Psychology Research and Behavior Management Dovepress

Open Access Full Text Article ORIGINAL RESEARCH

The Role of Disgust Certainty in Intuitive Thought Processing: Electrophysiological Evidence

Zhaoxian Li[1], Wei Bao[1], Yao Wang[1], Shangsong Yan[1], Hong Zheng[2], Junlong Luo[1,3]

[1]Psychology College, Shanghai Normal University, Shanghai, People's Republic of China; [2]Changning Mental Health Center Affiliated with East China Normal University, Shanghai, People's Republic of China; [3]Lab for Educational Big Data and Policymaking, Ministry of Education, Shanghai Normal University, Shanghai, People's Republic of China

Correspondence: Hong Zheng; Junlong Luo, Email zhhmm2@163.com; luo831023@vip.163.com

Introduction: The impact of emotions on intuitive and analytical thinking has been widely studied. Most research suggests that negative emotions enhance analytical processing. However, there are studies indicating that the sense of certainty associated with disgust can stimulate intuitive processing. Despite these findings, the neuroelectrophysiological evidence supporting the role of disgust in promoting intuitive processing remains unexplored.

Methods: This study aimed to investigate the neuroelectrophysiological mechanisms by which disgust promotes intuitive processing. A total of 54 participants were recruited and randomly assigned to specific emotion groups. Emotional states were induced by exposing participants to disgust and fear videos designed to evoke specific dimensions of certainty and uncertainty. Event-related potentials (ERP) and the Cognitive Reflection Test (CRT) were utilized as experimental materials to measure participants' responses.

Results: The results demonstrated that disgust facilitated intuitive thinking, as evidenced by the lowest accuracy in behavioral outcomes. ERP findings showed that disgust led to smaller N2 and larger P3b amplitudes under conditions of conflict. These results suggest that disgust reduces individuals' conflict-detection ability, resulting in a stronger sense of certainty in intuitive but incorrect answers.

Conclusion: This study provides neuroelectrophysiological evidence that disgust enhances intuitive thinking. The findings offer a new perspective on the influence of emotions on dual-process thinking, highlighting the role of disgust in shaping intuitive and analytical thought processes.

Keywords: certain, uncertain, disgust, fear, dual-process theory, N2, P3b

Introduction

The Dual-process Theory (DPT) categorizes thought into two types: intuitive processing (Type 1), an unconscious, rapid, automatic process that does not require cognitive resources, and analytical processing (Type 2), a slower, controlled process that necessitates cognitive resources.[1–3] These two processes interact, and many studies have explored how factors such as motivation and emotion affect analytical and intuitive thinking processes.

Numerous studies have explored the impact of emotions on decision-making.[4–6] Research shows that people tend to engage in more analytical processing during negative emotional states, while positive emotion often lead to more intuitive thinking.[7–10] In addition, scholars have proposed that the influence of emotions extends beyond happiness and sadness and should not be limited to positive and negative dimensions alone.[11,12] According to the emotion appraisal theory, once triggered, an emotion can predispose individuals to evaluate future events based on key appraisal dimensions, such as certainty, pleasantness, attentional focus, and control.[13,14] This theory suggests that emotions involve a form of appraisal, with each type of emotion being regarded as a unique form of affective appraisal.[15,16] Such appraisals, in turn, determine how people with a specific emotion make future judgment.[11,14,17] In terms of certainty and uncertainty, emotions associated with certainty tend to promote judgments that align with future situations, influencing cognitive processes accordingly.[18,19] This study focused on the dimensions of certainty and uncertainty in emotional appraisals.

Received: 17 May 2024
Accepted: 3 October 2024
Published: 24 October 2024

Disgust and fear are two common negative emotions experienced in daily life. Both are associated with threats and emotions that humans seek to eliminate or avoid,[20] which scholars have classified as certain and uncertain emotions, respectively.[21,22] Certainty refers to the extent to which individuals perceive a situation as predictable or unpredictable.[23] Past research found that high certainty and individual control are associated with disgust, whereas uncertainty and situational control are connected with fear.[11,22] Disgust originates from the sensory organs of the body and serves as a defensive emotion.[24] It enhances the parasympathetic response, lowers blood pressure and heart rate, and induces decreased respiration, manifesting as an associated inhibitory activity.[25,26] This typical withdrawal response helps us avoid harmful stimuli, manifesting as a feeling of certainty in reaction to intuitive physiological cues.[27,28] Emotions tied to certainty, such as disgust, anger, and contentment, lead to rapid and definitive reactions. Tiedens and Linton[6] evoked disgust and fear to explore the influence of uncertainty on decision-making and found that disgust, as an emotion, promoted a stereotype dominated by intuitive processing. Additionally, similar to anger, when individuals experience disgust, they tend to strongly reject certain stimuli or ideas. This emotional response is typically rapid, clear, and characterized by a sense of certainty[29,30]. Briñol[29] utilized various emotions associated with certainty and uncertainty to explore how emotions affect the thought validation process under different evaluative conditions. The findings revealed that when anger and disgust were elicited under conditions of confident evaluation, participants were more likely to rely on their pre-existing thoughts.

In contrast, fear stimulates sympathetic pathways that trigger the fight and flight responses. It conveys information about direct threat to survival while simultaneously increasing perception and attentional processing of specific stimuli.[31] Thus, an inevitably threatening message induces fear accompanied by a feeling of uncertainty. The emotions that accompany uncertainty include sadness, surprise, worry, and fear.[19] Lerner and Keltner[12] induced participants to feel anger or fear and found that their appraisals of certainty and control mediated the causal effects of fear and anger on optimism. Coget[4] used film directors as participants to study expert intuitive decision-making and emotional intuitive decision-making through interview coding after shooting a movie and found that a moderate degree of fear can induce analytical thinking. Lu[23] applied the Appraisal Tendency Framework to investigate the effects of anger and fear—both negative emotions differing in appraisals of certainty, responsibility, and control—on risk perception. The study found that the certain emotion of anger reduced individuals' driving risk perception, whereas the uncertain emotion of fear increased driving risk perception.

In these studies, scholars explored the influence of emotion on dual processing by inducing corresponding emotions, assigning them to a task, and inferring the influence of emotion on dual processing from the results of this task. Few scholars have explored the impact of emotions on cognitive processes and their neuroelectrophysiological mechanisms from the perspective of high temporal resolution ERP technology. The Cognitive Reflection Task (CRT)[32] is a commonly used task in research on dual processing. Its ball-and-racket problems (*A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost?*) can easily lead individuals to fall into the trap of intuition and provide the wrong answer (*0.1*), while the correct answer (*0.05*) requires analytical processing and careful consideration (the correct answer of *$0.05* is obtained by subtracting *$1.00* from the total cost of *$1.10* and then dividing by 2). De Neys[33] noted that individuals are cognitively parsimonious, tending to use fast intuitive processing rather than more effortful deliberative thinking. By designing a controlled version of the CRT (which do not induce intuitive traps) and comparing them with standard CRT, De Neys found that individuals exhibited significantly lower confidence in their responses to the CRT than to the controlled CRT. Boissin[34] research used CRT-like, adapting CRT into conflict and non-conflict problems. In the conflict conditions of CRT-like, we changed the expression but continued to use the calculation rules of balls and bats in CRT, which could also easily lead individuals into the trap of intuition. In this study, we used CRT-like as the experimental material and employed event-related potentials (ERP) to explore the impact of certain and uncertain emotions on dual processing. We hypothesized that fear would increase participants' feeling of uncertainty, improve their conflict-detection ability, and thus improve CRT-like accuracy. Conversely, disgust may enhance participants' intuitive thinking and increase the likelihood of obtaining the wrong answer intuitively.

In ERP studies of the dual process theory, Luo[35] investigated how participants could overcome intuitive processing by providing guidance for analytical thinking. They discovered that the N2 component was induced by conditional reasoning, while the P300 component appeared during syllogistic reasoning.[36] In addition, under conditional reasoning, Prado[37] induced the N2 component when participants were asked to overcome matching information under intuitive processing. Banks and Hope[38] reported similar results. The N2 component has also been detected in studies involving conditional reasoning[39] and Wason selection tasks.[40] Yin[41] employed an Embedded Chinese Character Task (ECCT) combined with the dual-process theory, revealing N2 and P3b components under conflicting conditions. Bago[42] found that, compared to non-conflict conditions, solving conflict problems induces large N2 and P3b amplitudes under time-limited response conditions, demonstrating the conflict between heuristic and logically intuitive answers. From the above studies, it can be concluded that the presence of N2 amplitude indicates the conflict-detection ability of analytical processing by inhibiting intuitive processing. The appearance of P3b indicates that, in the reasoning process, the participant's expectation of the conclusion generated after reading the premise is consistent with the final conclusion presented, namely expectation satisfaction.[43] Therefore, we predict that CRT-like will trap individuals in both intuitive errors and analytical correctness, as reflected in the N2 component representing conflict and in the P3b component presenting certainty and uncertainty. In addition, we hypothesize that disgust, as a certainty emotion, may reduce the sense of conflict, thereby decreasing the amplitude of N2 and providing a feeling of certainty, thereby enhancing the amplitude of P3b.

Materials and Methods

Participants

We utilized an effect size of $f = 0.27$ as an input parameter in G*Power[44] (with Power = 0.80, alpha = 0.05) to estimate the required sample size necessary to detect a moderate effect on the primary outcome. The calculation indicated that a sample size of 39 participants is needed. Sixty college students (41 females, mean age = 22.62 ± 2.20 years) at the Shanghai Normal University voluntarily participated in the study. Participants came to the lab and were randomly assigned to different emotion groups. Due to the specific nature of the CRT, participants are prone to falling into intuitive traps, leading to a very low accuracy rate. Therefore, in the analysis of EEG data, to ensure that the ERP data under conflict conditions met the observation criteria, we excluded data from conflict conditions where the number of correct trials was fewer than 10.[45] Finally, 54 participants (37 females, mean age = 22.48 ± 2.19 years old) were included in the analysis, including 18 in the disgust group, 19 in the fear group and 17 in the neutral group. All participants were right-handed with normal or corrected-to-normal vision and had no previous neurological/psychiatric history. The participants provided written informed consent and were paid for their participation. The study was conducted in accordance with the Declaration of Helsinki[46] and was approved by the Ethics Committee of Shanghai Normal University (Ethical Approval Number: 2023–088). Participants were compensated with 50 RMB upon completion of the experiment.

Stimuli and Procedures

We use videos to induce emotions. Disgust is evoked using a scene from the film *Trainspotting* involving a disgusting toilet.[47,48] To induce fear, we used the scene of *The Shining* boy riding his bike in the hallway.[49] We used video (BBC Planet Earth Seasonal Forests) as neutral emotional material.[50] Then 18 participants were recruited (6 males, mean age = 25.69 ± 2.40) to rate arousal of the fear, disgust, pleasure and sense of certainty of three selected videos on a Likert scale from 1 (*none*) to 7 (*strong*). Table 1 provides the means and standard deviations for these ratings. The disgust video elicited more certainty than did the fear video, $t(31) = -3.46$, $p < 0.01$, *Cohen's d* $= -1.24$. And there was no significant difference in pleasure between the fear group and the disgust group, $t(31) = -1.61$, $ps > 0.1$, *Cohen's d* $= -0.58$.

Table 1 The Rating Scores of the Three Video Materials (Mean ± SD)

	Fear	Disgust	Pleasure	Sense of Certainty
The shining	5.84 (0.91)	3.06 (0.97)	1.03 (0.17)	5.03 (1.61)
Trainspotting	2.06 (1.17)	6.15 (0.79)	1.03 (0.17)	6.25 (1.09)
BBC Planet Earth Seasonal Forests	1.06 (0.24)	1 (0)	3.06 (1.56)	4.78 (1.58)

For CRT-like, we used the same conflict and non-conflict materials provided in Boissin et al.[34] Under conflict conditions, an intuitive answer is usually incorrect and requires careful consideration to arrive at the correct answer. For example: Condition: *A cheese and two breads cost a total of 2.8 dollars; a cheese is 2 dollars more expensive than two breads*; Question: *how much does a bread cost?* Under non-conflict conditions, the answer can be obtained intuitively. For example: Condition: *there are 260 kangaroos and peacocks in the zoo; there are 200 kangaroos*; Question: *How many peacocks are there in the zoo?* In addition, to prevent the participants from guessing our experimental purpose and producing a practice effect, we also set interference items: Condition: *In an office, there are 150 pens and pencils in total. There are 100 pens*. Question: *How many kinds of stationery are there in the office?* In the Supplementary Materials, we have provided 10 examples for each condition.

Before the formal experiment, we recruited 19 college students (3 males, mean age = 24.79 ± 2.75 years) to evaluate the time need to read the questions. First, we presented the condition stem (*A bat and two balls cost $2.60 in total. The bat costs $2 more than the two balls)*. and asked the participants to press the spacebar on the keyboard immediately after they finished reading and understanding the question. Because Raoelison[51] set a time limit of 7000 ms to ensure that participants could read a question completely, we set the time limitation for this screen at 7000 ms. Then, the questions and answers (*How much does one ball cost?* 0.3/0.15) were presented, and participants were instructed to choose the correct answer. In this part of the experiment, we just calculated the reaction time for the two screens. The results indicated that participants needed, on average, 5187.56 ms (SD = 1004.16) to read and comprehend the question stem, and they needed 1648.08 ms (SD = 451.80) to read the problem and click on a response option. Hence, to ensure that most of the participants fully understood the question, the presentation time for the condition stem was set to 5200 ms, and the time for the question was set to 1500 ms in the formal experiment. The experimental flowchart is shown in Figure 1.

PsychoPy (Psychology Software Tools, Inc., https://www.psychopy.org/) was used for programming and behavioral data collection. The experiment was conducted on a Lenovo desktop computer with a resolution of 1920×1080 and a refresh rate of 60 hz. Upon arrival at the lab, participants filled out The Positive and Negative Affect Scale (PANAS)[52] to control their pre-test emotional state. The participants were then randomly assigned to either disgust, fear or neutral groups. After fully understanding the instructions, the practice experiment was conducted, and then the formal experiment was started by watching different types of video stimuli. The experiment consisted of two blocks, each with 60 trials of conflict stimuli, 60 trials of non-conflict stimuli, and 30 trials of interference stimuli. The experiment was conducted in a closed and undisturbed room.

Electrophysiological Recording and Analysis

Continuous ERP data was recorded from 64 Ag/AgCl electrodes mounted within an elastic cap according to the extended international 10–20 system (NeuroScan Inc., Sterling, VA, USA). During recording, the GND electrode serving as the grounding electrode was placed at the center of the forehead, and all electrodes were referenced to CZ and re-referenced offline to linked mastoids. The vertical electrooculograms (EOGs) were acquired using a bipolar pair of electrodes positioned at the external ocular canthi, and vertical EOGs were recorded from electrodes placed 1 cm above and below the left eye. The EEG and EOG were digitized at 500 hz with a 0.01–100 hz bandpass with the NeuroScan Synamps2 digital amplifier system (Neuroscan Labs, El Paso, TX, United States). The electrode impedances were kept below 5 kΩ.

MATLAB (R2022b), EEGLAB (v14.1.2),[53] and ERPLAB (v8.0.0)[54] were used for offline data analysis of the continuous EEG data. High-pass filtering (0.1 hz, 24 dB/octave) and low-pass filtering (30 hz, 12 dB/octave) were performed on continuous EEG data,[55] and ocular artifacts were corrected using independent component analysis (ICA).[56] EEG epochs that were time-locked to CRT-like question onset were extracted using a 1200-ms window-analysis time

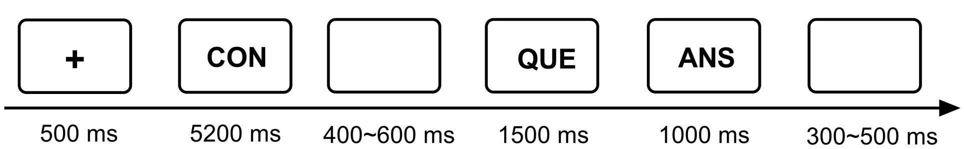

Figure 1 Experiment Flow Diagram.

(200 ms pre-stimulus until 1000 ms post-stimulus) and baseline-corrected according to a 200 ms window before question onset. Artifacts (activity exceeding ± 100 µV) were rejected from the analysis by simple voltage threshold in ERPLAB (v7.0.0).[57] Epochs were removed from data analysis by the simple voltage threshold function if residual artifact activity exceeded ± 80 µV.[58] All EEG analyses were performed in the corrected trials.

For the behavioral data, a 2 * 3 mixed repeated-measure analyses of variance (ANOVAs) with between-subject and within-subject variables: conflict (levels: conflict, non-conflict) and emotional group (levels: disgust, fear, neutral) were conducted.

For the ERP data, according to the group level ERP activity and previous ERP studies investigating dual-process thinking,[41,59] we identified 2 dominant ERPs: N2 and P3. N2 were defined as the negative deflections over the fronto-central area within 260 to 360 ms after target presentation. P3 was defined as the positive-going deflection within 300 to 600 ms after target presentation, with a maximal distribution over the centro-parietal region. For each participant and condition, the mean amplitudes of the N2 component were calculated at electrode sites FCz, FC1 and FC2 in the time range of 300–360 ms because it has a frontal–central distribution.[60] The mean amplitudes of the P3b component were calculated at electrode sites FC1, FC2, FCz, C1, C2, Cz, CP1, CP2, and CPz in the time range of 360–420 ms because it has the central-parietal distribution.[61,62] ANOVA were conducted for the mean amplitude of the N2 and p3b component with material category (levels: conflict, non-conflict) and emotions of different certainty group (levels: disgust-certain, fear-uncertain, neutral). We applied a Bonferroni correction for multiple comparisons.

Result

Behavioral results

We used F-test to analyze The Positive and Negative scores before the experiment, and found that there was no significant difference in the scores of the three groups of subjects before watching the movie, $F_{positive}(2, 53) = 1.502$, $p_{positive} = 0.232$, $F_{negative}(2, 53) = 0.725$, $p_{negative} = 0.489$.

The behavioral performance (mean reaction time and average correct rate) for three emotional groups are shown in Figure 2. Mixed repeated-measure analyses of variance showed a significant main effect for conflict condition on both accuracy [$F(1, 51) = 60.702$, $p < 0.001$, $\eta^2_p = 0.543$] and reaction time [$F(1, 51) = 5.748$, $p = 0.020$, $\eta^2_p = 0.101$]. The main effect of emotion showed marginal significance in accuracy [$F(2, 51) = 2.580$, $p = 0.086$, $\eta^2_p = 0.092$], the pairwise comparison showed that the disgust group had a higher accuracy than the fear group ($p = 0.084$, $mean = 0.074$), and no significant difference in response time [$F(2, 51) = 0.961$, $p = 0.386$, $\eta^2_p = 0.036$]. There was no significant difference in

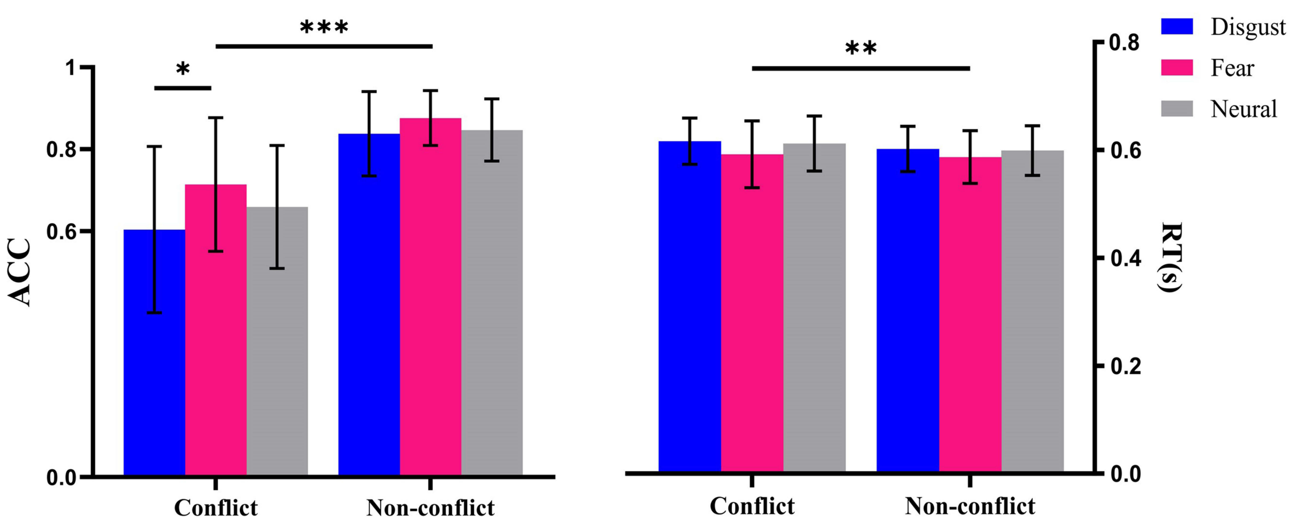

Figure 2 The accuracy of three emotional groups.
Notes: ***$p < 0.001$, **$p < 0.01$,*$p < 0.05$.

the interaction of emotion and conflict conditions in both accuracy and response time [$F_{accuracy}(2, 51) = 1.036$, $p = 0.362$, $\eta^2_p = 0.039$, $F_{response\ time}(2, 51) = 0.403$, $p = 0.670$, $\eta^2_p = 0.016$]. The descriptive statistical results are shown in Figure 2.

ERP Results

N2 Component

Only correctly solved trials are included in N2 and P3b analysis.

The mixed repeated-measure ANOVA analyzed of the N2 component in the 300–360 ms time window revealed a significant main effect of conflict condition [$F(1, 51) = 4.779$, $p = 0.033$, $\eta^2_p = 0.86$] and an insignificant difference in the emotional group [$F(1, 51) = 1.939$, $p = 0.154$, $\eta^2_p = 0.071$]. There was a significant interaction between conflict condition and emotion [$F(2, 51) = 4.816$, $p = 0.012$, $\eta^2_p = 0.159$]. Simple effect analysis found that the N2 amplitude of disgust was margin significantly higher than that of fear ($p = 0.072$, *mean* = 2.961), and neutral group ($p = 0.074$, *mean* = 3.036), and an insignificant difference between fear and neutral group ($p > 0.1$, *mean* = 0.075) under the conflict condition. Under non-conflict conditions, there were no significant differences in the N2 amplitude among the three emotion groups (disgust-fear: $p > 0.1$, *mean* = 1.383, disgust-neutral: $p > 0.1$, *mean* = 0.638, fear-mean: $p > 0.1$, *mean* = 0.745).

P3b Component

There was a significant main effect of conflict condition [$F(1, 51) = 5.175$, $p = 0.027$, $\eta^2_p = 0.092$], and a significant main effect for the emotional group [$F(2, 51) = 5.197$, $p = 0.09$, $\eta^2_p = 0.169$]. Additionally, there was a significant interaction between conflict and emotion groups [$F(2, 51) = 4.512$, $p = 0.016$, $\eta^2_p= 0.150$]. The simple main effects analysis suggested that the P3b amplitude of disgust group was larger than fear group ($p = 0.014$, *mean* = 3.260) and neutral group ($p = 0.018$, *mean* = 3.238), an insignificant difference between fear and neutral group ($p > 0.1$, *mean* = 0.022) under the conflict condition. Under non-conflict conditions, the P3b amplitude of the disgust group was significantly higher than that of the fear group ($p = 0.021$, *mean* = 2.445), but there were no significant differences between the disgust and neutral group ($p > 0.1$, *mean* = 0.776) or between the fear and neutral group ($p > 0.1$, *mean* = 1.669). Figures 3 and 4 show the waveform and topographic maps of N2 and P3b.

Discussion

The purpose of the present study was to explore the influence of certain and uncertain emotions on dual processing and to determine the neuroelectrophysiological mechanism of emotion on dual processing. To do this, we employed Event-related potentials (ERP) and compared participants with aversion related to certainty and fear of uncertainty, using a neutral group as a control. The results were consistent with studies examining the impact of different emotions distinguished on the appraisal dimension.

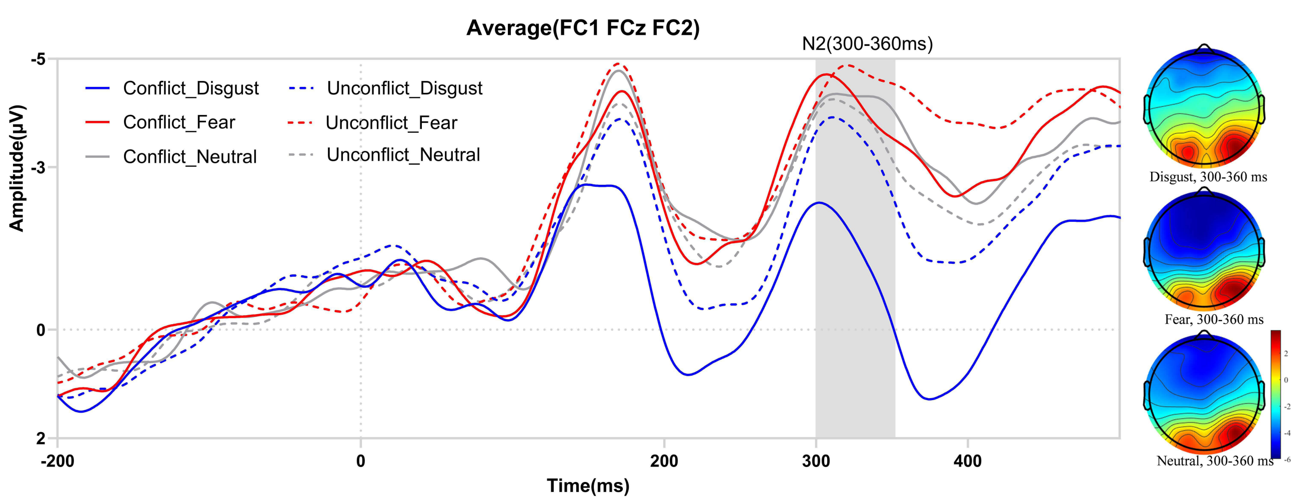

Figure 3 Waveform and topographic maps of N2 amplitude in three emotional groups.

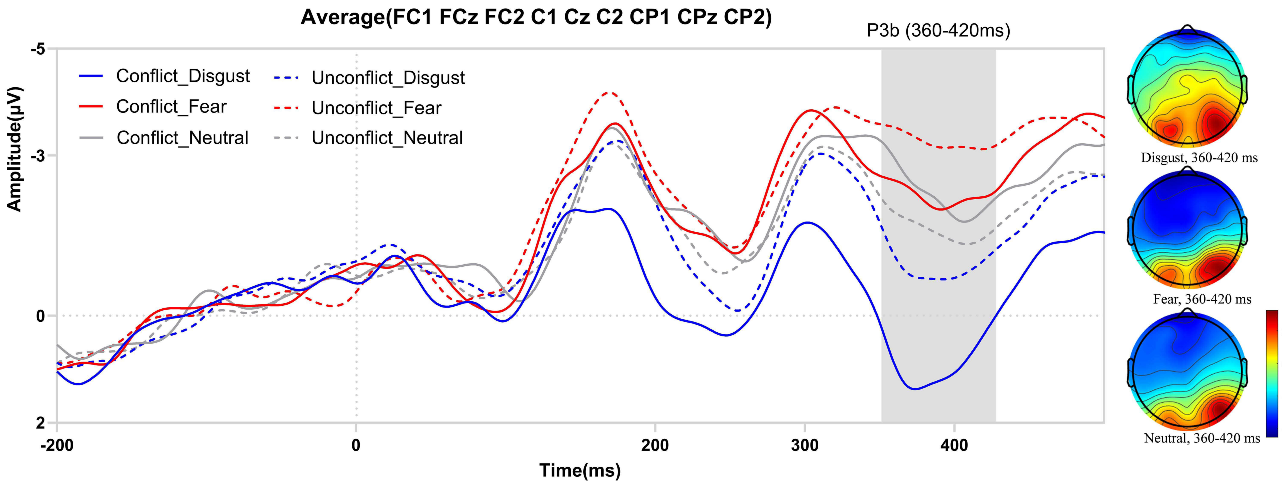

Figure 4 Waveform and topographic maps of P3b amplitude in three emotional groups.

From the behavioral results, it can be seen that disgust, as a certain emotion, has the lowest accuracy rate. In contrast, the fear group, as an uncertain emotion, has the best accuracy performance relative to the disgust group and the neutral group. Bollon and Bagneux[63] evaluated emotions using uncertainty and explored its impact on the Iowa Gambling Task (IGT). He assumed that deliberative processing does not lead to optimal conclusions in complex decision-making tasks with large amounts of information. The results showed that relative to uncertain emotions, disgust as a certain emotion promoted individuals to make optimal decisions. In other words, disgust promotes intuitive thinking, which is consistent with our results. Purcell[64] utilized eye-tracking and found greater visual uncertainty in the heuristic answers of the Cognitive Reflection Test (CRT) by comparing confidence ratings and eye-movements between heuristic lure and correct-no lure trials. Fink-Lamotte[65] employed a dot-probe paradigm combined with eye-tracking technology to investigate individuals' visual exploration and avoidance behaviors when confronted with disgust and fear stimuli. The results showed that although participants exhibited a longer attentional bias toward disgust stimuli, their accuracy in answering detail-related questions about disgust images was lower compared to fear images. Furthermore, they reported higher confidence in their responses to the detail questions related to disgust stimuli. In psychopathology, disgust is strongly associated with obsessive-compulsive disorder (OCD). Fink[66] further distinguishes between high and low disgust sensitivity and explores attentional biases related to fear and disgust using a visual search task, particularly focusing on how these biases manifest in individuals with OCD. The study found that patients with high levels of disgust traits exhibited better memory for disgusting stimuli, but their confidence or certainty was reduced. This finding does not contradict our results. Disgust is a highly defensive emotion, prompting individuals to quickly engage in avoidance responses to reach a defensive state, which may explain their better memory for disgust-related stimuli. However, the rapid response might leave fewer cognitive resources available for detailed analytical processing, potentially leading to reduced confidence. Importantly, the certainty in the rapid avoidance reaction remains intact, indicating that individuals are confident in their intuitive processing. From this perspective, the results are consistent with our findings. Similarly, Fink-Lamotte[67] assessed the impact of disgust and fear on attentional processing using an emotional go/no-go task, finding that individuals with higher disgust proneness exhibited faster and stronger urgency responses to disgust stimuli. Overall, our results are consistent with previous findings. Although disgust is a negative emotion, it functions as a highly certain emotion that facilitates intuitive processing in individuals.[5,6,68]

Consistent with our prediction, a large N2 amplitude was observed under CRT-like conflict conditions. N2 is a representative component of conflict detection,[39,43] and disgust reduces the amplitude of N2 under conflict conditions. This observation may be related to characteristics of disgust. Scholars have shown that disgust elicits an early attention-avoidance effect[69] that can quickly inhibit attention and redirect attention to its location through a top-down control mechanism.[70] It is manifested as a reduction in the amplitude of the N2. In addition, it may also be related to the shocking feeling of certainty that disgust brings to participants. Studies have shown that individuals with depression tend to adopt more systematic problem-solving approaches due to reduced confidence in their judgments.[71] Therefore, based on previous research and in conjunction with our results, it can be understood that a sense of certainty may increase an individual's confidence, reduce the conflict detection process, and manifest as a decrease in N2. On the other hand, the certainty of disgust may make the individual certain that the conflict in the task does indeed exist, thereby using fewer cognitive resources to process the conflict.

Studies have shown that the presence of the P3b component indicates a consistent association with the attentional processing of target stimulus events.[61,72] When an incorrect answer based on intuition is presented, disgust encourages participants to perceive that the intuitively incorrect answer better matches the answer presented on the screen, resulting in a larger P3b component. According to our results, disgust enhanced the match between an individual's intuitively wrong answer and the answer presented in the experimental task. This supports the finding that P3b is associated with a stronger feeling of certainty.[73,74] Yin[41] found differences in N2 and P3b between intuition questions, but not in analytical questions. This result is also confirmed by our findings: the disgust condition induces a larger P3b amplitude, biasing individuals towards intuitive processing. From a theoretical perspective, the Uncertainty Management Theory proposed by Van den Bos[75] posits that uncertainty leads individuals to doubt themselves, resulting in decreased self-awareness and a lack of security. To mitigate this discomfort and threat, individuals exhibit strong motivation or behavior to reduce this uncertainty, manifesting as a strong need for controllability.[75] In this context, disgust, as a certain emotion, reduces the perceived uncertainty threat, leading to greater self-certainty and a stronger P3b response.

Over the years, most research on the influence of emotion on decision-making and thinking has focused on decision-making tasks, and few studies have directly discussed the influence of emotion on the time course of the dual processing domain of thinking. In this study, the classical dual-processing task CRT-like was used as EEG research material for the first time to explore the influence of emotion on dual processing from the perspectives of emotional certainty and uncertainty. It was found that fear of uncertainty promoted analytical processing and improved task performance, while disgust with certainty increased the certainty of responses, promoted intuitive processing, decreased the amplitude of N2 with conflict, and increased the amplitude of P3b. In addition, emotion-cognition interactions are complex, and future research could strip away emotions and feelings of uncertainty to further validate the effects of certainty and uncertainty on dual processing. Alternatively, emotions and the feelings of certainty and uncertainty brought by emotions are controlled separately to explore how the two works in the double processing process, which is also of progress significance to the process of uncertain decision making. From an alternative perspective, the sense of certainty elicited by disgust may reflect an individual's clear rejection and avoidance of specific stimuli. In psychopathology, this sense of certainty may be excessively amplified or distorted, contributing to the emergence of certain symptoms. For instance, individuals with obsessive-compulsive disorder (OCD) may experience intense disgust towards certain thoughts or behaviors, leading to compulsive actions aimed at alleviating this disgust.[76] Thus, future research could integrate neuroscience, psychology, and psychopathology to explore the relationship between the certainty brought by disgust and various mental disorders. Such interdisciplinary studies could provide a more comprehensive understanding of the role of disgust in different pathological conditions.

Limitations

Several limitations of current study should be acknowledged. Firstly, the insufficient sample size may be a major limitation of this study. In addition, this study did not consider the impact of different thinking styles on the influence of certain and uncertain emotions on the thinking process, which could make our results more directional. Future research could appropriately increase the sample size, control for individual differences in thinking tendencies as an additional control variable and use a different emotion with the same valence but different certainty for replication studies.

Data Sharing Statement

The data that support the findings of this study are available upon request from the corresponding author. The data are not publicly available due to their confidential contents that could compromise the privacy of the research participants.

Ethics Approval and Consent to Participate

Approval was obtained from the ethics committee of Shanghai Normal University (The number is: Shanghai Normal University Ethics [2023] No. 088). The procedures used in this study adhere to the tenets of the Declaration of Helsinki. Written informed consent was obtained from individual participants.

Acknowledgments

We thank the Shanghai Education Development Foundation, and the Shanghai Municipal Education Commission for funding support. We also thank all the participants in our experiments, without whom this research would not be possible.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

This work was sponsored by the Medical Master's and Doctoral Innovation Talent Base Project of Changning District (RCJD2022S07), and the Changning District Health of Medical Specialty (Grant No.: 20232005).

Disclosure

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Evans JS, Stanovich KE. Dual-process theories of higher cognition: advancing the debate. *Perspect Psychol Sci*. 2013;8(3):223–241. doi:10.1177/1745691612460685
2. Evans JS. Dual-processing accounts of reasoning, judgment, and social cognition. *Annual Review of Psychology*. 2008;59(1):255–278. doi:10.1146/annurev.psych.59.103006.093629
3. Pennycook G, Neys W, Evans J, Stanovich KE, Thompson VA. The Mythical Dual-Process Typology. *Trends Cognit Sci*. 2018;22(8):667–668. doi:10.1016/j.tics.2018.04.008
4. Coget JF, Haag C, Gibson DE. Anger and fear in decision-making: the case of film directors on set. *Eur Manage J*. 2011;29(6):476–490. doi:10.1016/j.emj.2011.06.003
5. Heilman RM, Crişan LG, Houser D, Miclea M, Miu AC. Emotion regulation and decision making under risk and uncertainty. *Emotion*. 2010;10(2):257–265. doi:10.1037/a0018489
6. Tiedens LZ, Linton S. Judgment under emotional certainty and uncertainty: the effects of specific emotions on information processing. *J Pers Soc Psychol*. 2001;81(6):973–988. doi:10.1037//0022-3514.81.6.973
7. Barasz K, Hagerty SF. Hoping for the Worst? A paradoxical preference for bad news. *J Consum Res*. 2021;48(2):270–288. doi:10.1093/JCR/UCAB004
8. Mills C, Wu J, D'Mello S. Being sad is not always bad: the influence of affect on expository text comprehension. *Discourse Processes*. 2019;56:99–116. doi:10.1080/0163853X.2017.1381059
9. de Vries M, Holland RW, Corneille O, Rondeel E, Witteman CL. Mood effects on dominated choices: positive mood induces departures from logical rules. *J Behav Decis Making*. 2012;25(1):74–81. doi:10.1002/bdm.716
10. Remmers C, Zander T. Why you don't see the forest for the trees when you are anxious: anxiety impairs intuitive decision making. *Clin Psychol Sci*. 2018;6:48–62. doi:10.1177/2167702617728705
11. Lerner JS, Keltner D. Beyond valence: toward a model of emotion-specific influences on judgement and choice. *Cognit Emot*. 2000;14(4):473–493. doi:10.1080/026999300402763
12. Smith CA, Lazarus RS. Appraisal components, core relational themes, and the emotions. *Cognit Emot*. 1993;7(3–4):233–269. doi:10.1080/02699939308409189
13. Lerner JS, Li Y, Valdesolo P, Kassam KS. Emotion and decision making. *Annu Rev Psychol*. 2015;66:799–823. doi:10.1146/annurev-psych-010213-115043
14. Lerner JS, Keltner D. Fear, anger, and risk. *J Pers Soc Psychol*. 2001;81(1):146–159. doi:10.1037//0022-3514.81.1.146
15. Teroni F. Emotions and formal objects. *Dialectica*. 2007;61(3):395–415. doi:10.1111/j.1746-8361.2007.01108.x
16. Vazard J. Feeling the unknown: emotions of uncertainty and their valence. *Erkenntnis*. 2024;89(4):1275–1294. doi:10.1007/s10670-022-00583-1
17. Han S, Lerner JS, Keltner D. Feelings and consumer decision making: the appraisal-tendency framework. *J Consum Psychol*. 2007;17:158–168. doi:10.1016/S1057-7408(07)70023-2

18. Lin H, Jin H, Liang J, Yin R, Liu T, Wang Y. Effects of Uncertainty on ERPs to emotional pictures depend on emotional valence. *Front Psy*. 2015;6:1664. doi:10.3389/fpsyg.2015.01927
19. David D, Richard E, Derek D, Duane T, Julia B. Discrete emotions and persuasion: the role of emotion-induced expectancies. *J Personalit Soc Psychol*. 2004;1(86):43–56. doi:10.1037/0022-3514.86.1.43
20. Stark R. Hemodynamic responses to fear and disgust-inducing pictures: an fMRI study. *Int J Psychophysiol*. 2003;50(3):225–234. doi:10.1016/s0167-8760(03)00169-7
21. Ellsworth PC, Smith CA. From appraisal to emotion: differences among unpleasant feelings. *Motivation Emotion*. 1988;12:271–302. doi:10.1007/BF00993115
22. Smith CA, Ellsworth PC. Patterns of cognitive appraisal in emotion. *J Person Soc Psychol*. 1985;48:813–838. doi:10.1037/0022-3514.48.4.813
23. Lu J, Xie X, Zhang R. Focusing on appraisals: how and why anger and fear influence driving risk perception. *J Safety Res*. 2013;45:65–73. doi:10.1016/j.jsr.2013.01.009
24. Rozin P, Haidt J. The domains of disgust and their origins: contrasting biological and cultural evolutionary accounts. *Trend Cognit Sci*. 2013;17(8):367–368. doi:10.1016/j.tics.2013.06.001
25. Susskind JM, Lee DH, Cusi A, Feiman R, Grabski W, Anderson AK. Expressing fear enhances sensory acquisition. *Nat Neurosci*. 2008;11(7):843–850. doi:10.1038/nn.2138
26. Tybur JM, de Vries RE. Disgust sensitivity and the HEXACO model of personality. *Pers Individ Dif*. 2013;55(6):660–665. doi:10.1016/j.paid.2013.05.008
27. Curtis V, de Barra M, Aunger R. Disgust as an adaptive system for disease avoidance behaviour. *Philos Trans R Soc B*. 2011;366(1563):389–401. doi:10.1098/rstb.2010.0117
28. Russell PS, Giner-Sorolla R. Bodily moral disgust: what it is, how it is different from anger, and why it is an unreasoned emotion. *Psychol Bull*. 2013;139(2):328–351. doi:10.1037/a0029319
29. Briñol P, Petty RE, Stavraki M, Lamprinakos G, Wagner B, Díaz D. Affective and cognitive validation of thoughts: an appraisal perspective on anger, disgust, Surprise, and awe. *J Person Soc Psychol*. 2018;114(5):693–718. doi:10.1037/pspa0000118
30. Briñol P, Petty RE, Valle C, Rucker DD, Becerra A. The effects of message recipients' power before and after persuasion: a self-validation analysis. *J Person Soc Psychol*. 2007;93:1040–1053. doi:10.1037/0022-3514.93.6.1040
31. Adolphs R. The Biology of Fear. *Curr Biol*. 2013;23(2):R79–R93. doi:10.1016/j.cub.2012.11.055
32. Frederick S. Cognitive reflection and decision making. *J Econ Perspect*. 2005;19(4):25–42. doi:10.1257/089533005775196732
33. De Neys W, Rossi S, Houdé O. Bats, balls, and substitution sensitivity: cognitive misers are no happy fools. *Psychon Bull Rev*. 2013;20:269–273. doi:10.3758/s13423-013-0384-5
34. Boissin E, Caparos S, Raoelison M, De Neys W. From bias to sound intuiting: boosting correct intuitive reasoning. *Cognition*. 2021;211:104645. doi:10.1016/j.cognition.2021.104645
35. Luo J, Yang Q, Du X, Zhang Q. Neural correlates of belief-laden reasoning during premise processing: an event-related potential study. *Neuropsychobiology*. 2010;63(2):112–118. doi:10.1159/000317846
36. Luo J, Yuan J, Qiu J, Zhang Q, Zhong J, Huai Z. Neural correlates of the belief-bias effect in syllogistic reasoning: an event-related potential study. *Neuroreport*. 2008;19(10):1073–1078. doi:10.1097/WNR.0b013e3283052fe1
37. Prado J, Kaliuzhna M, Cheylus A, Noveck IA. Overcoming perceptual features in logical reasoning: an event-related potentials study. *Neuropsychologia*. 2008;46(11):2629–2637. doi:10.1016/j.neuropsychologia.2008.04.017
38. Banks AP, Hope C. Heuristic and analytic processes in reasoning: an event-related potential study of belief bias. *Psychophysiology*. 2014;51(3):290–297. doi:10.1111/psyp.12169
39. Bonnefond M, Castelain T, Cheylus A, Van der Henst JB. Reasoning from transitive premises: an EEG study. *Brain Cognition*. 2014;90:100–108. doi:10.1016/j.bandc.2014.06.010
40. Cai X, Li F, Wang Y, et al. Electrophysiological correlates of hypothesis evaluation: revealed with a modified Wason's selection task. *Brain Res*. 2011;1408:17–26. doi:10.1016/j.brainres.2011.06.056
41. Yin Y, Yu T, Wang S, et al. Event-related potentials support a dual process account of the Embedded Chinese Character Task. *Neuropsychologia*. 2018;121:186–192. doi:10.1016/j.neuropsychologia.2018.10.021
42. Bago B, Frey D, Vidal J, Houdé O, Borst G, De Neys W. Fast and slow thinking: electrophysiological evidence for early conflict sensitivity. *Neuropsychologia*. 2018;117:483–490. doi:10.1016/j.neuropsychologia.2018.07.017
43. Bonnefond M, Van der Henst JB. What's behind an inference? An EEG study with conditional arguments. *Neuropsychologia*. 2009;47(14):3125–3133. doi:10.1016/j.neuropsychologia.2009.07.014
44. Faul F, Erdfelder E, Buchner A, Lang AG. Statistical power analyses using G* Power 3.1: tests for correlation and regression analyses. *Behav Res Meth*. 2009;41(4):1149–1160. doi:10.3758/BRM.41.4.1149
45. Jensen KM, MacDonald JA. Towards thoughtful planning of ERP studies: how participants, trials, and effect magnitude interact to influence statistical power across seven ERP components. *Psychophysiology*. 2022;e14245. doi:10.1111/psyp.14245
46. World Medical Association. World medical association declaration of Helsinki: ethical principles for medical research involving human subjects. *JAMA*. 2013;310(20):2191–2194. doi:10.1001/jama.2013.281053
47. Schaefer A, Nils F, Sanchez X, Philippot P. Assessing the effectiveness of a large database of emotion-eliciting films: a new tool for emotion researchers. *Cognit Emot*. 2010;24:1153–1172. doi:10.1080/02699930903274322
48. Schnall S, Haidt J, Clore GL, Jordan AH. Disgust as embodied moral judgment. *Persona Soc Psychol Bullet*. 2008;34(8):1096–1109. doi:10.1177/0146167208317771
49. Gross JJ, Levenson RW. Emotion elicitation using films. *Cognition & Emotion*. 1995;9(1):87–108. doi:10.1080/02699939508408966
50. Vecchi M, Fan L, Keller K, Myruski S, Nayga Rudolfo M, Yang W. Understanding the Impact of Online Food Advertisements and Emotions on Adolescents. In: *Food Choices, "2022 Annual Meeting"*. Anaheim, California: Agricultural and Applied Economics Association; 2022.
51. Raoelison M, Keime M, De Neys W. Think slow, then fast: does repeated deliberation boost correct intuitive responding? *Memory Cognition*. 2021;49:873–883. doi:10.3758/s13421-021-01140-x
52. Watson D, Clark LA, Tellegen A. Development and validation of brief measures of positive and negative affect: the PANAS scales. *J Person Soc Psychol*. 1988;54:1063–1070. doi:10.1037/0022-3514.54.6.1063

53. Delorme A, Makeig S. EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *J Neurosci Methods*. 2004;134(1):9–21. doi:10.1016/j.jneumeth.2003.10.009
54. Lopez-Calderon J, Luck SJ. ERPLAB: an open-source toolbox for the analysis of event-related potentials. *Front Hum Neurosci*. 2014;8:213. doi:10.3389/fnhum.2014.00213
55. Tanner D, Morgan-Short K, Luck SJ. How inappropriate high-pass filters can produce artifactual effects and incorrect conclusions in ERP studies of language and cognition. *Psychophysiology*. 2015;52(8):997–1009. doi:10.1111/psyp.12437
56. Delorme A, Sejnowski T, Makeig S. Enhanced detection of artifacts in EEG data using higher-order statistics and independent component analysis. *Neuroimage*. 2007;34(4):1443–1449. doi:10.1016/j.neuroimage.2006.11.004
57. Jung TP, Makeig S, Humphries C, et al. Removing electroencephalographic artifacts by blind source separation. *Psychophysiology*. 2000;37(2):163–178. doi:10.1111/1469-8986.3720163
58. Sawaki R, Luck SJ. Active suppression of distractors that match the contents of visual working memory. *Vis cogn*. 2011;19(7):956–972. doi:10.1080/13506285.2011.603709
59. Bao W, Yu T, Wang Y, Luo J. The neural pattern of intuitive and analytical processes in the subliminal environment: N2 responses on the embedded Chinese character task. *Consciousn Cognit*. 2022;97:103260. doi:10.1016/j.concog.2021.103260
60. Aulbach MB, Harjunen VJ, Spapé M, Knittle K, Haukkala A, Ravaja N. No evidence of calorie-related modulation of N2 in food-related Go/No-Go training: a preregistered ERP study. *Psychophysiology*. 2020;57(4):e13518. doi:10.1111/psyp.13518
61. Polich J. Updating P300: an integrative theory of P3a and P3b. *Clin Neurophysiol*. 2007;118(10):2128–2148. doi:10.1016/j.clinph.2007.04.019
62. Walsh MM, Gunzelmann G, Anderson JR. Relationship of P3b single-trial latencies and response times in one, two, and three-stimulus oddball tasks. *Biol Psychol*. 2017;123:47–61. doi:10.1016/j.biopsycho.2016.11.011
63. Bollon T, Bagneux V. Can the uncertainty appraisal associated with emotion cancel the effect of the hunch period in the Iowa Gambling Task? *Cogn Emo*. 2013;27(2):376–384. doi:10.1080/02699931.2012.712947
64. Purcell ZA, Howarth S, Wastell CA, Roberts AJ, Sweller N. Eye tracking and the cognitive reflection test: evidence for intuitive correct responding and uncertain heuristic responding. *Mem Cogn*. 2022;50:348–365. doi:10.3758/s13421-021-01224-8
65. Fink-Lamotte J, Svensson F, Schmitz J, Exner C. Are you looking or looking away? Visual exploration and avoidance of disgust- and fear-stimuli: an eye-tracking study. *Emotion*. 2022;22(8):1909–1918. doi:10.1037/emo0000993
66. Fink J, Buchta F, Exner C. Differential response patterns to disgust-related pictures. *Cogn Emot*. 2018;32(8):1678–1690. doi:10.1080/02699931.2017.1423040
67. Fink-Lamotte J, Widmann A, Sering K, Schröger E, Exner C. Attentional processing of disgust and fear and its relationship with contamination-based obsessive–compulsive symptoms: stronger response urgency to disgusting stimuli in disgust-prone individuals. *Front Psychiatry*. 2021;12:596557. doi:10.3389/fpsyt.2021.596557
68. Lerner JS, Small DA, Loewenstein G. Heart strings and purse strings: carryover effects of emotions on economic decisions. *Psychol Sci*. 2004;15(5):337–341. doi:10.1111/j.0956-7976.2004.00679.x
69. Zimmer U, Keppel MT, Poglitsch C, Ischebeck A. ERP evidence for spatial attention being directed away from disgusting locations. *Psychophysiology*. 2015;52(10):1317–1327. doi:10.1111/psyp.12463
70. Liu Y, Zhang D, Luo Y. How disgust facilitates avoidance: an ERP study on attention modulation by threats. *Soc Cogn Affect Neurosci*. 2015;10(4):598–604. doi:10.1093/scan/nsu094
71. Edwards JA, Weary G. Depression and the impression formation continuum: piecemeal processing despite the availability of category information. *J Person Soc Psychol*. 1993;64:636–645. doi:10.1037/0022-3514.64.4.636
72. Donchin E, Coles MGH. Is the P300 component a manifestation of context updating? *Behav Brain Sci*. 2010;11(3):357–374. doi:10.1017/S0140525X00058027
73. Takács E, Barkaszi I, Altbäcker A, Czigler I, Balázs L. Cognitive resilience after prolonged task performance: an ERP investigation. *Exp Brain Res*. 2019;237(2):377–388. doi:10.1007/s00221-018-5427-8
74. Ullsperger M, Fischer AG, Nigbur R, Endrass T. Neural mechanisms and temporal dynamics of performance monitoring. *Trend Cognit Sci*. 2014;18(5):259–267. doi:10.1016/j.tics.2014.02.009
75. Van den Bos K. On the subjective quality of social justice: the role of affect as information in the psychology of justice judgments. *J Person Soc Psychol*. 2003;85(3):482–498. doi:10.1037/0022-3514.85.3.482
76. Bhikram T, Abi-Jaoude E, Sandor P. OCD: obsessive-compulsive … disgust? The role of disgust in obsessive-compulsive disorder. *J Psychiatry Neurosci*. 2017;42(5):300–306. doi:10.1503/jpn.160079