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Are you sure about your choice? EEG correlates of decision confidence before and after reframing

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ABSTRACT

Decision–making is pivotal in everyday life and can often be influenced by the framing effect, whereby the presentation of information influences decisions. This study investigates how reframing affects decision confidence in young adults. 46 healthy participants performed a resistance–to–reframe task, making work–related decisions by selecting the best option from four alternatives and rating their confidence before and after a negative reframing. Behavioural data and EEG frequency bands (delta, theta, alpha, beta and gamma) were recorded. Reframing significantly affected decision confidence, especially initially, by increasing the complexity of choices. Increased reaction times after reframing reflected greater cognitive complexity due to perspective changes. EEG results showed significant activity in the delta, theta and alpha bands, with higher activation in the right frontal area (AF8). Reframing affects decision–making by increasing cognitive workload and modulating confidence, suggesting the role of executive functions and metacognition in managing uncertainty.

Keywords: decision-making; cognitive bias; reframe; confidence assessment; EEG frequency bands

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1. INTRODUCTION

A core principle of rational decision–making is the maintenance of logical consistency across choices, regardless of how they are presented. However, as far as human decision–making is concerned, research indicates that it is susceptible to biases influenced by context and risk and substantial empirical evidence challenges the notion that human decisions remain unaffected options are described (McNeil et al., 1982; Tversky & Kahneman, 2000). For instance, a seller might label juice as "95% sugar–free" rather than "5% of sugar" to make it more appealing to consumers and, in turn, this frame may affect consumers' choice, even though both statements convey identical information.

This tendency for decisions to be swayed by how information is framed, known as the "framing effect", has been extensively documented in various decision–making scenarios (Tversky & Kahneman, 1981). Individuals differ significantly in their susceptibility to decision–making biases, though the underlying causes of this variability remain unclear. Notably, these biases are observed across different cultural contexts (Kahneman & Tversky, 1979; Sharp & Salter, 1997) and continue to persist despite efforts to mitigate them through training (McNeil et al., 1982). Thus, despite in decision–making studies, flexibility, perspective–changing, and adaptability to change are regarded as positive qualities characterizing expert decision–makers (Laureiro-Martínez & Brusoni, 2018), also maintaining one's decision–making confidence, regardless of the influence of context (i.e., a different frame or a new positive/negative reframe) can also be deemed as advantageous.

In neuroscience literature, although still limited, neuroimaging research with functional magnetic resonance imaging (fMRI) has begun to explore the neural mechanisms that underlie framing–related biases in decision–making. In particular, such works exploited classical gambling tasks proposing different frames of gain and losses and have found that the amygdala exhibits heightened activation when decisions align with the framing of an option — meaning that positively framed choices (or "gain choices") are more likely to be accepted, whereas negatively framed ones (or "loss choices") are more likely to be avoided. Conversely, the anterior cingulate cortex (ACC) and regions of the dorsomedial and dorsolateral prefrontal cortex display increased activity when individuals contrast the framing effect (De Martino et al., 2006; Roiser et al., 2009). Moreover, genetic variations in susceptibility to framing biases have been found to be reflected in differential amygdala activation and its connectivity with the ACC and medial prefrontal cortex (Roiser et al., 2009). More broadly, neuroscience research is increasingly focusing not only on the effects of decision–making biases but also on individual neurophysiological susceptibility to these biases and the neural mechanisms underlying resistance to them. For example, some studies have highlighted how positive/favourable vs. negative/unfavourable feedback from the environment can influence the sense of efficacy associated with the choice made (Cohen et al., 2007; Crivelli et al., 2023). Others (Burmeister & Schade, 2007; Samuelson & Zeckhauser, 1988), On the contrary, have highlighted the need to seek consistency regardless of the quality (positive or negative) of the feedback, referring to the concept of "status quo bias".

However, less is known about how framing influences decision confidence, defined as the metacognitive ability to reflect on one's choice and reassess one's judgment after a shift in framing. Starting from the studies of Fleming and colleagues (Fleming et al., 2012), there is a close link between decision–making and metacognition if we consider confidence as a monitoring signal that can affect other cognitive processes. In this sense, metacognition is closely related to the executive function, which includes planning, problem–solving, working memory and performance monitoring (Balconi, 2023; Balconi, Angioletti, et al., 2020; Balconi et al., 2025)

With the aim of testing the resistance to framing effect, we recently examined if professionals of different seniority levels can resist contextual biases, specifically to reframing and decoy effects during decision–making tasks (Angioletti et al., 2024), Also, we explored if different decision–making styles predicted a higher resistance to reframing. Participants completed two tasks designed to assess their resistance to cognitive biases: the Resistance to Reframe Task (RRT) and the Resistance to Alternatives Task (RAT), both of which were characterized by ecologically valid organizational situations. Reframing was here operationalized with a situation which was later presented from another perspective, particularly a negative perspective (i.e., a negative reframing situation). The results showed that professionals, regardless of their seniority, were generally able at resisting the reframing effect presented in the task. However, the study also highlighted that individuals with specific decision–making styles can be more vulnerable to these influence strategies.

Despite this work being one of the first to examine resistance to reframing in an applied context on a sample of professionals and to calculate behavioral indices assessing their overall resistance to reframing (Angioletti et al., 2024), it lacks the analysis of other key aspects relevant to the neuroscience of decision–making. First, it did not explore the dynamics of decision–making when reframing is presented, which is crucial for understanding how cognitive processes unfold in real time and how individuals integrate new information when revising their choices. Secondly, the changes in confidence levels regarding one's decision before and after reframing were not measured, even though this aspect is essential for assessing the stability of decisions (Krumpe et al., 2019) and the extent to which reframing influences not only choices but also the certainty with which they are made. Thirdly, it did not explore changes in neurophysiological activity related to the impact of reframing on decision confidence, which is important for identifying the neural mechanisms underlying resistance to reframing and determining whether specific brain responses predict greater susceptibility or resilience to its effects. These points highlight some gaps in the literature on the effects of reframing on confidence in decision–making and the neural processes underlying this phenomenon.

Focusing on the last point, it should be noted that, compared to neuroimaging techniques (such as fMRI), electroencephalography (EEG) has been widely employed as a valid, easy–to–use, low cost and with high temporal resolution technique to investigate the neurophysiological responses supporting decision–making process. It could also provide valuable insights into the neural dynamics related to decision–making biases such as framing and reframing effects.

To the best of our knowledge, no previous neuroscientific studies exploited EEG to investigate the neurophysiological correlates of reframing, providing valuable insights into the neural dynamics accompanying the confidence in one's decision under such decision bias. However, several studies have demonstrated the value of EEG in providing information about cognitive and emotional processing involved in decision–making and decision confidence by analyzing the functional roles and the localization of the different EEG frequency bands (delta, theta, alpha, beta and gamma)(Balconi & Lucchiari, 2005b, 2005a; Balconi & Pozzoli, 2005b; Boldt & Yeung, 2015; Krumpe et al., 2019; Selimbeyoglu et al., 2012).

For instance, delta band is considered a marker of implicit monitoring (Balconi & Lucchiari, 2005a, 2005b; Balconi & Pozzoli, 2005a; Harmony, 2013) and has been demonstrated to be linked to attentional cognitive processes, the formation of explicit and declarative memories, as well as motivation and emotional states (Balconi et al., 2020; Knyazev, 2012). Similarly, theta band has been linked to cognitive control (Cavanagh & Shackman, 2015) and increased strongly following errors compared to correct responses, which is crucial for decisions that involve integrating and controlling actions (Balconi et al., 2020) and act as a "startle signal" for behavioral adaptation (Beste et al., 2023). With specific reference to decision confidence, both delta and theta bands' increase was found to signal subjective uncertainty about the response in decision–making tasks (Selimbeyoglu et al., 2012). Alpha band has been linked to attentional processes and cognitive demand (Davis et al., 2011; Klimesch, 2012). Furthermore, according to the phenomenon of cortical idling, the increase of alpha activity would reflect a state of cortical inactivity or a reduction in cognitive processing (Pfurtscheller et al., 1996). Beta band is associated with heightened attention and vigilance, supporting conscious, goal–oriented decision–making (Engel & Fries, 2010). Lastly, gamma band activity is linked to a complex interplay of mental fatigue, sustained attention, vigilance, and enhanced cognitive performance (Borghetti et al., 2021; Herrmann et al., 2010). Nonetheless, EEG markers for the effects of reframing on confidence in decision–making have not yet been defined.

Thus, to explore these aspects, we developed the current study which aims at exploring the behavioural and EEG correlates of the influence of reframe on decision's confidence dynamics. To do so, we asked a sample of healthy participants to complete a decision–making task, composed of two steps, in which they rated their confidence in their decisions before and after a reframing of the situation, highlighting negative consequences. Accordingly, confidence scores and reaction times (RTs) were collected to measure behavioural markers of confidence in one's decision before and after the reframing in the two decision–making steps.

Additionally, RTs served as an indirect indicator of the cognitive workload and effort involved in the decision–making process (Kramer, 2020; van Winsum, 2018). Throughout the whole task, EEG activity was also continuously recorded to allow the analysis of EEG frequency bands (delta, theta, alpha, beta and gamma) as neurofunctional markers of the process.

Building on these premises, our first hypothesis regarding behavioural data posits that participants will demonstrate significantly higher confidence in their decisions before reframing at each step. This expectation arises from the reframing effect, which prompts individuals to reassess their choices based on a newly introduced perspective, potentially altering their initial confidence assessment.

Secondly, we anticipate that RTs will be significantly longer when participants assess their confidence after reframing. This is because the cognitive demands associated with reconsidering both their decision and their confidence within a new frame of reference are expected to increase.

Finally, we predict that confidence assessment levels will be lower, and RTs will be longer in the second compared to the first step of the task. The heightened awareness of the task's growing complexity may lead participants to engage in deeper reflection, thereby influencing both their confidence and the time required to express it.

Regarding EEG data, since the increase of low frequencies (delta and theta bands) marks subjective uncertainty during decision–making tasks (Selimbeyoglu et al., 2012), we expect an increase of these EEG frequencies during confidence assessments after the reframing in both steps of the tasks.

Specifically, we also expect increased delta power in frontal regions during the final confidence assessment compared to earlier confidence assessments, based on the role of delta oscillations in implicit monitoring and attentional processes (Harmony, 2013), which may become more pronounced when participants reach higher awareness of their decision after reframing.

Additionally, given the role of frontal theta oscillations in cognitive control and conflict resolution (Cavanagh & Shackman, 2015), we expect theta power to be higher in frontal regions compared to temporo–parietal sites, reflecting the engagement of prefrontal areas in managing cognitive conflict during the task.

We predict a significant decrease in alpha power after reframing, consistent with its association with cognitive effort and attentional demands and the phenomenon of cortical idling, for which lower alpha band power marks high cognitive activation (Pfurtscheller et al., 1996). Moreover, we anticipate that alpha power will recover in the second step, perhaps reflecting adaptation to the increased cognitive complexity of the task.

Since high–frequency bands oscillations (beta and gamma bands) are linked to attention and goal–directed decision–making, we hypothesize that they will be modulated by confidence assessments. Specifically, we expect higher beta and gamma activity in frontal sites during later confidence assessments compared to earlier ones, as participants adjust their decision–making strategies.

2. METHOD

2.1 Participants

A sample of 46 healthy individuals (Mean age = 22.1; DS = 2.27; 26 males), voluntarily took part in the study, without receiving any financial compensation for their participation. An a priori power analysis was conducted using G*Power (version 3.1.9.7) to determine the required sample size for the planned repeated–measures analysis of variance (ANOVA). This analysis indicated that, for a effect size f of 0.25, an alpha level of 0.05, and a statistical power of 0.95, a minimum of 36 participants was necessary to achieve reliable results. Estimating a 20% of participants drop out, we recruited ten more participants.

Participants were recruited by the following exclusion criteria: severe levels of depression and perceived stress, history of psychiatric or neurological disorders, abnormal short and long–term memory or low global cognitive functioning, and undergoing treatment with psychoactive drugs, which could affect cognitive decision–making processes. Participants provided written informed consent, and they were informed of their right to withdraw at any time. The study was authorized by the Ethics Committee of the Department of Psychology at the Catholic University of the Sacred Heart, Milan, Italy (approval code: 125/24 - Valutare il Decision–Making: consapevolezza e metacognizione decisionale; approval date: 23 July 2024) and according to the GDPR – Reg. UE 2016/679 and its ethical guidelines) and was conducted following the Declaration of Helsinki principles (2013) and the GDPR (Reg. EU 2016/679) and its ethical guidelines.

2.2 Procedure and experimental task

The experiment was performed in a quiet, designated room, ensuring a distraction–free environment. Participants were seated comfortably in front of a computer, positioned approximately 80 cm away. Before beginning, written informed consent was obtained from participants to participate in the study, after which they were familiarized with the experimental setup and procedures.To start, an EEG device was fitted onto their heads to record 120 seconds of resting–state baseline activity. Following this, the participants were provided with detailed instructions on how to complete the RTT task. These instructions were delivered through a web–based survey and experiment–management platform (Qualtrics XM platform; Qualtrics LLC, Provo, UT, USA).

2.2.1 Resistance to Reframe Task (RRT)

In the RRT, participants engaged in two distinct decision–making steps. In each step, they were asked to put themselves in each situation in which they must decide and select the option they found most appropriate from a set of multiple choices.

Decision–making situation: during both steps, participants were presented with a situation depicting a critical workplace dilemma, requiring them to decide. For example, in the first step, they were presented with a decision–making situation in which they were told they were required to take part in a challenging decision alongside all the executives of their company.

Due to budget cuts, they must determine whether to shut down certain factories and lay off employees. Their company operates four plants and employs a total of 6,000 workers. Then four workers working in the company facilities were introduced to them (showing them a picture of the four factories along with the four workers). Their task was to decide which of the four plants should remain open by selecting one of the available options.

First Confidence Assessment (CA1): once they made their choice, participants rated their confidence in their decision using a Likert scale ranging from 1 to 5, where 1 indicated “not confident at all” and 5 represented “completely confident”.

Reframing of the situation: next, participants were presented with a negative reframing of the situation, emphasizing the negative consequences of their decision. They were told that based on the choice they made, the employees at the other factories would lose their jobs.

Second Confidence Assessment (CA2): after receiving this new additional information, participants were asked to reassess their confidence in their decision again using the same 1–to–5 Likert scale.

Following the completion of the first step, participants proceeded to the second one, which followed the same structure. Confidence assessment was collected also for the second step (respectively, CA3 and CA4). For both steps of the task, confidence scores (ranging from 1 to 5) and RTs were recorded during CA1, CA2, CA3, and CA4. EEG activity was then recorded throughout the task. The whole experimental procedure lasted approximately 15 minutes (Figure 1).

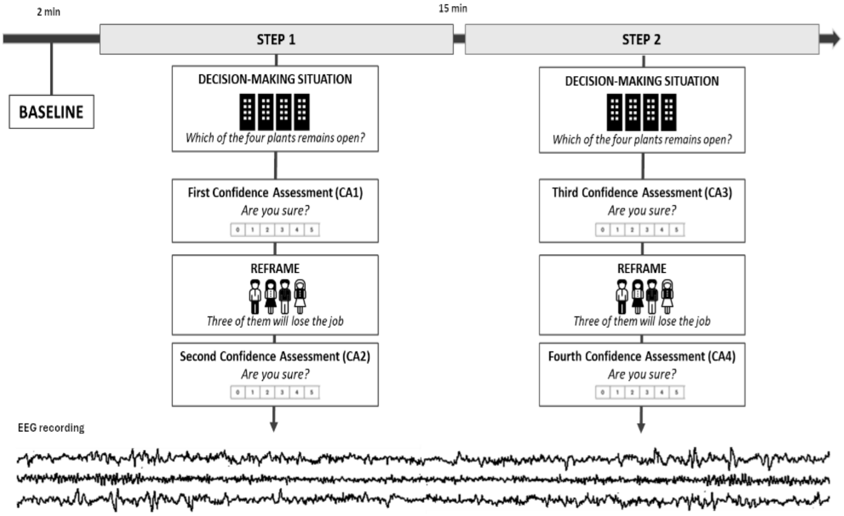

Figure 1. Description of the experimental procedure and RRT

2.2.2 EEG data acquisition

The EEG wearable MUSE™ headband (version 2; InteraXon Inc., Toronto, ON, Canada) was used to collect data about EEG brain activity (during the resting state baseline and the RRT). This device measures EEG activity through use of an accelerometer, a gyroscope, a pulse oximeter, and seven electrodes composed of conductive materials, specifically silver and silicone rubber. Three electrodes function as references, while the other four record activity from the frontal and temporoparietal regions, following the international 10–20 system. Specifically, electrodes were positioned in the right and left hemispheres: AF7 and AF8 for the frontal area, and TP9 and TP10 for the temporo–parietal area.

Data was sampled at 256 Hz with a 50 Hz notch filter, recorded through a system equipped with an accelerometer, gyroscope, and pulse oximetry, synchronized via the Mind Monitor mobile app over Bluetooth. Participants were asked to minimize eye movements and blinking to limit artifacts, which were later manually identified and removed by visual inspection. Mind Monitor application generates data output in .csv from which we removed artifacts including blinks, jaw clenching, and general movement (less than 1% of data was removed).

Data segments were rejected within ±1 second windows around the time of each blink detection to ensure data quality. Power Spectral Density (PSD) was computed from the EEG data using Fast Fourier Transformation for the delta (1–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz), and gamma (30–44 Hz) bands. Mind Monitor automatically analyzes the raw data by employing a fast Fourier transform, which enables the extraction of brain waves across various frequency bands. The algorithm used is proprietary from Mind Monitor app and not shared.

Task–related variations in EEG power values were computed as follows:

$$TRPSD = ((PSDtask - PSDopen{-}bl)/PSDopen{-}bl)$$

where TRPSD represents task–related variations in EEG power values for each frequency band and each RoI, PSDtask represents EEG power values during the task conditions for each frequency band, and PSDopen-bl represents EEG power values in eye–open baseline for each frequency band.

2.3 Data analysis

Behavioral data: concerning behavioral data analyses, two ANOVAs were conducted with Confidence Assessment (4: CA1, CA2, CA3, CA4) as the within–subject factor and the behavioural scores (confidence response score and RTs) as dependent variables.

EEG data: regarding EEG, five repeated measure ANOVAs with Confidence Assessment (4: CA1, CA2, CA3, CA4) and Electrode (4: TP9, AF7, AF8, TP10) as independent within–subject factors were applied to each frequency band as dependent variable (delta, theta, alpha, beta and gamma). Pairwise comparisons were applied to the data in case of significant effects. Simple effects for significant interaction were further checked via pairwise comparisons, and Bonferroni correction was used to reduce multiple comparisons potential biases. For all the ANOVA tests, the degrees of freedom were corrected using Greenhouse–Geisser epsilon where appropriate. Furthermore, the normality of the data distribution was preliminarily assessed by checking kurtosis and asymmetry indices. The normality assumption of the distribution was supported by these preliminary tests. The size of statistically significant effects was estimated by computing partial eta-squared (η2) indices. All statistical analyses were performed using Jamovi (version 2.6.22; The Jamovi Project, 2022).

3. RESULTS

3.1 Behavioural result

The ANOVAs for the behavioral confidence score showed a main effect for Confidence Assessment (F [3,75] = 8.54, $p < .001$, $\eta^2 = .072$). Pairwise comparisons revealed higher confidence in the choice in CA1 compared to CA2 ($p = .011$), and in CA3 compared to CA2 ($p < .001$) and CA4 ($p = .008$). Secondly, a main effect for Confidence Assessment was also found for the RTs (F [3,84] = 44.9, $p < .001$, $\eta^2 = .462$). Pairwise comparisons revealed higher RTs for CA1 compared to CA3 ($p < .001$), as well as higher RTs in CA2 compared to CA1 ($p < .001$), CA3 ($p < .001$) and CA4 ($p < .001$). Also, higher RTs were found in CA4 compared to CA3 ($p = .005$).

3.2 EEG results

Analysis of EEG data revealed statistically significant results for delta, theta, alpha, and beta waves, but not for gamma waves.

3.2.1 Delta

Regarding the delta frequencies, a main effect on Electrodes was found (F [3,135] = 3.80, $p = .012$, $\eta^2 = .032$), for which higher values were found for AF8 (M = 0.405, SE = 0.084), compared to AF7 (M = 0.214, SE = 0.060), TP9 (M = 0.171, SE = 0.051) and TP10 (M = 0.217, SE = 0.057), but did not survive multiple comparisons correction. Moreover, it was observed a significant interaction effect Confidence Assessment × Electrodes (F [9,405] = 4.07, $p < .001$, $\eta^2 = .010$) with higher delta values in AF8 during CA4 compared to TP10 during CA2 ($p = .014$) (Figure 2a–b).

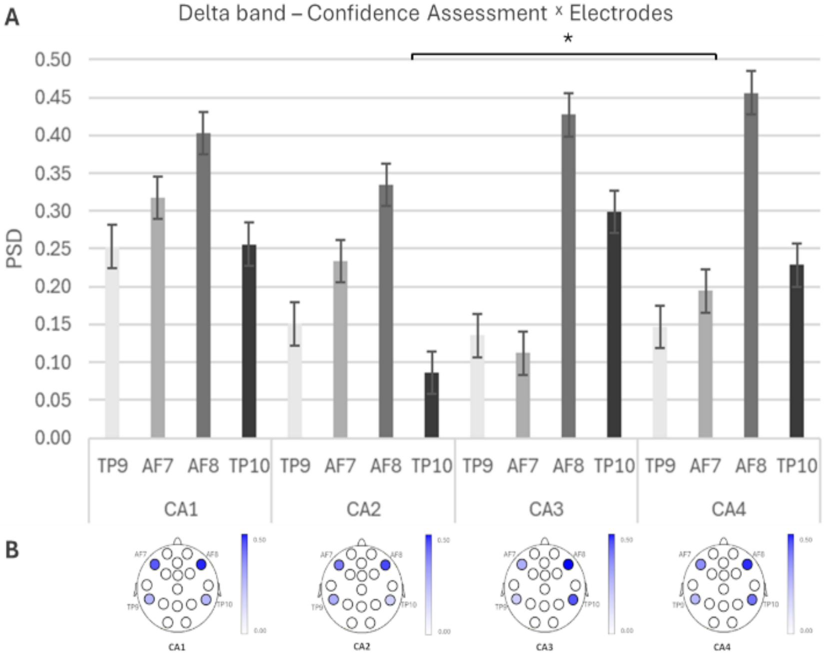

Figure 2a–b. EEG delta band results. (a) The bar charts show significant differences for the delta band in Confidence Assessment × Electrodes, with higher values in AF8 during CA4 compared to TP10 during CA2. Bars represent ± 1 standard error and stars (*) mark statistically significant comparisons (p ≤ .005). (b) The more intense color in the rendering of the head (below) represents the increase in EEG power at the specific EEG electrodes

3.2.2 Theta

As for the theta band, a main effect on Confidence Assessment was observed (F [3,135] = 2.67, p = .050, η^2 = .005), with greater theta band values in CA1 compared to CA2 (p = .002). It was found also a main effect Electrodes (F [3,135] = 5.36, p = .002, η^2 = .042), for which pairwise comparisons revealed higher theta values in AF8 than in TP9 (p = .022). Furthermore, a significant interaction effects the Confidence Assessment × Electrodes was reported (F [9,405] = 1.92, p = .048, η^2 = .005). Pairwise comparisons revealed higher theta values in AF8 during CA4 compared to CA2 in TP9 (p = .015), CA2 in TP10 (p = .015) and CA3 in AF7 (p = .043) (Figure 3a–b).

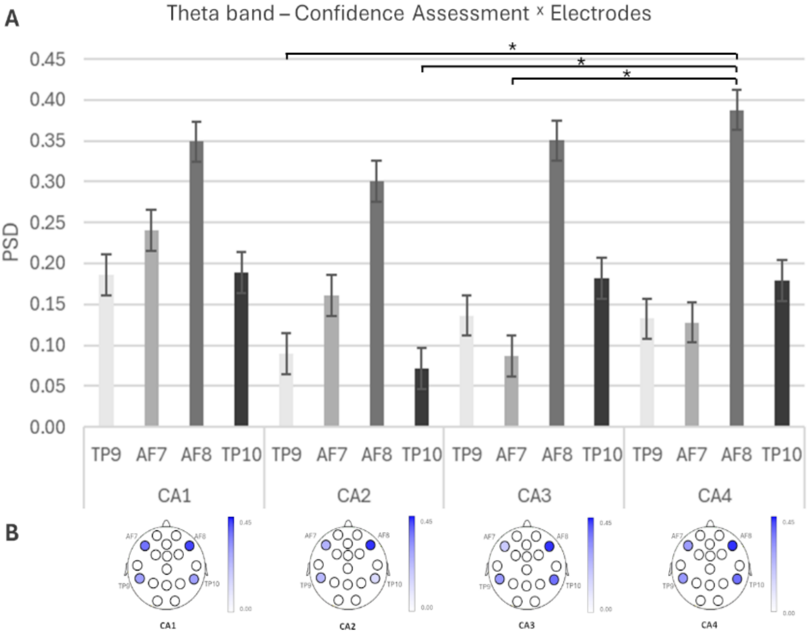

Figure 3a–b. EEG theta band results. (a) The bar charts show significant differences for the theta band in Confidence Assessment x Electrodes, with higher values in AF8 during CA4 compared to CA2 in TP9 and TP10, and CA3 in AF7. Bars represent ± 1 standard error and stars (*) mark statistically significant comparisons ($p \leq .005$). (b) The more intense color in the rendering of the head (below) represents the increase in EEG power at the specific EEG electrode

3.2.3 Alpha

Concerning alpha activity, the results revealed a main effect for Confidence Assessment (F [3,135] = 5.616, p = .001, η^2 = .007). Pairwise comparisons showed higher alpha mean values in CA1 compared to CA2 (p = .002). Also, greater alpha mean values were found in CA3 (p = .046) and CA4 ($p.$ = .004) compared to CA2 (Figure 4).

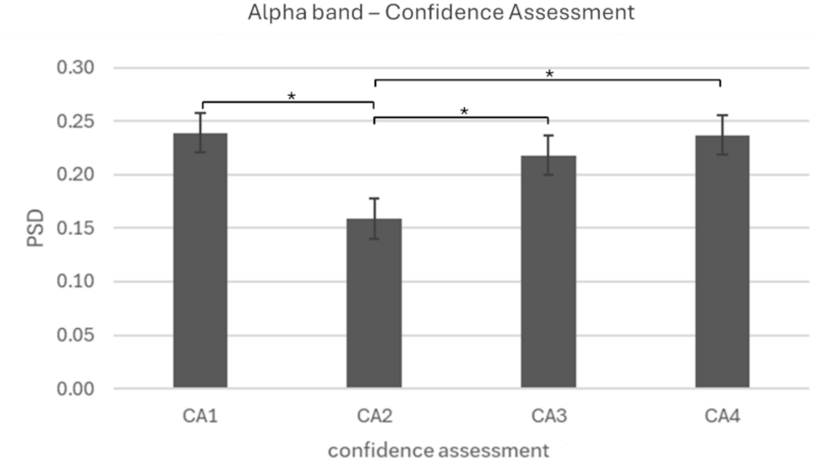

Figure 4. EEG alpha band results. The bar charts show significant differences for the alpha band in Confidence Assessment step, with higher activity in CA1 compared to CA2, and in CA3 and CA4 compared to CA2. Bars represent ± 1 standard error and stars (*) mark statistically significant comparisons ($p \leq .005$)

3.2.4 Beta

In relation to the beta waves, it was noted a main effect Electrodes (F [3,135] = 2.83, p = .041, η^2 = .022); for which higher values were found for AF8 (M = 0.239, SE = 0.066), compared to AF7 (M = 0.292, SE = 0.089), TP9 (M = 0.119, SE = 0.044) and TP10 (M = 0.161, SE = 0.046), but did not survive multiple comparisons correction (Figure 5 a–b).

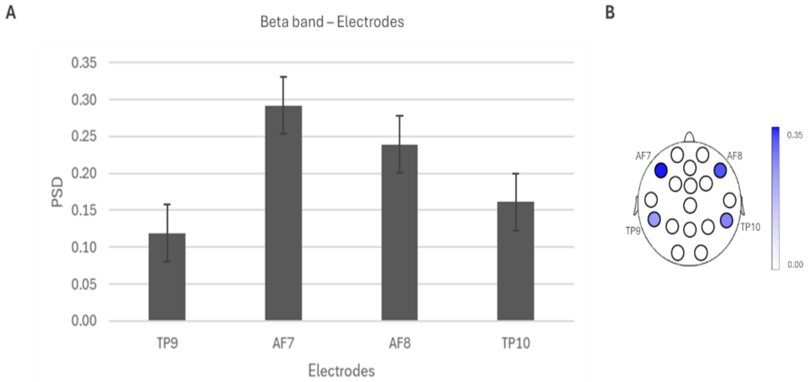

Figure 5a–b. EEG beta band results. (a) The bar charts show significant differences for the beta band in Electrodes, with higher values in AF8 compared to AF7, TP9, and TP10. Bars represent ± 1 standard error. (b) The more intense color in the rendering of the head (on the right) represents the increase in EEG power at the specific EEG electrode

4. DISCUSSION

The present study investigated the behavioural and EEG correlates of the influence of reframing on decision–making in a sample of healthy participants. Participants were asked to complete a decision–making task based on a real–life situations while EEG activity was monitored. The task consisted of two steps in which participants rated their confidence in the decision before and after the presentation of a reframe emphasizing the negative consequences of the choice.

The results contribute to the growing interest in decision–making and provide insights into the relationship between cognitive bias, metacognition and reframing.

On one hand, concerning the behavioural data, the analysis focused on the assessment of decision confidence and RTs In line with our hypotheses, participants showed greater confidence before the reframe in both steps, suggesting that the reframe can interrogate the initial choice and encourage reconsideration of the decision in the light of new information or a contextual change, especially when negatively connoted (Peeters & Czapinski, 1990; Tversky & Kahneman, 1981). However, the greater confidence found in the first confidence assessment of the second step may reflect a familiarity effect with the task resulting from exposure to the previous step or, at the same time, a possible attempt to re–establish confidence in one's decision–making ability after the reframe. In terms of RTs, an increase after the reframe is observed in both steps, suggesting that reconsidering one's decision requires more cognitive effort, as participants must integrate the new frame of reference with the original decision. In addition, higher RTs in the first step than in the second step support the hypothesis of a familiarity effect: lower demand for cognitive effort in the evaluation of the second step could be due to experience.

Similarly, significantly higher RTs in the first confidence assessment than the others may indicate a higher initial cognitive demand to restructure one's choice, with a progressive reduction in RTs in the subsequent confidence assessment as evidence of adaptation to the task.

These behavioural results highlight the impact of reframing on decision–making and metacognition. In particular, reframing affects confidence in the decision, with individuals resisting reorientation in similar repeated situations, resulting in increased processing time, as sign of increased cognitive load (Kramer, 2020; Tversky & Kahneman, 1981; van Winsum, 2018).

On the other hand, analysis of the EEG data revealed significance in the delta, theta, and alpha bands, providing insight into the modulation of brain activity during the task. At a general level, greater right frontal activation was observed, particularly in the delta and theta bands, than in the temporo–parietal areas. This EEG finding supports the hypothesis that low–frequency bands are involved in executive control and uncertainty management related to the decision–making task (Cavanagh & Shackman, 2015; Harmony, 2013).

Furthermore, these results support the idea that reframe effects involve areas dedicated to ambiguity management and cognitive flexibility, here understood as the ability to use new adaptive decision–making strategies.

Specifically, the increase in activity in the delta band follows a specific pattern in the different steps of the task. After the reframe of the first step, the unexpected restructuring of information activates TP10, located in the right temporo–parietal junction, an area involved in the detection of expectation violations (Corbetta et al., 2008; Krall et al., 2015). However, after the reframe of the second step, although the restructuring is still unanticipated, there is increased activity in AF8, suggesting greater involvement of executive control to manage the conceptual change already experienced. Overall, these results suggest that as experience with the task increases, greater cognitive control and higher levels of adaptation become essential.

As regards the theta band, the analysis of the evolution of the task reveals a change in the distribution of theta activity. Indeed, in the first step, after the reframe, a general increase in activity is observed in the temporo–parietal region, whereas after the reframe of the second step, activation is higher in AF8. Additionally, a similar trend is found in the second step, when comparing the initial confidence assessment and the confidence assessment after the reframe, with an increase in activity in AF7. These results may be explained by research showing that the temporo–parietal junction (which includes both the left and right temporo–parietal areas) is known to be involved in empathy and mentalization processes (Canessa et al., 2012; Luyten & Fonagy, 2015; Saxe & Wexler, 2005). Therefore, in this decision confidence task, the presentation of a negative valence reframe may have stimulated implicit monitoring by activating internal feedback loops that are used to assess the validity and relevance of decisions in terms of their possible effects. Taken together, these EEG results suggest that the theta band plays a key role in the adaptation of decision–making. Furthermore, the influence of reframing appears to require greater cognitive effort to rework and integrate the new information, as evidenced by increased frontal activity.

Concerning the alpha band, a reduction in activity was observed after the first reframe compared to the first confidence assessment of the first step; in addition, this reduction is also significant compared to both of the second step's confidence assessments, suggesting a greater cognitive effort in response to the first reframe, with subsequent adaptation to the task and a reduction in cognitive demand in later stages through the development of more efficient strategies for dealing with the reframe. Therefore, alpha increases in the second step may reflect a reduced need for active processing, facilitated by increased task familiarity and reduced cognitive load associated with decision reframing.

Indeed, the reduction in alpha would reflect an increased cognitive load in response to the uncertainty introduced by the first reframe, consistent with the role of this band in decision–making processes (Keil et al., 2006; Runnova et al., 2021). Thus, this finding is consistent with studies showing a reduction in alpha in decision–making scenarios as a response to the need to process new information or revise previous evaluations (Balconi et al., 2024; Başar & Güntekin, 2012; Cona et al., 2020).

Finally, as regards beta activity, greater activation was observed in the right frontal lobe compared to the left frontal lobe and to the temporo–parietal areas of both hemispheres, regardless of the steps of the task. This finding is consistent with evidence linking beta activity to processes of judgement, problem–solving and task concentration (Engel & Fries, 2010; Lin et al., 2011). Finally, right frontal activation suggests that the task requires adaptation of the decision–making process with the adoption of new modes of action. In addition, the predominance of frontal activity over temporo–parietal one suggests that the decision–making aspect of the task is more important than the social cognition aspect (Decety & Lamm, 2007).

In summary, the results showed that the negative reframe had a significant impact on decision confidence, requiring greater cognitive effort to evaluate choices, as reflected in increased reaction time and changes in confidence ratings. In addition, EEG analysis revealed increased activity in the delta, theta, and alpha bands, particularly in the right frontal lobe, suggesting involvement of brain areas associated with executive control and cognitive flexibility related to enhancing decisional adaptation. This finding highlights the interdependence between executive functioning and metacognition, both of which are supported by activation of frontal regions (Balconi et al., 2020; Cleeremans et al., 2007; Fleming, 2024).

Despite the study's providing interesting data, however, it is important to consider some possible limitations. The first limitation concerns the sample size, which, although moderate, may affect the generalizability of the findings to larger populations with different age groups or occupational categories. Future studies could recruit samples from various settings, such as different organizations, to explore differences in resistance or susceptibility to reframing.

Second, the study used a limited number of steps; future research should consider others to test reframing effects and potential familiarity biases.

It would also be valuable to examine whether positive reorientation influences trust and whether the observed EEG patterns generalize across different framing effects. To improve the understanding of brain activity during reframing and to strengthen the findings, other complementary neuroimaging techniques should be considered. In addition to EEG, which offers high temporal resolution, functional near–infrared spectroscopy (fNIRS) could provide insights into cortical activation and connectivity during decision–making. Finally, the study of emotional processes associated with decision confidence through measures such as cardiac or electrodermal activity could be informative. Future research may also benefit from analyzing individual differences or personality traits to assess whether certain profiles are more resistant to reframing.

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Ethics approval statement

The study's experimental design and procedures were reviewed and approved by the Ethics Committee of the Department of Psychology at the Catholic University of the Sacred Heart, Milan, Italy (approval code: 125/24—Valutare il Decision–Making: consapevolezza e metacognizione decisionale; approval date: 23 July 2024) and according to the GDPR – Reg. UE 2016/679 and its ethical guidelines. The participants provided their written informed consent to participate in this study.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The data presented in this study are available on request from the corresponding author due to ethical reasons for sensitive personal data protection (requests will be evaluated according to the GDPR – Reg. UE 2016/679 and its ethical guidelines).

Conflicts of interest disclosure

The authors declare no conflicts of interest.

REFERENCES

Angioletti, L., Acconito, C., Crivelli, D., & Balconi, M. (2024). Can professionals "keep the tiller straight" in organizations? Resistance to reframing and decoy alternatives in workplace decision–making. *Frontiers in Psychology*, 15. https://doi.org/10.3389/fpsyg.2024.1270012

Balconi, M. (2023). Why a dynamic multicomponential model of decision making: some milestones and a preliminary tool. *Neuropsychological Trends*, 33, 9–16. https://doi.org/10.7358/neur–2023–033–balm

Balconi, M., Allegretta, R. A., & Angioletti, L. (2025). Metacognition of one's strategic planning in decision–making: the contribution of EEG correlates and individual differences. *Cognitive Neurodynamics*, *19*(1), 4. https://doi.org/10.1007/s11571–024–10189–8

Balconi, M., Angioletti, L., & Crivelli, D. (2020). Neuro–Empowerment of Executive Functions in the Workplace: The Reason Why. *Frontiers in Psychology*, 11. https://doi.org/10.3389/fpsyg.2020.01519

Balconi, M., & Lucchiari, C. (2005a). Event–Related Potentials Related to Normal and Morphed Emotional Faces. *The Journal of Psychology*, *139*(2), 176–192. https://doi.org/10.3200/JRLP.139.2.176–192

Balconi, M., & Lucchiari, C. (2005b). In the face of emotions: Event–related potentials in supraliminal and subliminal facial expression recognition. *Genetic, Social, and General Psychology Monographs*, *131*(1), 41–69. https://doi.org/10.3200/mono.131.1.41–69

Balconi, M., & Pozzoli, U. (2005a). Comprehending Semantic and Grammatical Violations in Italian. N400 and P600 Comparison with Visual and Auditory Stimuli. *Journal of Psycholinguistic Research*, *34*(1), 71–98. https://doi.org/10.1007/s10936–005–3633–6

Balconi, M., & Pozzoli, U. (2005b). Morphed facial expressions elicited a N400 ERP effect: A domain-specific semantic module? *Scandinavian Journal of Psychology*, *46*(6), 467–474.https://doi.org/10.1111/j.1467–9450.2005.00478.

Balconi, M., Rovelli, K., Angioletti, L., & Allegretta, R. A. (2024). Working Memory Workload When Making Complex Decisions: A Behavioral and EEG Study. *Sensors*, *24*(17), 5754. https://doi.org/10.3390/s24175754

Balconi, M., Venturella, I., Fronda, G., & Vanutelli, M. E. (2020). Leader–employee emotional "interpersonal tuning". An EEG coherence study. *Social Neuroscience*, *15*(2), 234–243. https://doi.org/10.1080/17470919.2019.1696226

Başar, E., & Güntekin, B. (2012). A short review of alpha activity in cognitive processes and in cognitive impairment. *International Journal of Psychophysiology*, *86*(1), 25–38. https://doi.org/10.1016/j.ijpsycho.2012.07.001

Beste, C., Münchau, A., & Frings, C. (2023). Towards a systematization of brain oscillatory activity in actions. *Communications Biology*, *6*(1). 1–11. https://doi.org/10.1038/s42003–023–04531–9

Boldt, A., & Yeung, N. (2015). Shared Neural Markers of Decision Confidence and Error Detection. *The Journal of Neuroscience*, *35*(8), 3478–3484. https://doi.org/10.1523/jneurosci.0797–14.2015

Borghetti, L., Morris, M. B., Jack Rhodes, L., Haubert, A. R., & Veksler, B. Z. (2021). Gamma oscillations index sustained attention in a brief vigilance task. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *65*(1), 546–550. https://doi.org/10.1177/1071181321651122

Burmeister, K., & Schade, C. (2007). Are entrepreneurs' decisions more biased? An experimental investigation of the susceptibility to status quo bias. *Journal of Business Venturing*, *22*(3), 340–362. https://doi.org/10.1016/j.jbusvent.2006.04.002

Canessa, N., Alemanno, F., Riva, F., Zani, A., Proverbio, A. M., Mannara, N., Perani, D., & Cappa, S. F. (2012). The Neural Bases of Social Intention

Understanding: The Role of Interaction Goals. *PLoS ONE*, *7*(7), 1–11. https://doi.org/10.1371/journal.pone.0042347

Cavanagh, J. F., & Shackman, A. J. (2015). Frontal midline theta reflects anxiety and cognitive control: Meta–analytic evidence. *Journal of Physiology Paris*, *109*(1–3), 3–15. https://doi.org/10.1016/j.jphysparis.2014.04.003

Cleeremans, A., Timmermans, B., & Pasquali, A. (2007). Consciousness and metarepresentation: A computational sketch. *Neural Networks*, *20*(9), 1032–1039. https://doi.org/10.1016/j.neunet.2007.09.011

Cohen, M. X., Elger, C. E., & Ranganath, C. (2007). Reward expectation modulates feedback–related negativity and EEG spectra. *NeuroImage*, *35*(2), 968–978. https://doi.org/10.1016/j.neuroimage.2006.11.056

Cona, G., Chiossi, F., Di Tomasso, S., Pellegrino, G., Piccione, F., Bisiacchi, P., & Arcara, G. (2020). Theta and alpha oscillations as signatures of internal and external attention to delayed intentions: A magnetoencephalography (MEG) study. *NeuroImage*, *205*, 116295. https://doi.org/10.1016/j.neuroimage.2019.116295

Corbetta, M., Patel, G., & Shulman, G. L. (2008). The Reorienting System of the Human Brain: From Environment to Theory of Mind. *Neuron*, *58*(3), 306–324. https://doi.org/10.1016/j.neuron.2008.04.017

Crivelli, D., Allegretta, R. A., & Balconi, M. (2023). The "status quo bias" in Response to External Feedback in Decision–Makers. *Adaptive Human Behavior and Physiology*, *9*(4), 426–441. https://doi.org/10.1007/s40750–023–00230–1

Davis, C. E., Hauf, J. D., Wu, D. Q., & Everhart, D. E. (2011). Brain function with complex decision making using electroencephalography. *International Journal of Psychophysiology*, *79*(2), 175–183. https://doi.org/10.1016/j.ijpsycho.2010.10.004

De Martino, B., Kumaran, D., Seymour, B., & Dolan, R. J. (2006). Frames, Biases, and Rational Decision–Making in the Human Brain. *Science*, *313*(5787), 684–687. https://doi.org/10.1126/science.1128356

Decety, J., & Lamm, C. (2007). The Role of the Right Temporoparietal Junction in Social Interaction: How Low–Level Computational Processes Contribute to Meta-Cognition. *The Neuroscientist*, *13*(6), 580–593. https://doi.org/10.1177/1073858407304654

Engel, A. K., & Fries, P. (2010). Beta–band oscillations–signalling the status quo? *Current Opinion in Neurobiology*, *20*(2), 156–165. https://doi.org/10.1016/j.conb.2010.02.015

Fleming, S. M. (2024). Metacognition and Confidence: A Review and Synthesis. *Annual Review of Psychology*, *75*(1), 241–268. https://doi.org/10.1146/annurev–psych–022423–032425

Fleming, S. M., Huijgen, J., & Dolan, R. J. (2012). Prefrontal Contributions to Metacognition in Perceptual Decision Making. *The Journal of Neuroscience*, *32*(18), 6117–6125. https://doi.org/10.1523/jneurosci.6489–11.2012

Harmony, T. (2013). The functional significance of delta oscillations in cognitive processing. *Frontiers in Integrative Neuroscience*, *7*(83), 1-10. https://doi.org/10.3389/fnint.2013.00083

Herrmann, C. S., Fründ, I., & Lenz, D. (2010). Human gamma–band activity: A review on cognitive and behavioral correlates and network models. *Neuroscience & Biobehavioral Reviews*, *34*(7), 981–992. https://doi.org/10.1016/j.neubiorev.2009.09.001

Kahneman, D., & Tversky, A. (1979). Prospect theory: an analysis of decision under risk. *Econometrica*, *47*(2), 263–292. https://doi.org/10.2307/1914185

Keil, A., Mussweiler, T., & Epstude, K. (2006). Alpha–band activity reflects reduction of mental effort in a comparison task: A source space analysis. *Brain Research*, *1121*(1), 117–127. https://doi.org/10.1016/j.brainres.2006.08.118

Klimesch, W. (2012). Alpha–band oscillations, attention, and controlled access to stored information. *Trends in Cognitive Sciences*, *16*(12), 606–617. https://doi.org/10.1016/j.tics.2012.10.007

Knyazev, G. G. (2012). EEG delta oscillations as a correlate of basic homeostatic and motivational processes. *Neuroscience and Biobehavioral Reviews*, *36*(1), 677–695. https://doi.org/10.1016/j.neubiorev.2011.10.002

Krall, S. C., Rottschy, C., Oberwelland, E., Bzdok, D., Fox, P. T., Eickhoff, S. B., Fink, G. R., & Konrad, K. (2015). The role of the right temporoparietal junction in attention and social interaction as revealed by ALE meta–analysis. *Brain Structure and Function*, *220*(2), 587–604. https://doi.org/10.1007/s00429–014–0803–z

Kramer, A. F. (2020). Physiological metrics of mental workload: A review of recent progress. *Multiple Task Performance*, 279–328. https://doi.org/10.1201/9781003069447-14

Krumpe, T., Gerjets, P., Rosenstiel, W., & Spüler, M. (2019). Decision confidence: EEG correlates of confidence in different phases of an old/new recognition task. *Brain-Computer Interfaces*, *6*(4), 162–177. https://doi.org/10.1080/2326263X.2019.1708539

Laureiro-Martínez, D., & Brusoni, S. (2018). Cognitive flexibility and adaptive decision-making: Evidence from a laboratory study of expert decision makers. *Strategic Management Journal*, *39*(4), 1031–1058. https://doi.org/10.1002/smj.2774

Lin, C.–T., Chen, S.–A., Ko, L.–W., & Wang, Y.–K. (2011). EEG–based brain dynamics of driving distraction. *The 2011 International Joint Conference on Neural Networks*, 1497–1500. https://doi.org/10.1109/ijcnn.2011.6033401

Luyten, P., & Fonagy, P. (2015). The neurobiology of mentalizing. *Personality Disorders: Theory, Research, and Treatment*, *6*(4), 366–379. https://doi.org/10.1037/per0000117

McNeil, B. J., Pauker, S. G., Sox, H. C., & Tversky, A. (1982). On the Elicitation of Preferences for Alternative Therapies. *New England Journal of Medicine*, *306*(21), 1259–1262. https://doi.org/10.1056/NEJM198205273062103

Peeters, G., & Czapinski, J. (1990). Positive–Negative Asymmetry in Evaluations: The Distinction Between Affective and Informational Negativity Effects. *European Review of Social Psychology*, *1*(1), 33–60. https://doi.org/10.1080/14792779108401856

Pfurtscheller, G., Stancák, A., & Neuper, Ch. (1996). Event–related synchronization (ERS) in the alpha band – an electrophysiological correlate of cortical idling: A review. *International Journal of Psychophysiology*, *24*(1–2), 39–46. https://doi.org/10.1016/S0167–8760(96)00066–9

Roiser, J. P., de Martino, B., Tan, G. C. Y., Kumaran, D., Seymour, B., Wood, N. W., & Dolan, R. J. (2009). A Genetically Mediated Bias in Decision Making Driven by Failure of Amygdala Control. *The Journal of Neuroscience*, *29*(18), 5985–5991. https://doi.org/10.1523/jneurosci.0407–09.2009

Runnova, A., Selskii, A., Kiselev, A., Shamionov, R., Parsamyan, R., & Zhuravlev, M. (2021). Changes in eeg alpha activity during attention control in patients: Association with sleep disorders. *Journal of Personalized Medicine*, *11*(601), 1–13. https://doi.org/10.3390/jpm11070601

Samuelson, W., & Zeckhauser, R. (1988). Status quo bias in decision making. *Journal of Risk and Uncertainty*, *1*(1), 7–59. https://doi.org/10.1007/BF00055564

Saxe, R., & Wexler, A. (2005). Making sense of another mind: The role of the right temporo–parietal junction. *Neuropsychologia*, *43*(10), 1391–1399. https://doi.org/10.1016/j.neuropsychologia.2005.02.013

Selimbeyoglu, A., Keskin–Ergen, Y., & Demiralp, T. (2012). What if you are not sure? Electroencephalographic correlates of subjective confidence level about a decision. *Clinical Neurophysiology*, *123*(6), 1158–1167. https://doi.org/10.1016/j.clinph.2011.10.037

Sharp, D. J., & Salter, S. B. (1997). Project Escalation and Sunk Costs: A test of the International Generalizability of Agency and Prospect Theories. *Journal of International Business Studies*, *28*(1), 101–121. https://doi.org/10.1057/palgrave.jibs.8490095

Tversky, A., & Kahneman, D. (1981). The Framing of Decisions and the Psychology of Choice. *Science*, *211*(4481), 453–458. https://doi.org/10.1126/science.7455683

Tversky, A., & Kahneman, D. (2000). *Choices, values, and frames*. Cambridge University Press New York. https://doi.org/10.1017/cbo9780511803475

van Winsum, W. (2018). The effects of cognitive and visual workload on peripheral detection in the detection response task. *Human Factors*, *60*(6), 855–869. https://doi.org/10.1177/0018720818776880