyprep.NoisyChannels (mean = 2.1, SD = 1.62) (Bigdely-Shamlo et al. 2015). This function uses a combination of criteria: "extreme amplitudes (deviation criterion), lack of correlation with any other channel (correlation criterion), lack of predictability by other channels (predictability criterion), and unusual high-frequency noise (noisiness criterion)" in addition to the random sample consensus method (Fischler and Bolles 1987). After interpolating, a copy of the data was created in order to apply an automatic Independent Component Analysis (ICA) to detect eye movements, with a high-pass filter of 1 Hz, with a number of components calculated in order to represent 99.99% of the data. The high-pass filter of 1 Hz allows an improvement of the performance of the ICA (Winkler et al. 2015). To detect eye movements (i.e. blink and saccades) with the automatic ICA, we used the 'find_bad_eog()' function in MNE-Python. This method calculates a correlation between the independent components and the electrodes that are labeled as EOG (i.e. electrooculography). We used as EOG the two external electrodes that recorded horizontal eye movement, as well as the "Fp1" and "Fp2" electrodes for the vertical eye movements, as they are closest electrodes from the eyes. Independent components with a correlation higher than 0.5 were removed from the original data (mean = 2, SD = 0), and the copy of the data was not used thereafter. We visually checked the ICA components to ensure that they were correct, resulting in their reselection for 14/50 participants.

We then re-referenced the channels using the reference-electrode standardization technique with a point at infinity, with a head model, and the forward method (Yao 2001, Gramfort et al. 2013, Yao et al. 2019). The data were epoched on electrode Cz in a window from −3 to 1 s around the hand press. Cz was selected as typically used to measure the RP (Maoz et al. 2019, Verbaarschot et al. 2019, Blignaut and Heever 2022). The reason is that this electrode is located above the supplementary motor area, which seems to generate the RP (Shibasaki and Hallett 2006). As the sampling rate of the handgrip was 10 Hz, it could produce a maximal delay of 100 ms from the crossing of the force threshold (at 2 newtons) until it was detected by the handgrip. We thus shifted the EEG data 100 ms forward, which meant that we could be certain that the grip was registered by $t = 0$. We used a baseline from −50 to 50 ms around the hand press to avoid making any assumptions about the onset of the RP [see (Khalighinejad et al. 2018)]. We also extracted and analyzed the slope of the RP, which is not influenced by the selection of baseline. Moreover, measuring the mean and the slope helps in getting more confidence in the results if they do converge. We considered the time from −1 to 0 s relative to movement onset as the timing of the RP, guided by the literature and based on a visual inspection of the grand averages across all conditions and participants (Maoz et al. 2019, Nann et al. 2019, Parés-Pujolràs et al. 2019, Verbaarschot et al. 2019, Travers et al. 2021, Travers and Haggard 2021, Blignaut and Heever 2022). Epochs containing artifacts were rejected based on the value of the mean, the peak-to-peak magnitude, and the slope during this period within each participant (see "Data exclusion" section below).

Statistical analysis

Our main analysis method relied on Bayesian linear mixed models, using the 'brms' R package (Bürkner 2017). For each parameter, we report the estimated medians (Med) and the 89% Highest Density Interval ($HDI_{89\%}$). Furthermore, for each comparison we report the estimated medians difference (Med_{diff}), the 89% HDI [$HDI_{89\%}$ (McElreath 2016, Makowski et al. 2019b)], the Probability Direction [PD Makowski et al. 2019a, 2019b)], the Bayes Factor in favor of H_1 [$BF_{10} > 3$ in favor of H_1, $BF_{10} < 1/3$ in favor of H_0 (Dienes 2011, Kruschke 2018)], and the Robustness Range that leads to the same Bayes Factor conclusion [e.g. RR_{H0} if $BF_{10} < 1/3$ or RR_{IN}

if $1/3 < BF_{10} < 3$ (Dienes 2019, 2014)]. See Supplementary Information S3, Statistical analysis, for further information. Note that the PD is roughly equivalent to a *P*-value (Makowski et al. 2019a; Shi and Yin 2021). Hence, a *P*-value of .05 would correspond to a PD of 97.5% for a two-sided test, and to a PD of 95% for a one-sided test.

Data exclusion

We wanted participants to pay attention to the balloon-token stimulus for at least 1 s. Hence, we did not record handgrip squeezes in the first second after the balloon-token stimulus onset. Thus, the recording was initiated at 1.1 s. However, we also wanted to ensure that any trials in which the participants did not wait at least 1 s before starting to squeeze the handgrip were removed. To achieve this, we needed to take into account that the sampling rate of the handgrip was 10 Hz, indicating that any value transmitted by the device could be delayed by up to 100 ms. Following the assumption that participants could not produce a grip force of 2 newtons in less than 100 ms, we therefore removed trials in which the RTs were faster than 1.2 s. Overall, this resulted in the rejection of 13.9% of trials (SD = 15.8%).

We also removed trials that were outliers within each participant, due to behavioral or EEG data. We used the Median Absolute Deviation (MAD) method with a threshold of three to demarcate outliers (Leys et al. 2019, 2013, Osborne and Overbay 2019). This method rejected 6.5% of trials (SD = 5.9%) for the RTs, 6.1% (SD = 5.9%) for the RP, 3.2% (SD = 5.9%) for the TB, and 2.2% (SD = 3.7%) for the EE. In total, with the exclusion of the slow RTs and the exclusion of the outliers for each measurement, we rejected 19.4% of trials (SD = 15.7%) for the RTs, 19.3% (SD = 15.6%) for the RP, 16.8% (SD = 16.1%) for the TB, and 15.8% (SD = 15.7%) for the EE. As a reminder, we had 72 trials per condition; thus, even the exclusion of 50% of the trials leaves us with 36 trials, which remain a sufficient number for further analyses (Boudewyn et al. 2018).

In addition to removing outlier trials within participants, we also removed outlier participants. For the TB measure, we wanted to ensure that participants correctly discriminated the three durations of the delays (i.e. 200, 500, and 800 ms). We set up a contrast with −1, 0, 1 for the 200, 500, and 800 ms delays, respectively. We then performed a linear regression analysis using the 'lm()' function in R with interval estimate as an outcome, and the three delays as a predictor, for each participant separately. We only kept participants with a significant positive linear trend (i.e. $P < .05$) for the contrast across the delays. This resulted in the removal of 6/50 (12%) participants. We also removed participants who were considered to be outliers using the 3MAD method on each measurement (see Supplementary Information S3, Statistical analysis for more details). Based on this method, we removed 6/50 participants for the RTs, 2/50 participants for the reported SoV, 4/23 participants for the Reported Deliberation, 2/50 participants for the slope of the RP, 2/50 participants for the mean of the RP, 0/44 participants for the TB (six were already removed due to the absence of significant linear trend), and 1/50 participants for the EE.

SoV questions

We calculated Cronbach's alpha over the 11 questions to ensure inter-item reliability. To do so, we used the 'cronbach.alpha()' function of the ltm library in R (Rizopoulos 2007), with 1000 bootstraps and a 89% confidence interval. A value above 0.7 is usually taken as evidence for reliability (Tavakol and Dennick 2011). We found evidence for reliability between the 11 questions ($\alpha = 0.792$, $CI_{89\%} = [0.766, 0.815]$). The questions were thus aggregated into a single score of SoV; the score was the average of the 11 questions.

Effort exerted transformations

We normalized the EE within each participant by taking the difference between each value (x_i) and the minimum value of that participant and dividing the result by the difference between the maximum and minimum values for that participant [i.e. $(x_i - \min(x))/(\max(x) - \min(x))$]. Thus, each participant had an EE ranging from 0% of their minimum squeezing force to 100% of their maximum squeezing force exerted during the experiment.

Results

We systematically contrasted the three levels of deliberation: Arbitrary, Easy Deliberation, and Hard Deliberation. The aim was to examine how these levels impacted our four different measures of volition: the reported SoV, the RP, the TB, and the Effort Exerted (EE). We also investigated how these variations influenced reaction times (RT) and Reported Deliberation as additional measures of deliberation. All analyses were conducted using Bayesian mixed models (see section "Statistical analysis" above). Specific hypotheses can be found in Table 1, with our results corresponding to these hypotheses presented in Table 2. For more details about the results, see the Supplementary Information S4.

Behavioral results

Reported Deliberation

Reported Deliberation refers to the amount that the participants reported deliberating overall during their experimental session in each condition (see Methods). We measured this variable mainly to make sure that the participants understood and followed the design of our task. As expected, we observed reliably lower Reported Deliberation in the Arbitrary condition (Med = 20.6, $HDI_{89\%} = [13.5\ \ 28.9]$) compared to both the Easy Deliberation condition (Med = 65.9, $HDI_{89\%} = [59.4\ \ 72.9]$; $Med_{difference} = -45.1$, $HDI_{89\%}$ [−54.8 −35.2], PD = 100%, $BF_{10} > 1000$, $RR_{H1} = [<25\ \ 1334]$ and the Hard Deliberation condition (Med = 86.5, $HDI_{89\%} = [80.6\ \ 91.7]$; $Med_{difference} = -65.7$, $HDI_{89\%}$ [−75.1 −56.0], PD = 100%; $BF_{10} > 1000$, $RR_{H1} = [<25\ \ 25\,000]$; Fig. 2). We further observed reliably lower Reported Deliberation in the Easy Deliberation condition (Med = 65.9, $HDI_{89\%} = [59.4\ \ 72.9]$) compared to the Hard Deliberation condition (Med = 86.5, $HDI_{89\%} = [80.6\ \ 91.7]$; $Med_{difference} = -20.4$, $HDI_{89\%}$ [−27.4 −13.3], PD = 100%, $BF_{10} = 371$, $RR_{H1} = [<25\ \ 2027]$), again as expected. These results suggest that our experimental design was effective and that participants indeed felt more deliberative in the two Deliberation conditions compared to the Arbitrary condition, as well as in the Hard Deliberation condition compared to the Easy Deliberation condition, in line with our task design.

Reaction times

RT refers to the time that elapsed between the presentation of the two balloon-token pairs and the first recorded handgrip press value of 2 or more newtons (see Fig. 1 and the paragraph Handgrips in the Methods section). We observed reliably longer RTs in the Hard Deliberation condition (Med = 2.69 s, $HDI_{89\%} = [2.51\ \ 2.88]$) compared to both the Arbitrary condition (Med = 2.32 s, $HDI_{89\%} = [2.17\ \ 2.46]$; $Med_{diff} = -0.37$ s, $HDI_{89\%}$ [−0.48 −0.25], PD = 100%, $BF_{10} > 1000$, $RR_{H1} = [<1\ \ 17.5]$) and the Easy Deliberation condition (Med = 2.37 s, $HDI_{89\%} = [2.24\ \ 2.51]$; $Med_{difference} = -0.32$ s, $HDI_{89\%}$ [−0.41 −0.21], PD = 100%, $BF_{10} > 1000$, $RR_{H1} = [<1\ \ 14.2]$;

Table 2. Summary—“observed results.”

Results	**Meaningless versus meaningful** **Arbitrary versus Deliberate (Hard and Easy Deliberation)**	**Low deliberation versus High deliberation** Easy Deliberation vs Hard Deliberation
 reported Sense of Volition	Lower for Meaningless	Similar
 Readiness Potential	Flatter for Meaningless	Similar
 Temporal Binding	Higher interval estimates for Meaningless[a]	Similar
 Effort exerted	Lower for Meaningless	Similar

The first column represents the comparisons between meaningless versus meaningful decisions. The second column represents the comparisons between lower and higher deliberate decisions. Each row represents one of the measures that we investigated during the experiment. [a]For the TB, the effect was only found for the 500 ms delay, and remain inconclusive comparing the easy-deliberation condition and the arbitrary condition.

Fig. 3). Further comparing the RTs between the Arbitrary (Med = 2.32 s, $HDI_{89\%}$ = [2.17 2.46]) and the Easy Deliberation conditions (Med = 2.37 s, $HDI_{89\%}$ = [2.24 2.51]; Med_{diff} = −0.05 s, $HDI_{89\%}$ [−0.12 0.02]), we found evidence that there was no difference between them (PD = 89.31%, BF_{10} = 0.09, RR_{H0} = [0.27 <1]).

Importantly, our experimental design mandated that the participant wait for at least 1 s before acting, with the instruction to observe and evaluate the balloon-token pairs. Hence, unlike speeded reaction time tasks, it is difficult to directly relate the RT in our paradigm to cognitive effort, deliberation, or other cognitive load measures prior to action selection. So, it is notable that we nevertheless observed longer RTs in the Hard Deliberation condition compared to the other conditions, demonstrating that participants took more time to evaluate the stimuli in this condition.

Reported SoV

The reported SoV refers to the average score of the 11 questions in the questionnaire that the participants answered after each block (see Methods and specifically the Statistical analysis section). We observed reliably lower reported SoV in the Arbitrary condition (Med = 69.9, $HDI_{89\%}$ = [66.6 73.2]) compared to both the Easy Deliberation condition (Med = 74.8, $HDI_{89\%}$ = [71.9 77.9]; Med_{diff} = −4.9, $HDI_{89\%}$ [−6.7 −3.0], PD = 99.99%, BF_{10} = 74, RR_{H1} = [<25 176]) and the Hard Deliberation condition (Med = 74.4, $HDI_{89\%}$ = [71.5 77.4]; Med_{diff} = −4.4, $HDI_{89\%}$ [−6.3 −2.6], PD = 99.98%; BF_{10} = 35, RR_{H1} = [<25 116]; Fig. 4). We found conclusive evidence that there was no difference between the reported SoV in the Easy-deliberation condition (Med = 74.8, $HDI_{89\%}$ = [71.9 77.9]) and the Hard-deliberation condition (Med = 74.4, $HDI_{89\%}$ = [71.5 77.4]; Med_{diff} = 0.5, $HDI_{89\%}$ [−0.8 1.8], PD = 72.59%, BF_{10} = 0.04, RR_{H0} = [3 <25]).

Neural activity

Readiness potential

The slope of the RP

The slope of the RP has been extracted between −1 and 0 s for each trial on electrode Cz (see Fig. 5 and Fig. 6, as well as the EEG subsection of the Methods). We found inconclusive evidence that the slope of the RP was flatter in the Arbitrary condition (Med = −1.81 μV, $HDI_{89\%}$ = [−2.69 −0.92]) compared to the Easy-deliberation condition (Med = −2.52 μV, $HDI_{89\%}$ = [−3.24 −1.84]; Med_{diff} = 0.72 μV, $HDI_{89\%}$ [0.09 1.33], PD = 96.58%, BF_{10} = 2.09, RR_{IN} = [0.66 6.6]) and conclusive evidence that it was flatter compared to the Hard-deliberation condition (Med = −2.68 μV, $HDI_{89\%}$ = [−3.33 −2.07]; Med_{diff} = 0.88 μV, $HDI_{89\%}$ [0.12 1.23], PD = 97.74%; BF_{10} = 3.16, RR_{H1} = [<1.00 1.07]). We also observed inconclusive evidence for no difference between the slope of the RP in the Easy Deliberation (Med = −2.52 μV, $HDI_{89\%}$ = [−3.24 −1.84]) and Hard Deliberation conditions (Med = −2.68 μV, $HDI_{89\%}$ = [−3.33 −2.07]; Med_{diff} = 0.16 μV, $HDI_{89\%}$ [−0.38 0.72], PD = 68.28%, BF_{10} = 0.39, RR_{IN} = [0.12 1.23]).

The mean (amplitude) of the RP

The mean of the RP is the average value within the time window −1 to 0 s across trials (see Fig. 5 and Fig. 7, as well as the EEG subsection of the Methods). We observed evidence that the mean of the RP across participants was lower in the Arbitrary condition (Med = 0.98 μV, $HDI_{89\%}$ = [0.50 1.46]) compared to the Easy Deliberation condition (Med = 1.49 μV, $HDI_{89\%}$ = [1.06 1.92]; Med_{diff} = −0.51 μV, $HDI_{89\%}$ [−0.84 −0.17], PD = 99.12%, $InBF_{10}$ = 3.97, RR_{H1} = [<1 1.42]) and inconclusively lower compared to the Hard Deliberation condition (Med = 1.45 μV, $HDI_{89\%}$ = [1.05 1.85]; Med_{diff} = −0.46 μV, $HDI_{89\%}$ [−0.83 −0.11], PD = 98.08%; BF_{10} = 1.97, RR_{IN} = [0.61 6.13]). We observed evidence for no difference between the mean of the RP in the Easy Deliberation condition (Med = 1.49 μV, $HDI_{89\%}$ = [1.06 1.92]) and the Hard Deliberation condition (Med = 1.45 μV, $HDI_{89\%}$ = [1.05 1.85]; Med_{diff} = 0.05 μV, $HDI_{89\%}$ [−0.28 0.36], PD = 59.41%, BF_{10} = 0.21, RR_{H0} = [0.57 <1]).

Implicit measures

Temporal binding

TB refers to each participant’s reported interval estimation compression between the action and the tone that follows it, on each trial. We found evidence for some similarities and some differences in TB across our levels of deliberation, depending on the actual action-tone delay (i.e. 200, 500, or 800 ms; see Fig. 8). For the 200 ms delay, there was evidence for similar TB, between the Easy-deliberation

condition (Med = 363 ms, $HDI_{89\%}$ = [330 396]) and both the Arbitrary condition (Med = 362 ms, $HDI_{89\%}$ = [330 396]; Med_{diff} = −0 ms, $HDI_{89\%}$ [−14 15], PD = 51.79%, BF_{10} = 0.31, RR_{H0} = [28 >30]), and the Hard-deliberation condition (Med = 361 ms, $HDI_{89\%}$ = [328 393];

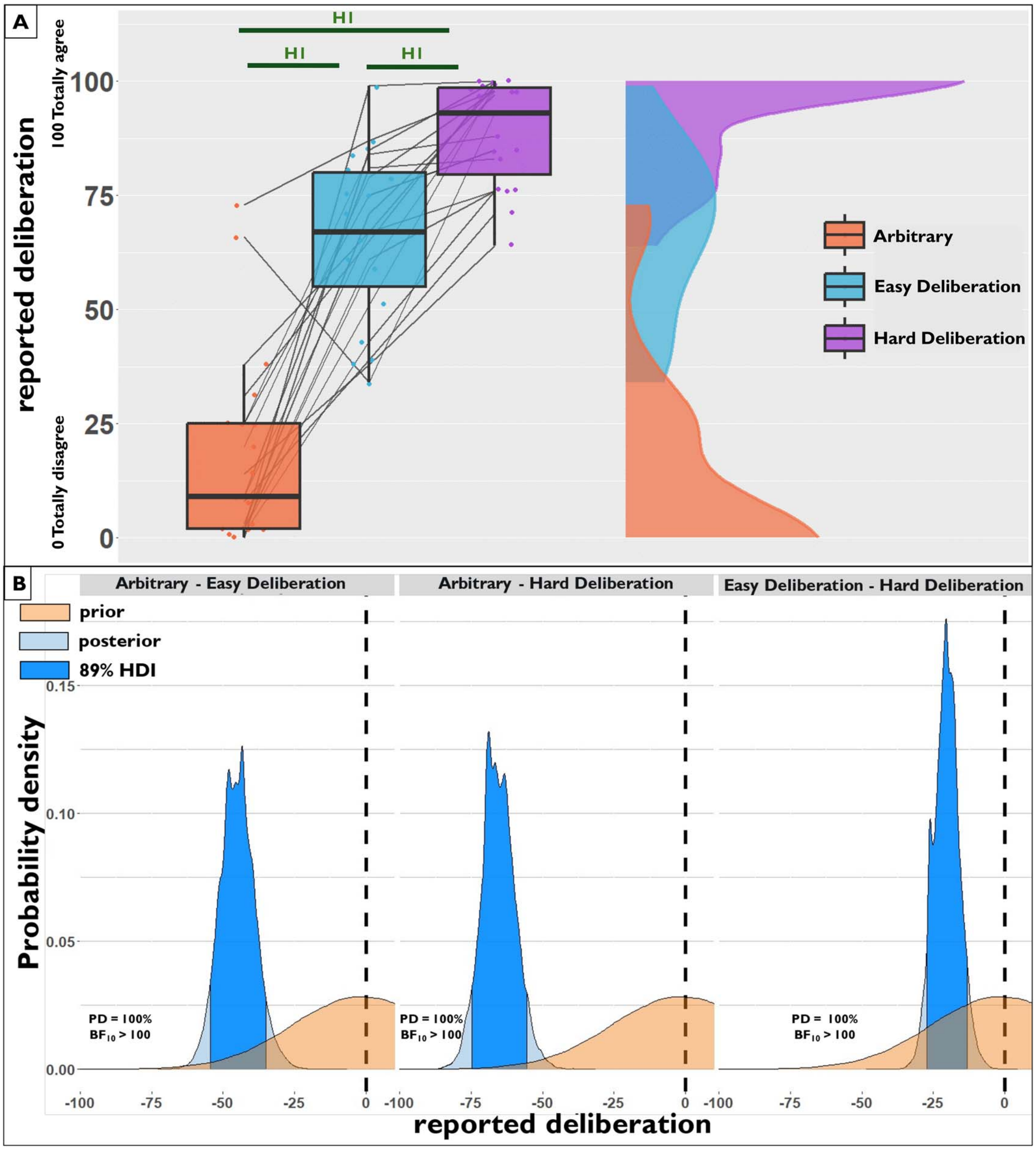

Figure 2. Reported Deliberation. (A) In each boxplot, the thick horizontal black line represents the median. The top and bottom parts of the box represent the 75% and 25% percentiles of the data. The vertical lines represent the 1.5 interquartile range starting from the 25% percentile at the bottom and the 75% percentile on top. Each line connecting the boxplots and dots represents the Reported Deliberation of a single participant. H1 represents evidence for a difference (see Statistical analysis for more details). (B) Posterior analysis of Reported Deliberation. Each column represents the posterior distribution of the difference between two conditions (e.g. "Arbitrary - Easy-deliberation," is the resulting posterior distribution of the arbitrary minus the Easy Deliberation condition). The distribution of the prior used to run the model and to calculate the BF_{10} is in orange. It has a normal distribution centered on 0 with a SD of 25. The blue distribution is the posterior distribution, with the 89% HDI (in darker blue). The dashed vertical line is at 0 (no difference).

$Med_{diff} = 2$ ms, $HDI_{89\%}$ [−13 16], PD = 57.75%, $BF_{10} = 0.31$, RR_{H0} = [26 >30]). We observed inconclusive evidence for similar TB in the Arbitrary condition and the Hard-deliberation condition ($Med_{diff} = 1$ ms, $HDI_{89\%}$ [−15 17], PD = 54.90%, $BF_{10} = 0.34$, RR_{IN} = [3 32]). For the 500 ms delay, there was evidence for lower TB (i.e. longer interval estimates) in the Arbitrary condition (Med = 486 ms, $HDI_{89\%}$ = [456 518]) compared to the Hard-deliberation condition (Med = 464 ms, $HDI_{89\%}$ = [434 494]; Med_{diff} = 23 ms, $HDI_{89\%}$ [6 40], PD = 98.37%, $BF_{10} = 3.39$, RR_{H1} = [<30 35]), and inconclusive lower TB in the Arbitrary condition compared to the Easy-deliberation condition (Med = 469 ms, $HDI_{89\%}$ = [439 499]; $Med_{diff} = 17$ ms, $HDI_{89\%}$ [2 30], PD = 97.17%, $BF_{10} = 1.83$, RR_{IN} = [17 172]). We observed inconclusive evidence for similar TB in the Easy-deliberation condition and the Hard-deliberation condition ($Med_{diff} = 6$ ms, $HDI_{89\%}$ [−9 20], PD = 73.35%, $BF_{10} = 0.38$, RR_{IN} = [4 35]). For the 800 ms delay, there was evidence for similar TB, between the Easy-deliberation condition (Med = 610 ms, $HDI_{89\%}$ = [576 643]) and both the Arbitrary condition (Med = 607 ms, $HDI_{89\%}$ = [573 462]; $Med_{diff} = 3$ ms, $HDI_{89\%}$ [−12 17], PD = 61.56%, $BF_{10} = 0.32$, RR_{H0} = [28 >30]), and the Hard-deliberation condition (Med = 608 ms, $HDI_{89\%}$ = [574 641]; $Med_{diff} = 1$ ms, $HDI_{89\%}$ [−13 17], PD = 55.96%, $BF_{10} = 0.32$, RR_{H0} = [28 >30]). We observed inconclusive evidence for similar TB in the Arbitrary condition and the Hard-deliberation condition ($Med_{diff} = -1$ ms, $HDI_{89\%}$ [−18 15], PD = 55.28%, $BF_{10} = 0.35$, RR_{IN} = [3 32]).

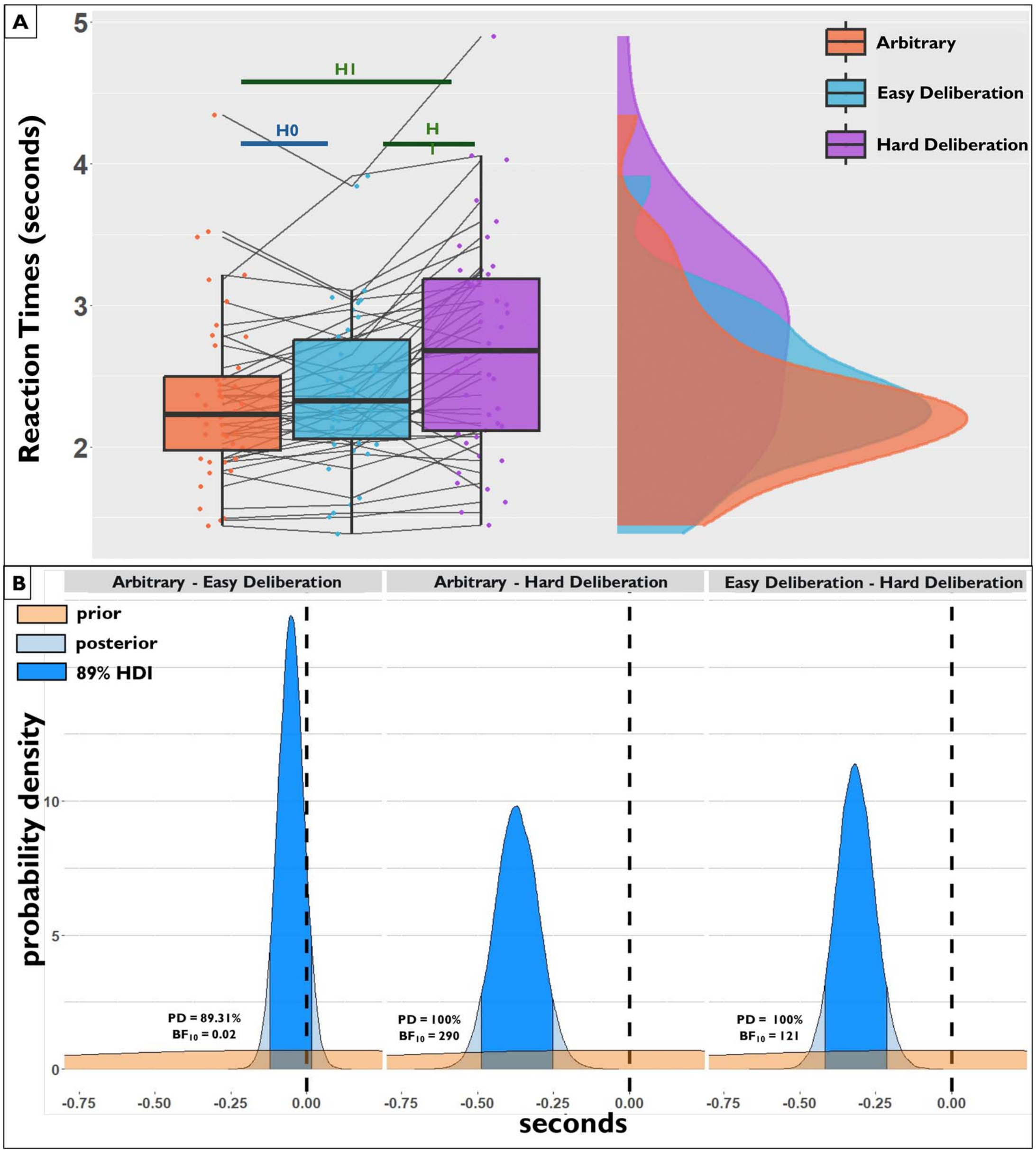

Figure 3. RT. (A) Similar as Fig. 2A. H_0 represents evidence for similarity and H_1 for difference. (B) Posterior analysis of the RTs. Similar as Fig. 2B. Here, the SD of the prior distribution (in orange) is 1.

Effort exerted

The effort exerted (EE) refers to the maximum value recorded by the handgrips in response to the selection of the balloon-token pair. The EE was reliably lower in the Arbitrary condition (Med = 31.99%, $HDI_{89\%}$ = [29.8 34.24]) compared to both the Easy-deliberation condition (Med = 35.09%, $HDI_{89\%}$ = [32.66 37.58]; $Med_{difference}$ = −3.13%, $HDI_{89\%}$ [−4.76 −1.45], PD = 99.82%, BF_{10} = 8.93, RR_{H1} = [<10 26.6]) and the Hard-deliberation condition (Med = 35.11%, $HDI_{89\%}$ = [32.52 37.79]; $Med_{difference}$ = −3.13, $HDI_{89\%}$ [−4.82 −1.43], PD = 99.83%, BF_{10} = 7.88, RR_{H1} = [<10 26.6]; see Fig. 9). We observed conclusive evidence for the absence of difference between the EE in the Easy Deliberation condition (Med = 35.09%, $HDI_{89\%}$ = [32.66 37.58]) and the Hard Deliberation condition (Med = 35.11%, $HDI_{89\%}$ = [32.52 37.79]; $Med_{difference}$ = −0.00, $HDI_{89\%}$ [−1.62 1.62], PD = 50.02%, BF_{10} = 0.10, RR_{H0} = [2.85 <10]).

Results summary

Table 2 presents a summary of the main results. For more details about the results, see the Supplementary Information S4. We find differences between Arbitrary decisions and Deliberate ones for the SoV, RP, TB, and EE. But we generally found evidence for no difference between the Easy and Hard Deliberation conditions.

Discussion

The present study investigated the effects of deliberation on volition. We contrasted unrewarded, meaningless decisions (the Arbitrary condition) with rewarded, meaningful decisions (the Deliberate conditions) and also compared degrees of deliberation by contrasting Easy Deliberation with Hard Deliberation decisions. We found that shifting from arbitrary to deliberate decision-making affected several volition-related measures (summarized

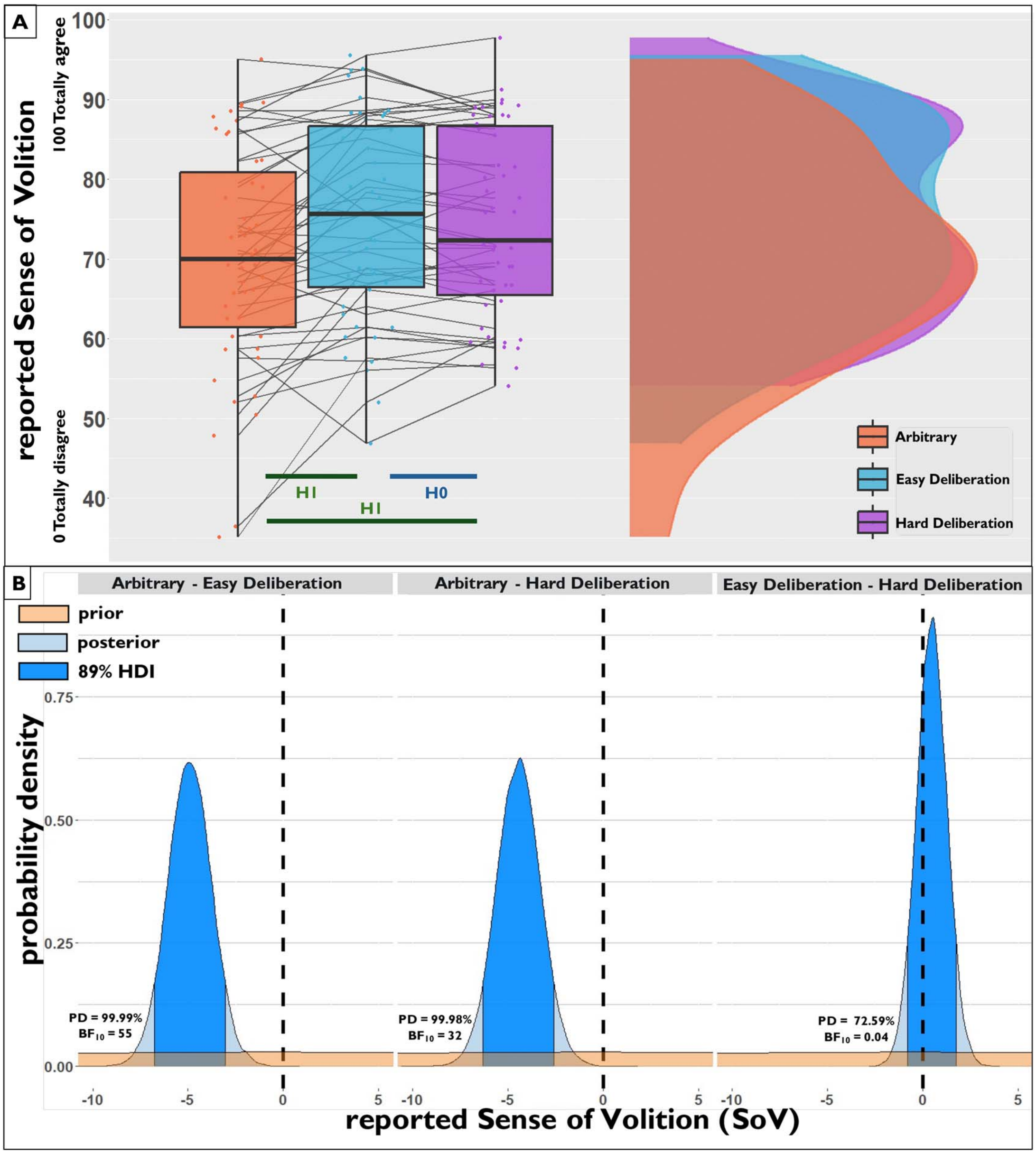

Figure 4. Self-reported SoV. (A) Similar as Fig. 2A. H_0 represents evidence for similarity and H_1 for difference. (B) Posterior analysis of the reported SoV. Similar as Fig. 2B. The SD of the prior distribution (in orange) is 25.

in Table 2). Participants reported a higher SoV, exhibited a stronger RP as well as increased TB, and exerted more effort (EE). However, across all measurements, our results indicated no significant differences between the Easy and Hard Deliberation conditions.

More specifically, when investigating the reported SoV, we observed an increase in SoV in both the Easy and Hard Deliberation conditions compared to the Arbitrary condition, consistent with our hypothesis. This suggests that our experimental manipulation was effective. Interestingly, and contrary to our hypothesis, we observed evidence for similarity in SoV between the Easy and Hard Deliberation conditions. Hence, overall, our results indicate that deliberation increased the SoV, but the extent of deliberation failed to further alter it. The latter result appears to contradict literature that suggests that more deliberative decisions—decisions that require the integration of more inputs—are more volitional (Schüür and Haggard 2011, Kane 2019, Slors 2019). In contrast, our results seem to indicate that the higher number of inputs to encode in the Hard Deliberation compared to the Easy Deliberation condition did not impact the subjectively reported volition by the participants. In this, our results are in line with a study that also found differences between the abstract description of freedom and the self-reported experience of freedom (Lau et al. 2015). Participants did not report feeling freer when given decisions that included more alternatives, complexity, or uncertainty, even though—conceptually—such factors increase freedom in virtue of increasing the number of alternative possibilities. Future studies are needed to better capture this apparent dissonance between predictions of conceptual characterizations of volition and the experience reported by the participants.

Contrary to our prediction, we observed a stronger RP before deliberate decisions compared to arbitrary decisions. We expected a reduced RP for deliberate decisions based on the results of

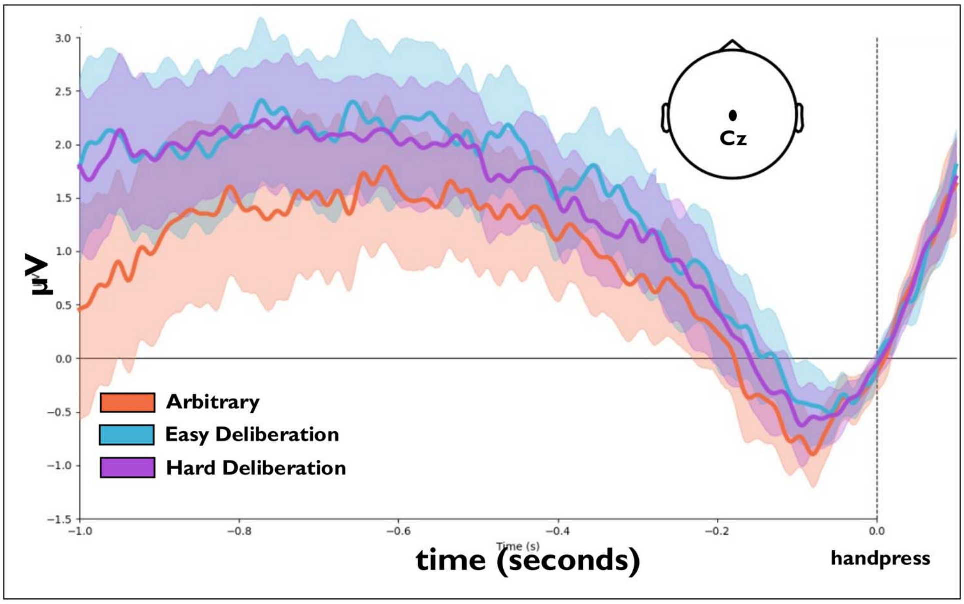

Figure 5. EEG plot of the RP. Each line represents a condition with its 95% confidence interval (i.e. the shaded area around each curve). The curves represent activity from the Cz electrode, time-locked on the hand press.

Maoz et al. (2019). Those authors found evidence for a reduced RP before deliberate decisions compared to arbitrary decisions. Interestingly, our results go in the opposite direction; if anything, we found a lower and flatter RP for arbitrary decisions. However, two differences between the studies should be kept in mind regarding these divergent results. First, the way in which actions were carried out differed between this study and Maoz et al's study. In the latter, participants pressed a button to indicate their choice as soon as they had made up their mind. In contrast, our participants had to wait for at least a second before acting, and they indicated their choice using handgrips, which sampled the exerted force every 100 ms. This resulted in an RP with a shape that is somewhat different from the shape most commonly reported in the literature (Fig. 5), which might explain at least part of the difference in the results.

Second, on a more conceptual level, while both Maoz et al.'s and the present study included experimental conditions that involved deliberate decisions, the nature and goals of those decisions were quite different in each study. In our study, participants could increase their own remuneration, a self-reward, whereas in Maoz et al's study, participants could increase the likelihood of a donation to NGOs, which is perhaps more of a vicarious reward. Some studies found overlapping activation between self and vicarious rewards in the ventral striatum and ventromedial prefrontal cortex, but there were individual differences that depended on individuals' characteristics (Morelli et al. 2018, Spaans et al. 2019). These differences between the tasks could explain the different effects found on the RP between Maoz and colleagues (2019) and our study. Nevertheless, these results support the claims of Maoz et al. regarding neural differences between arbitrary and deliberate decisions. What is more, two previous studies reported higher RP in an arbitrarily rewarded condition compared to an arbitrary non-rewarded condition (McAdam and Seales 1969, Pornpattananangkul and Nusslock 2015). In addition, the valuation of our token-balloon pairs was quantitative (in Neuros that translated into Euros), while the valuation of the two NGOs also implies qualitative comparisons. These different valuations may well have had a different effect on the RP. While the field of neuroeconomics found evidence for a common-currency neural system in the orbito-frontal cortex that is responsible for the valuation of divergent choices (Levy and Glimcher 2012), other views of the choice system propose alternatives. For example, participants might use heuristics or probabilities when making decisions in our more quantitative paradigm (Hayden and Niv 2021), which may rely on different neural processes than the more qualitative comparisons of Maoz and colleagues (2019). More research is needed to clarify this point.

Our results also stand in contrast with three studies that failed to find differences in RP between arbitrary and deliberate decisions (Blignaut and Heever 2022, Verbaarschot et al. 2019, Nann et al. 2019). However, the statistical techniques used in those studies were not suitable for providing evidence for similarity between the conditions. We thus cannot rule out the possibility that the null results in those studies stemmed from underpowered experiments (Dienes 2011, Kruschke 2018). Our diverging results lend credence to previous claims (Dominik et al. 2024) that more research is needed to compare and contrast the neural processes that accompany arbitrary and deliberate decisions.

In line with another hypothesis, we found evidence for similar RPs between the Easy Deliberation condition and the Hard Deliberation condition. Maoz et al. (2019) also reported comparable results for easy and Hard Deliberation decisions, though they did not provide specific statistics about this comparison. Altogether, our findings support the view of the RP as a marker of volition, as it increased for a goal-directed decision compared to an arbitrary decision (Roskies 2010, Brass et al. 2013, Haggard 2019). Our results provided more evidence that the RP is unaffected by the degree of deliberation needed to achieve the goal. The RP thus appears to be related to the goal of the action but not to be correlated with the deliberation *per se*. Finally, our study strengthens claims that previous results studying the RP using meaningless decisions cannot be simply generalized to meaningful decisions (Mudrik et al. 2020).

The RP has traditionally been measured over the (pre-) supplementary motor areas—key regions involved in the initiation of voluntary actions (Matsuhashi and Hallett 2008,

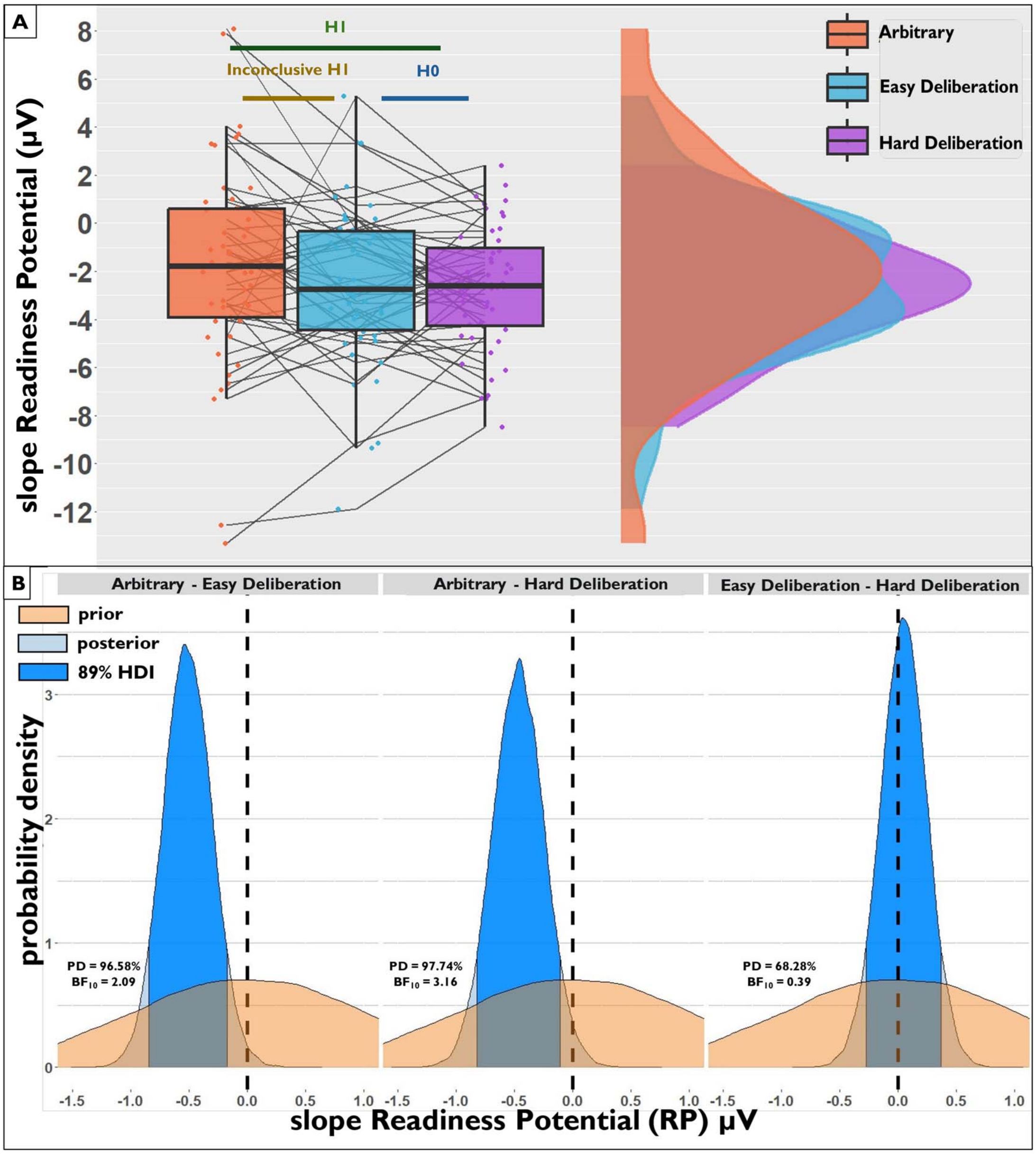

Figure 6. Slope of the RP. (A) Similar as Fig. 2A. H_0 represents evidence for similarity, H_1 for difference, and inconclusive $\mathbf{H_1}$ represents inconclusive evidence for H_1 (i.e. PD above 95% and HDI89% not overlapping 0, but BF_{10} inconclusive). (B) Posterior analysis of the slope of the RP. Similar as Fig. 2B. The SD of the prior distribution (in orange) is 1.

Kornhuber and Deecke 2016). However, some literature suggests that the origin of volitional actions may instead lie in medial frontal and parietal regions, which are thought to contribute to both the generation and the subjective experience of voluntary action (Desmurget et al. 2009, Desmurget and Sirigu 2009, Haggard 2019). These areas have been linked not only to goal-directed and intentional, deliberate actions (Fried et al. 2017) but also to outcome processing (Gehring and Willoughby 2002, Paulus et al. 2002), and they are known to communicate with the (pre-)SMA (Haggard 2008). Therefore, in tasks that require deliberate decision-making and valuation of outcomes, one potential mechanism for the effect of deliberation on the RP is that such deliberation enhances activity in frontal and parietal regions. Through communication with the (pre-)SMA, this enhancement could explain the amplification of the RP. Future studies are needed to explore and confirm this proposed mechanism.

We initially hypothesized that TB would increase from arbitrary to deliberate actions, reflecting greater volition when acting toward a meaningful goal compared to a meaningless one. When the actual delay was 500 ms, we found evidence for lower TB in the arbitrary condition compared to the hard-deliberation condition, and inconclusive evidence for lower TB in the arbitrary condition compared to the easy-deliberation condition. The 200 and 800 ms durations showed either inconclusive comparisons or evidence of similarity between arbitrary to deliberate actions. A previous study comparing meaningful and meaningless actions did find differences in TB (Di Costa et al. 2018). Hence, our study provides some additional evidence that the perceived time-compression could be affected by the goal of the action. Surprisingly, our effect is mostly inconclusive despite the relatively large number of participants ($n = 44$). This is likely due to the variability of the effect between participants as observed in Fig. 8C. Our results support the findings that TB seems variable between participants (Saad

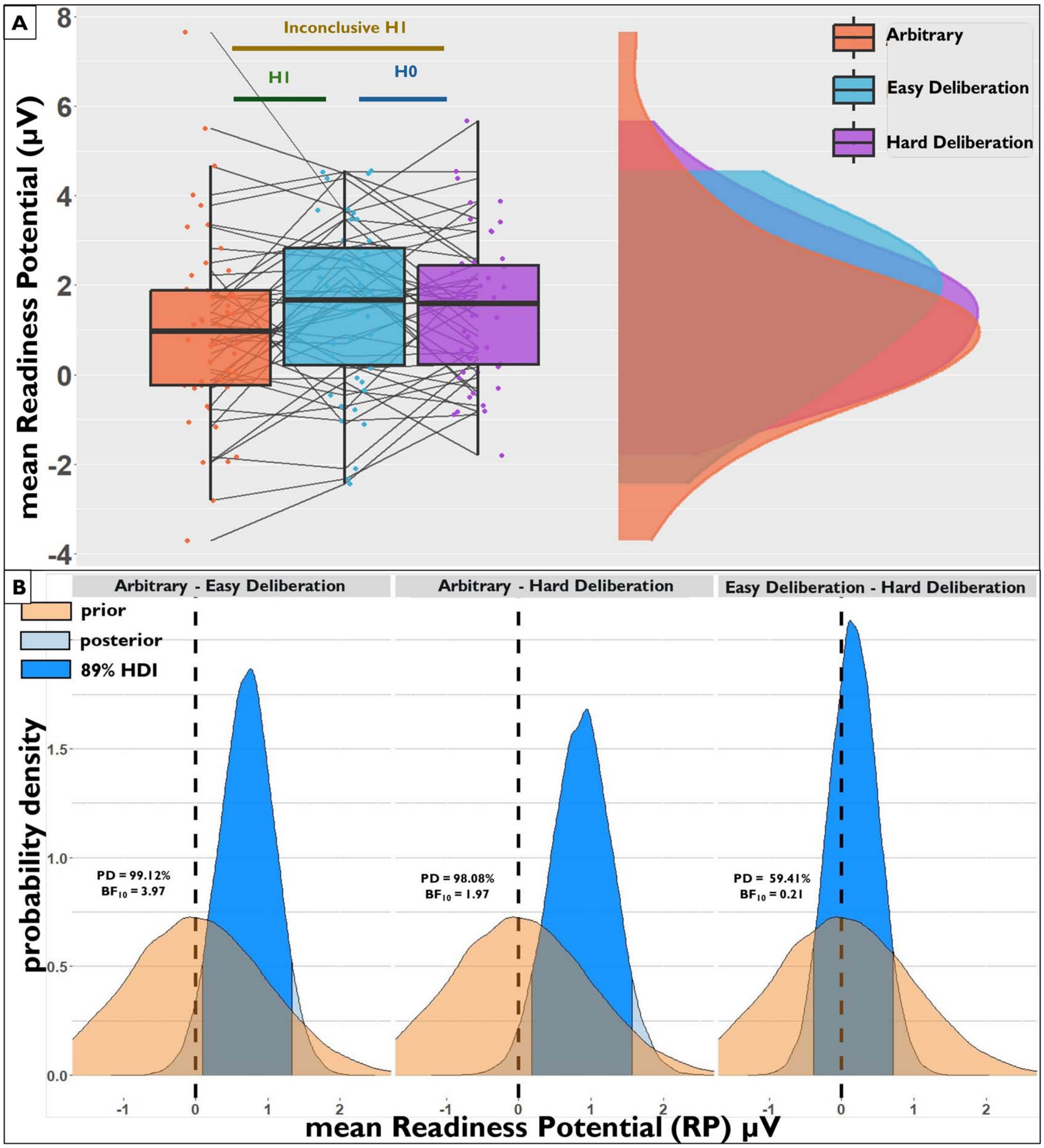

Figure 7. Mean of the RP. (A) Similar as Fig. 2A. H_0 represents evidence for similarity, H_1 for difference, and inconclusive H_1 represents inconclusive evidence for H_1 (i.e. PD above 95% and HDI89% not overlapping 0, but BF_{10} inconclusive). (B) Posterior analysis of the mean of the RP. Similar as Fig. 2B. The SD of the prior distribution (in orange) is 1.

et al. 2022). Of note, most TB studies rely on a baseline condition without an action or without an outcome (Haggard et al. 2002, Suzuki et al. 2019, Wiesing and Zimmermann 2024), which allows researchers to interpret differences in time estimation when the condition includes both an action and an outcome. In the present study, we did not include such a baseline condition. Instead, we relied on alternative forms of experimental control, comparing time estimations across two or more active experimental conditions to infer where TB was strongest [similarly as: (Caspar et al. 2016, Barlas et al. 2018, 2017, Pech and Caspar 2021)].

We also expected the TB to increase from Easy-Deliberation to Hard-Deliberation decisions. However, we found evidence that the TB is not affected by the degree of deliberation prior to a decision. Interestingly, previous studies found increased TB prior to free decisions compared to instructed ones (Kulakova et al. 2017, Barlas et al. 2018, 2017, Caspar et al. 2020, 2018, 2016, Herman and Tsakiris 2020, Pech and Caspar 2021, 2022). These findings could have been produced by an increased deliberation before a free decision that is less pronounced for an instructed decision, as the reasoning about the choice is already made. However, our results seem to go against this hypothesis and highlight the fact that the increased TB before a free decision, reflecting an increase of volition, might be better explained by other factors, such as the limited freedom in the instructed condition, or a reduction in the perceived causality, as the intention of choice is not up to the participants themselves. Further studies are needed to test these alternative explanations.

Based on previous literature, we also investigated the relation between volition and the use of available resources (Brass et al. 2013). We used handgrips to measure participants' EE. We hypothesized that more volitional actions would result in higher EE, even though there was no incentive to raise the EE for deliberate decisions, as the amount of force exerted did not

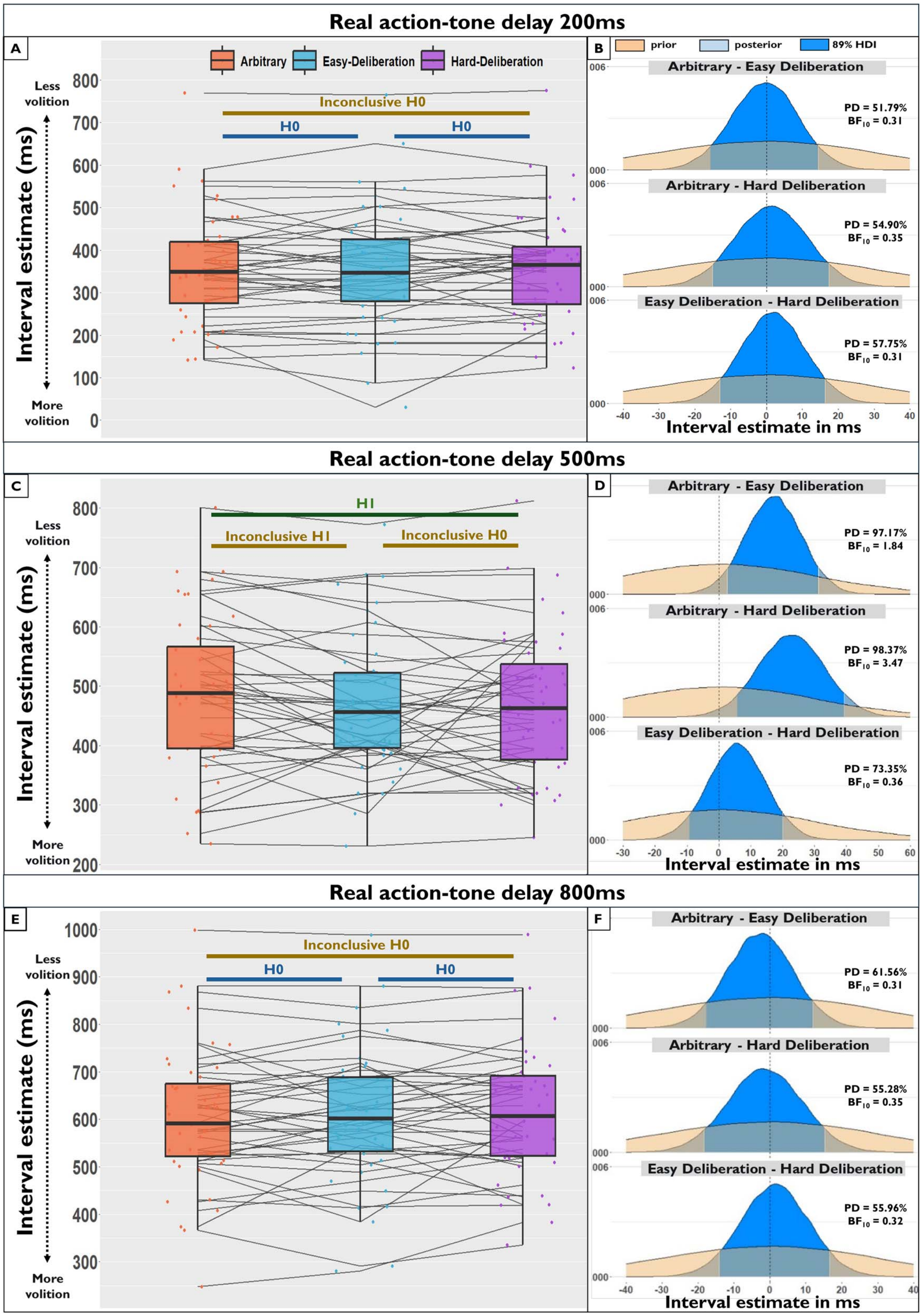

Figure 8. TB measured with interval estimation, separated by real action-tone delays. (A, C, E) Similar as Fig. 2A. H_0 represents evidence for similarity, H_1 for difference, inconclusive $\mathbf{H_1}$ represents inconclusive evidence for H_1 (i.e. PD above 95% and HDI89% not overlapping 0, but BF_{10} inconclusive) and inconclusive H_0 represents inconclusive evidence for H0 (i.e. PD below 95%, BF_{10} inconclusive, but RR_{IN} indicating a prior change of conclusion being more likely for H_0 than H_1. (B, D, F) Posterior analysis of the TB. Similar as Fig. 2B. The SD of the prior distribution (in orange) is 30.

influence the reward. The results indeed showed that participants increased their EE for deliberate decisions compared to arbitrary ones, which suggests that it was the goal of the decision that modulated the effort. However, contrary to our hypothesis, the

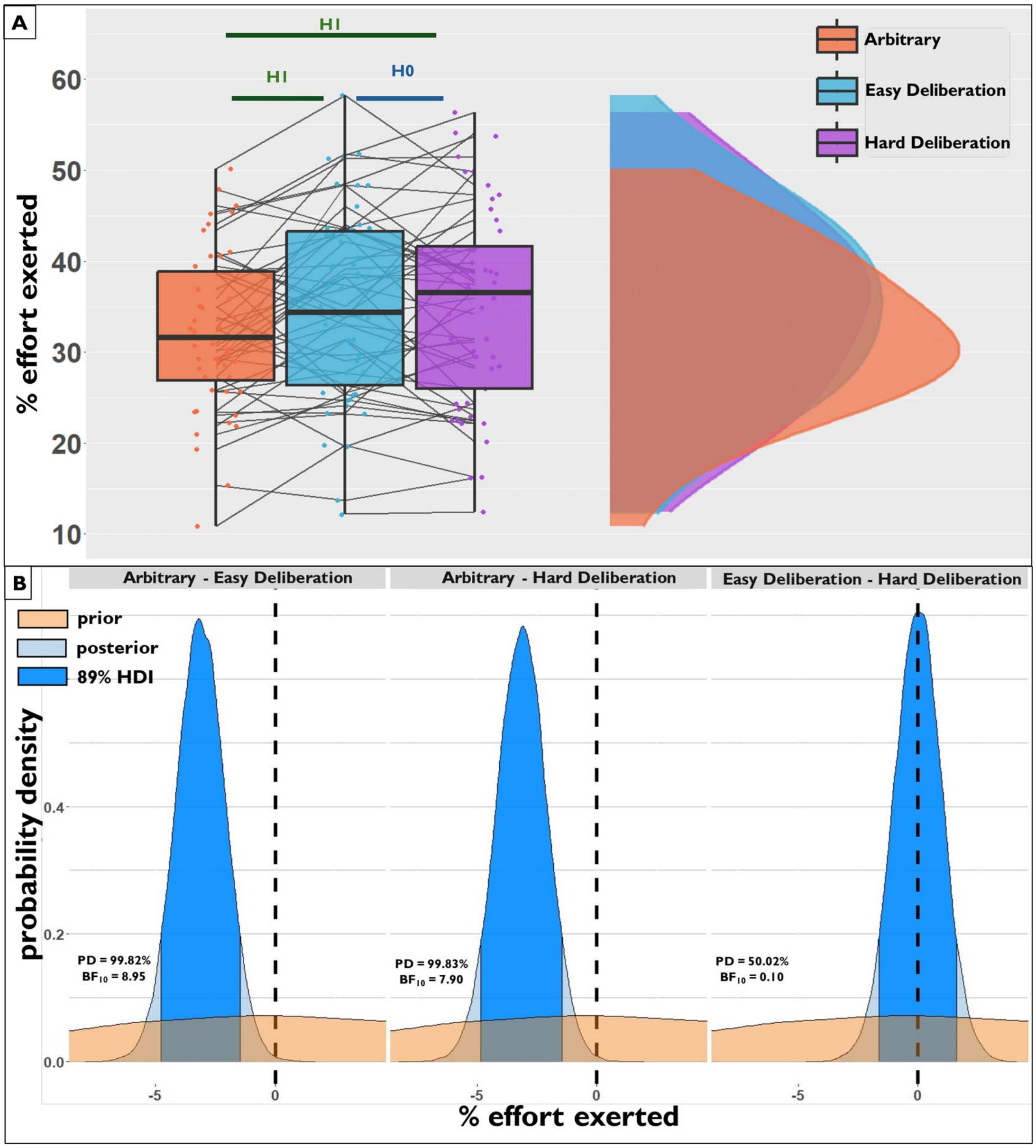

Figure 9. Effort exerted (EE). (A) Similar as Fig. 2A. H_0 represents evidence for similarity and H_1 for difference. (B) Posterior analysis of the EE. Similar as Fig. 2B. The SD of the prior distribution (in orange) is 10.

degree of deliberation did not influence the EE. If anything, our results indicate similar EE between the Easy-Deliberation and Hard-Deliberation conditions. Some previous work suggests that the feeling that "I" am exercising a quantitative effort, be it mental or physical, to produce an act (known as the sense of effort) is related to volition or is even a central process of volition (Lafargue and Sirigu 2006, Pacherie 2008, Lafargue and Franck 2009). Furthermore, the more effort is associated with making a decision, the more the act seems to be perceived as volitional (Lafargue and Franck 2009). Our results thus seem to indicate that goal-directed actions require more resources and therefore involve more effort than arbitrary actions. However, increased deliberation does not appear to result in greater effort. As far as we know, ours is the first study that investigates the relation between volition and the physical resources allocated to the action. Future studies are needed to better understand the mechanisms involved in the allocation of resources for meaningful vs meaningless actions and to understand the role of motivation. A previous study indeed found that motivation interacts differently with effort exerted during the choice and the execution phase of a decisional process, with motivation playing a greater role during the choice phase (Ludwiczak et al. 2020). This result could indicate that motivation might play a role in the effort exerted when the choice and the execution are not teased apart, which is the case in our study. Future studies would be needed to test this further. Our results link volition and the effort or resources required to carry out the action (i.e. willpower) (Baumeister et al. 2018), including as part of attentional, motivational, or memory processes (Achtziger and Gollwitzer 2018, Inzlicht and Friese 2019).

While our study resulted in clear and reliable differences between the conditions, with Hard Deliberate resulting in most deliberation, Easy deliberate in less, and Arbitrary in least, future studies could investigate even larger contrasts between the conditions—e.g. with more features that vary between the easier- and harder-deliberation conditions. Another limitation of our study is the sampling rate of the handgrips that had produced a possible jitter of up to 100 ms, which may have reduced the effect between the conditions. Future studies could use electromyography (EMG) to achieve better time precision in capturing the actions made by the participants. An inherent limitation of comparing deliberate and arbitrary decisions is that the latter might involve preplanning the movement (before stimulus onset or even before trial onset), as no stimulus-related information would affect the movement in that condition. We posit that such preplanning is more likely to increase RP, in contrast to our results. Nevertheless, an interleaved (rather than blocked) design could mitigate the effect of this issue. Though we have found interleaved arbitrary and deliberate decisions challenging and confusing for the participants. Also, such a design leaves open the possibility of contamination, especially between consecutive trials of different types. Nevertheless, future studies might design a proper interleaved paradigm or find other ways to manufacture arbitrary decisions devoid of preplanning. Finally, the findings of this study are limited by the context in which it was applied. It is hard to claim that all types of deliberation are similar; thus, other studies are needed to generalize these findings. For example, we focused on positive outcomes to increase the level of deliberation. Future studies could also manipulate complexity using negative outcomes (e.g. reduced rewards).

Conclusion

To conclude, our results indicate that whether a decision has a goal or not (i.e. whether it is deliberate or arbitrary) influences the volitional aspect of the action associated with that decision, as assessed by a range of measures: the self-reported feeling of volition (SoV), brain activity (RP), implicit mechanisms (TB), and EE. Interestingly, all our measurements indicate similarity between different levels of deliberation. Our results, therefore, suggest that it is not the complexity of the deliberation prior to the action that makes it more volitional, but rather whether the decision serves a meaningful goal. Finally, in the present study, we also introduced a new implicit measure of volition—EE, as measured gradually and automatically via handgrips. EE successfully aligned with other measures of volition and should therefore prove useful in future studies of volition.

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Author contributions

Guillaume P. Pech (Conceptualization [lead], Data curation [lead], Formal analysis [lead], Funding acquisition [lead], Investigation [lead], Methodology [lead], Visualization [lead], Writing—original draft [lead]), Emilie A. Caspar (Conceptualization [equal], Funding acquisition [equal], Methodology [equal], Supervision [equal], Writing—review & editing [equal]), Elisabeth Pacherie (Conceptualization [equal], Funding acquisition [equal], Methodology [equal], Writing—review & editing [equal]), Axel Cleeremans (Conceptualization [equal], Funding acquisition [equal], Methodology [equal], Resources [lead], Supervision [equal], Writing—review & editing [equal]), and Uri Maoz (Conceptualization [equal], Funding acquisition [equal], Methodology [equal], Project administration [lead], Supervision [equal], Writing—review & editing [equal])

Supplementary data

Supplementary data is available at *Neuroscience of Consciousness* online.

Conflict of interest

None declared.

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Data availability

All the codes for the task and analysis are available on OSF with the material, the runned Bayesian models and the data (https://osf.io/udgnw/).

Declaration of generative AI

During the preparation of this work, the authors used GPT-4 for edits. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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