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Moral Neuroscience Mechanisms Underlying Daily Moral Decision-Making: Evidence from ERPs

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Abstract:

Morality has been one of the key elements of moral judgment research, but due to the complexity of moral mechanism, individuals are susceptible to the influence of social desirability in moral decision making, resulting in low validity of questionnaire and interview method results. With the development of cognitive neuroscience techniques, it is possible to explore the internal neural mechanisms of individuals in moral decision-making through neuroscience techniques. As a result, the mechanisms of moral neural processing have recently received much attention. This study intends to explore the internal mechanisms of moral neural processing through a neuroscientific research paradigm. This experiment was conducted with 23 student subjects from a university, and the experimental design was a one-factor experimental design with moral decision types: immoral vocabulary, moral vocabulary, and non-moral vocabulary. Analyses were conducted using a two-factor repeated measures ANOVA for moral type 3 (immoral vocabulary vs. moral vocabulary vs. non-moral vocabulary) x 4 brain region location (left forebrain vs. right forebrain vs. left hindbrain vs. right hindbrain). An event-related potentiation technique was used to respond to moral and immoral words and to explore the electrophysiological information in the processing of moral-related words. The results showed that N2 wave amplitude for moral decision type3 (moral vs. immoral vs. non-moral) x EEG location4 (left forebrain vs. right forebrain vs. left hindbrain vs. right hindbrain) two-factor repeated measures ANOVA found a significant $F(6, 108) = 6.824$, $p < .000$, 2 for the interaction between moral decision type and EEG location =.414. As the interaction was significant therefore the simple effects were analysed and found that the simple effect of moral decision type and EEG location was significant at $p<0.000$, EEG location at the moral level was significant $F(3, 54) = 16.00$, $p<0.001$, EEG location at the immoral level was significant $F(3, 54) = 16.00$, $p<0.001$ and EEG location at the immoral level was significant $F(3, 54)=19.00$, $P<0.000$. A two-factor repeated measures ANOVA on P3 latency for moral decision type3 (moral vs. immoral vs. non-moral) x EEG location4 (left forebrain vs. right forebrain vs. left hindbrain vs. right hindbrain) found a significant $F(6, 108) = 4.328$, $p < 0.003$, interaction between moral decision type and EEG location. Moral decision type interacted significantly with EEG location $F(6, 108) = 8.900$, $p < 0.000$. Since the interaction was significant, simple effects were analyzed, controlling for the EEG location factor, moral decisions

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differed significantly $F(3, 54) = 14.69$, $p < 0.000$, unethical decisions differed significantly $F(3, 54) = 7.62$, $p < 0.000$, and unethical decisions differed significantly $F(3, 54) = 11.62$, $p < 0.000$. The neural time processing of moral decision-making processing and unethical decision-making processing are more consistent. Moral decision-making activates more brain areas; Moral decision-making is relatively more complicated. The processing process of moral decision-making is consistent with that of unethical decision-making. Moral decision-making activates more EEG components.

Keywords: *Morality, Decision-making, Cognitive nerve, ERPs, The late positive potential*

I. INTRODUCTION

Early studies on moral psychology decision-making believed that moral psychology decision-making was rational and pointed out the key role reasoning and rational thinking played in moral decision-making [1]. Advances in cognitive neuroscience provide a new direction for the study of moral decision-making. Through studying emotional processing in patients with brain injuries, Antonio (1994) prompted the birth of emotional, moral neuroscience [2]. Moral disorders in mentally-ill patients [3-5], moral development of nerve damage [6-8] and the impact of physical exhaustion on morality [9] have all contributed to the advancement of neurological research on moral decision-making. Also, many psychological components and brain functional areas related to moral decision-making have been discovered [10]. Haidt (2001), who believed that emotion plays a big role in the moral decision-making process, found that the subjects became silent during the moral decision-making process. That is, though able to make decisions quickly in this process, the subjects, when asked their reason, could not provide an answer (Haidt, 2001). Believing that moral decision-making is a quick, automatic, and unconscious evaluation process, Haidt proposed the Social Intuitionist Model for moral decision-making. Greene (2001), based on fMRI neurobrain imaging research, found that moral decision-making depends largely on social emotion [11]. Neuroimaging studies found that when faced with a moral dilemma that required a decision, utilitarian decision-making takes longer to respond, and the dorsolateral prefrontal cortex (DLPFC) and inferior parietal lobe are also activated. These areas are related to deliberative processing that involves cognitive engagement. The response time for moral decision-making is relatively shorter, and the activated brain areas are more complicated, such as the VMPFC, superior temporal lobe and the amygdala. These areas are related to emotional processing and unconscious thinking [12-14], indicating that moral judgement is a dual processing mechanism [15]. Although people have developed a better understanding of the neural mechanism of moral decision-making, some analyses have found an insufficiency of studies on the mechanism of moral decision-making. Most of the above studies used fMRI, which has a strong spatial positioning ability but cannot guarantee the accuracy of the moral decision-making process because of low time accuracy. In addition, moral dilemmas were adopted as the research materials, so there was the problem of methodological homogeneity [16], adding a distinctive cross-cultural component to morality [17, 18]. Sarlo adapted Greene's moral decision-making experiment materials in 2012. Using ERPs to analyze its time course, he found a positive component appearing around 260ms after the decision-making. He believed that P260 was related to moral decision-making [19], and pointed out that P300 was positively related to the usage of psychological resources to a certain extent. When the subjects make more cognitive

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efforts, the volatility is greater. Scenario-based experimental materials were still used in the study. In moral decision-making control, subjects were required to make decisions at specific times rather than when they saw the materials. But the above experiment control has been subject to a lot of doubts. Generally, individuals perform a keystroke reaction after they see the materials and make a decision. Their EEG components during keystroke analysis are not based on EEG processing when subjects made moral decisions. Also, in the studies of Greene et al., the material type was unclear, and the project was inadequately differentiated; moreover, many of the subsequent studies are based on Greene's experimental materials. The research differences are rather likely to be caused by the dilemma type [20]. In addition, the types of materials used are extreme moral dilemmas and their inference validity is not high. Therefore, this study uses more realistic moral phenomena to improve the ecological validity of the experimental materials. Taking this as an entry point, this study used real-life moral phenomena as experimental research materials. Moral phrases in the Chinese language can be controlled by altering the length and scenario, evident in phrases such as “spitting phlegm on the ground at will” and “illegally selling counterfeit items” and so on. These phrases have consistency in length and depend on the scenario to a certain degree. Through the pre-experiment collection, this study evaluated and standardized the moral experiment materials, and then used the Go-Nogo paradigm to study the neural mechanism of individual moral decision-making and discuss the neural processing mechanism of moral decision-making, aiming to reveal the brain activity law of moral decision-making, provide a theoretical basis for effective moral construction and develop and enrich moral neuroscience theories.

II. METHOD

2.1 Participants

120 right-handed participants at Jinan University participated in the study. Participants were screened for a history of neurological disorders, brain injury, or developmental disabilities. All of them had normal or corrected-to-normal vision. 2 participants’ EEG data were rejected due to a technical problem (recording failed) and the other 2 were rejected due to intensive head movements during EEG recording (> 0.2 bad epochs). 23participants’ data were included in the analysis (11 females, age: 29 ± 1.51y[mean ±sd]).

2.2 Experimental Materials and Design

The experimental design used a moral decision-making model: single-factor experimental design of immoral phrase, moral phrase, non-moral phrase. The analysis used the two-factor repeated-measures ANOVA of three moral types (immoral phrase, moral phrase and non-moral phrase) × 4 areas of the brain (left forebrain, right forebrain, left hindbrain and right hindbrain). The moral experiment materials are classified according to the above 3 types, e.g., immoral materials: counterfeiting, theft, faking and betraying; moral materials: helping, serving society and altruism; morality-irrelevant materials: self-consolation with false hope, self-deception and being joyful and cheerful. Each type of experimental material is limited to 4 Chinese characters or less. The experimental materials obtained from the

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pre-experiment, 70 phrases in each group, were selected to conduct an F-test on the number of characters in the experimental materials. The result showed P>0.05 and a non-significant difference in the number of characters in the three groups. After all phrases were sent to 60 subjects and invalid data was eliminated, 58 subjects were found to meet the evaluation requirements (including 24 men, with an average age of 29.7 ± 2.3). The materials were evaluated to see whether they belonged to immoral, moral, or unrelated moral phrases. Finally, 50 phrases in each group were selected for the study. These materials were validated before use (Tang & Lin, 2015). Each phrase category would appear 60 times in the study.

2.3 Experimental Procedure

The stimulus display and behavioral data acquisition were performed using E-Prime 2.0 professional software (Psychology Software Tools). During the task, the participants sat comfortably in an electrically shielded room approximately 80 cm from a 17-inch color computer screen. The segments were printed in black font against a white background, the horizontal Angle of view is 1.5°, and the vertical Angle is about 1.5°. In the experiment, words were presented to the subjects randomly, experiments are divided into exercises and formal experiments. Each word was presented for 3000 ms. Each word began with a fixation cross that was presented for 1000 ms. A jittered interval of 600 to 800 ms was set between trials.The experiment contains 180 trials in total. All trials were randomly presented in three blocks. (Fig. 1). The subjects were required to press the button reaction, and if they thought it was moral, they would press the "1". Immoral and normal behaviors were not pressed, and then they entered the next trial.

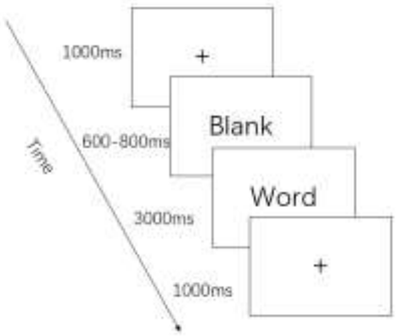

Figure 1: Experimental Procedure and Sample Trials.

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III. RESULT AND ANALYSIS

3.1 Analysis on ERPS EEG Components

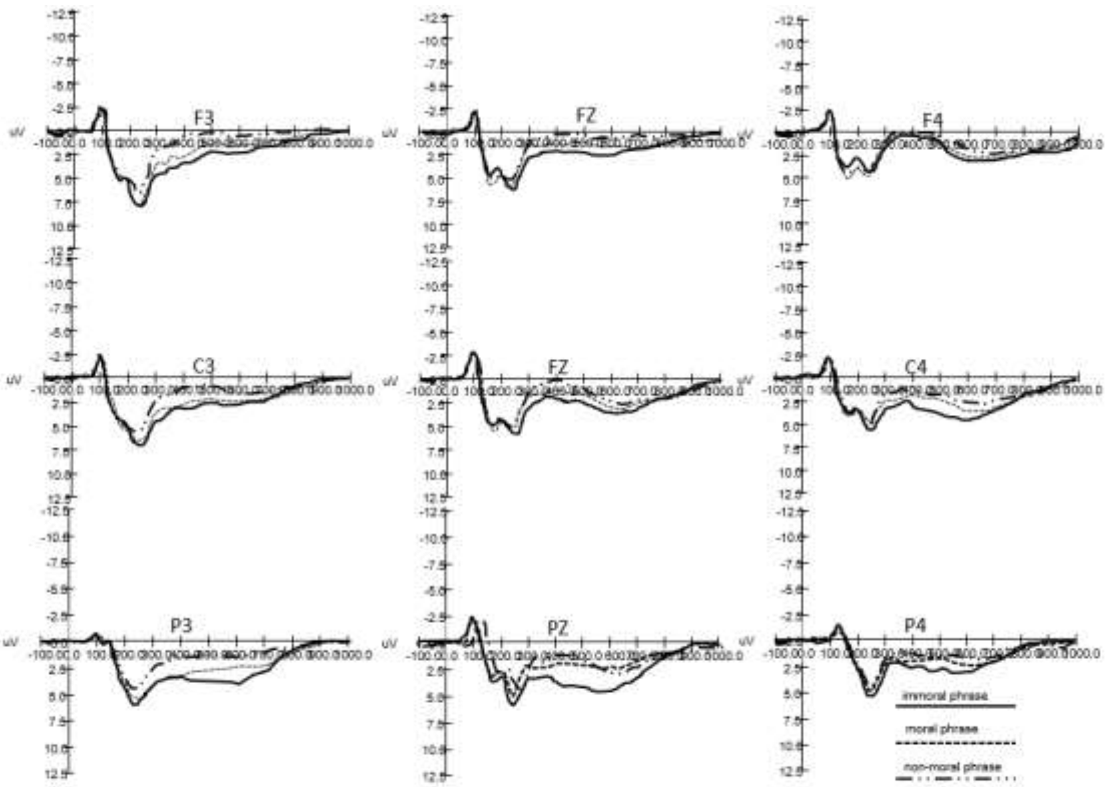

Figure 2: Grand Average of ERPs EEG

3.2 N2 Component Analysis

The two-factor repeated-measures ANOVA of the three types of morality (moral, immoral and non-moral) × 4 areas of the brain (left forebrain, right forebrain, left hindbrain and right hindbrain) was used for N2 volatility and found a significant interaction between the moral decision-making type and EEG position F (6, 342)=6.824, P=0.000, 2=414. A simple effect analysis was conducted due to the significant interaction and found a significant simple effect between the moral decision-making type and EEG position, P=0.000: at the moral level, EEG position was significantly F (3,114)=16.00, P=0.001; at the immoral level, EEG position was significantly F (3,114)=16.00, P=0.001; at the non-moral level, EEG position was significantly F (3,114)=19.00, P=0.000. According to Bonferroni: at the moral level, a significant difference of P=0.000, P=0.000 was found in the left forebrain, right forebrain and right hindbrain, a significant difference of P=0.000 between the left hindbrain and the right forebrain; at the immoral level, a significant difference of P=0.000, P=0.000 in the left forebrain, right forebrain and right hindbrain, a significant difference of P=0.001 between the left hindbrain and the right hindbrain(Fig. 2). At the non-moral level, a significant difference was noted between the right hindbrain and left hindbrain; at

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the level of the left forebrain and right hindbrain, a significant difference of P=0.003, 0.004 was noted between the moral decision-making and immoral decision-making, other differences were not significant.

3.3 P2 Component Analysis

The two-factor repeated-measures ANOVA of three types of morality (moral, immoral and non-moral) × 4 areas of the brain (left forebrain, right forebrain, left hindbrain and right hindbrain) was used for P2 volatility and found a significant interaction between the moral decision-making type and EEG position F (6, 342)=26.005, P=0.000, 2= .354. A simple effect analysis was conducted due to the significant interaction and found that the moral decision-making was significantly different at EEG position, F(3,114)=23.00, P=0.000; the immoral decision-making was significantly different at EEG position, F(3, 114)=17.25, P=0.000; the non-moral decision-making was significantly different at EEG position, F(3, 114)=17.86, P=0.000(Fig. 2). By conducting Bonferroni on the above differences, it was found that at the moral decision-making level, there was significant difference of P=0.000 in the four EEG positions and a significant difference of P=0.025 between the right forebrain and right hindbrain. At the immoral level, a significant difference of P=0.003, P=0.003 was found among the left forebrain, right forebrain and right hindbrain. Under the condition of controlling the moral decision-making type, the left forebrain position showed significant difference in moral decision-making F(3,114)=32.50, P=0.000; the right forebrain EEG position had a significant difference in moral decision-making F(3,114)=32.50, P=0.000; the left hindbrain had a significant difference in moral decision-making F (3,114)=8.52, P=0.001; the right hindbrain had a significant difference in moral decision-making F(3,114)=9.32, P=0.001. The Bonferroni for the above differences found that in the left forebrain, there was a significant difference of P=0.000 between moral decision making and immoral decision-making, and a significant difference of P=0.000 between immoral and non-moral decision-making. In the right forebrain, there was a significant difference of P=0.000, P=0.003 among moral, immoral, and non-moral decision-making, and a significant difference of P=0.000 between immoral and non-moral decision-making. In the right hindbrain, there was a significant difference of P=0.036 between moral and non-moral decision-making, and a significant difference of P=0.036 between moral and immoral decision-making. In the left hindbrain, there was a significant difference of P=0.004, P=0.020 among moral, immoral, and non-moral decision-making.

The two-factor repeated-measures ANOVA of three types of morality (moral, immoral and non-moral) × 4 brain areas (left forebrain, right forebrain, left hindbrain and right hindbrain) was used for P2 volatility and found a significant main effect in the moral decision-making type, F (3,114) =89.068, P=0.00 (moral=7.454±0.242μV, immoral=5.741±0.288μV, non-moral=4.200±0.251μV). According to Bonferroni, there was a significant difference of P=0.000, P=0.000 among moral, immoral, and non-moral decision-making, and a significant difference of P=0.000 between immoral and non-moral decision-making. The main effect of the EEG position was significant, F(3,114)=10.090, P=0.000, 2=.410 (left forebrain=6.813±0.409μV, right forebrain=5.932±0.269μV, left hindbrain=5.290±0.175μV, right hindbrain=5.156±0.298μV). According to the Bonferroni, there was a significant difference of P=0.008, P=0.001 between the left forebrain, right hindbrain and left hindbrain, and other differences were not

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significant. The interaction between moral decision-making type and EEG position was not significant F (6,342) =1.438, P=0.191.

3.4 P3 Component Analysis

The two-factor repeated-measures ANOVA of three types of morality (moral, immoral and non-moral) × 4 brain areas (left forebrain, right forebrain, left hindbrain and right hindbrain) was used for N2 volatility and found a significant interaction between the moral decision-making type and EEG position F (6,342)=4.328, P=0.003, 2=397. A simple effect analysis was conducted due to the significant interaction and found that the moral decision-making was significantly different at EEG position, F (3,114)=6.741, P=0.000; the immoral decision-making had a significant margin difference at EEG position, F(3,114)=2.77, P=0.051; the non-moral decision-making was insignificantly different at EEG position, F(3, 114)=0.87, P=0.460. By conducting Bonferroni on the above differences, it was found that at the moral decision-making level, there was a significant difference of P=0.044 in the left forebrain and right hindbrain; at the moral decision-making level, there was a significant difference of P=0.014 between the right forebrain and left forebrain.

The two-factor repeated-measures ANOVA of three types of morality (moral, immoral and non-moral) × 4 brain areas (left forebrain, right forebrain, left hindbrain and right hindbrain) was used for P3 volatility and found a significant interaction between the moral decision-making type and EEG position F (6, 342)=5.896, P=0.000, 2=430. A simple effect analysis was conducted due to the significant interaction and found: at the moral level, the difference in EEG position was significant, F (6,342) =16.02, P=0.000; at the immoral level, the difference of EEG position was significant, F(6,3428)=10.03, P=0.000; at the non-moral level, the difference of EEG position was significant, F(6,342)=10.08, P=0.000. By conducting Bonferroni on the above differences, it was found that at the moral decision-making level, there was a significant difference of P=0.000, P=0.003 among the left forebrain, right forebrain and right hindbrain, a significant difference of P=0.000 between the right forebrain and left hindbrain, and a significant difference P=0.000 between the right hindbrain and right forebrain. At the immoral level, a significant difference of P=0.000, P=0.002 among the left forebrain, right forebrain and right hindbrain, and a significant difference of P=0.000 between the right forebrain and left hindbrain. At the non-moral decision-making level, a significant difference of P=0.10 was noted between the left forebrain and right forebrain, a significant difference of P=0.031 between the right hindbrain and left forebrain, and a significant difference of P=0.005 between the right forebrain and right hindbrain was noted. Factors controlling the EEG position found that the moral level at the left forebrain was significantly different, F (6,342) =7.84, P=0.001; the moral level at the right forebrain was insignificantly different F (6,342) =0.37, P=0.697; the moral level at the right hindbrain was significantly different F (6,342) =8.79, P=0.001. The Bonferroni for the above differences found that in the left forebrain, there was a significant difference of P=0.004 between moral and immoral decision-making, and a significant difference of P=0.038 between immoral and non-moral decision-making; in the left hindbrain, there was a significant difference of P=0.004, P=0.005 among non-moral, moral and immoral decision-making.

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3.5 LPC

The two-factor repeated-measures ANOVA of three types of morality (moral, immoral and non-moral) × 4 brain areas (left forebrain, right forebrain, left hindbrain and right hindbrain) was used for the average volatility within the 500-700ms time window and found significant interaction between the moral decision-making type and EEG position F (6,342) =8.900, P=0.000. A simple effect analysis was conducted due to the significant interaction, and found that under the factors controlling the EEG position, moral decision-making was significantly different at EEG position F (3,114) =14.69, P=0.000. Immoral decision-making was significantly different at EEG position F (3,114) =7.62, P=0.000. Non-moral decision-making was significantly different at EEG position F (3,114) =11.62, P=0.000. The Bonferroni for the above significant differences found that at the moral decision-making level, there was a significant difference of P=0.000. P=0.004 among the left forebrain, right forebrain and right hindbrain, a significant difference of P=0.000 between the right forebrain and left hindbrain, and a significant difference of P=0.000 between the right forebrain and right hindbrain; at the immoral level, a significant difference of P=0.000, P=0.011 was noted among the left forebrain, right forebrain and right hindbrain, a significant difference of P=0.000 between the right forebrain and left hindbrain. Under the factors controlling the moral decision-making type, the left forebrain was significantly different F (3,114) =8.69, P=0.001, and the left hindbrain was significantly different F (3,114) =9.38, P=0.001. The Bonferroni for the above significant differences found that there was a significant difference of P=0.001 between moral and non-moral decision-making.

IV. DISCUSSION

As can be seen from the above-mentioned grand average waveform, the difference between individuals' immoral processing and moral processing is mainly found in the late component LPC (500-700ms). Moral decision-making and immoral decision-making are generally similar in terms of processing mechanism, indicating that they have similar processing. The volatility and latency of morality-irrelevant behaviors are relatively small, indicating a large difference existing between the moral judgment process and ordinary judgment process. The difference between the latency and volatility of the earliest N1 component is not significant, mainly because N1 is an endogenous attention processing component [21-23] and shown as visual processing. The BEAM shows that about 100ms after the moral stimulus presentation, change occurs in brain discharge. Moral processing emits a large amount of negative electricity near the frontal lobe, while that of immoral processing is relatively low. A P2 component appeared approximately 160ms after the stimulus was presented. There are differences in the processing of moral and immoral decision-making, and the processing of immoral decision-making has greater volatility [24], indicating that individuals when confronted with immoral behaviors, will be more focused and subsequently, pay more attention. The volatility of moral decision-making processing is smaller[19], indicating a difference existing between moral processing and immoral processing at around 160ms. Greene (2010) believed that the immoral and moral decision-making process in moral processing is a simultaneous parallel processing. The brain areas activated by moral decision-making have more complex processing. An analysis on the time window reveals that the moral brain is more activated. A positive shift

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P2 component appeared around 240ms after the stimulus was presented. The processing time of moral decision-making is shorter than that of immoral decision-making, and this component is associated with emotional processing[25]. The time for moral decision-making to enter emotional processing is relatively shorter, while the emotional processing for immoral decision-making enters rather slowly, and the volatility of moral decision-making is higher than that of immoral decision-making. Greene's dual-processing theory maintains that no emotional processing is involved in immoral decision-making, and it is based only on a simple cognitive process [26]. The above experiment found that this process also included emotional processing, and this might be caused by the fact that fMRI has a time resolution too low to make a distinction; furthermore, Greene's experimental materials failed to clearly define emotions, which could lead to processing differences[1] .

The P3 volatility varied significantly in moral and immoral decision-making. The P3 component is susceptible to emotional valence [27, 28] the greater the emotional valence, the greater the volatility. The above experiment found that the P300 differs greatly among moral behavior, immoral behavior, and non-moral behavior. Moral decision-making showed the biggest volatility, and immoral decision-making showed a smaller volatility. Cognitive control processing had a greater impact on immoral decision-making at this point [11], and P300 was sensitive to negative emotion, but negative emotion caused by immoral decision-making processing is less than that of moral behavior. In this study, it is the subjects who evaluate whether the moral phrase is reasonable, and their involvement is at a low level, resulting in a relatively small P300 volatility of emotional processing. According to psychological theory, when people relive what had happened before, emotion could be an indicator to help individuals make the fastest decision and generate emotional memory for them to make decisions directly [29]. When confronted with common immoral behaviors, individual processing directly enters emotional memory. That is why EEG shows a relatively smaller volatility. However, compared with non-moral decision-making, immoral decision-making has greater volatility, indicating that the entire process is not cognitive control processing in a pure sense and may include emotional processing components. A comparison of the average volatility of the 500-700ms time window can also reveal the difference among moral processing, immoral processing, and non-moral processing behaviors.

In the BEAM, compared with moral/immoral decision-making, non-moral decision-making activates the brain to a lesser degree, that is, immoral decision-making activates the brain less strongly. Moral decision-making and immoral decision-making have a similar degree of activation but show great differences in the location of different brain areas: the left forebrain is more activated. That is probably because DLPFC and VMPFC, located near the left forebrain, have a relatively high degree of activation during the moral decision-making process [11]. Therefore, a higher EEG volatility has been induced, and these areas are strictly related to emotion processing. LPC (Late Positive Component: 300ms later) analysis shows that the brain activation degree of moral decision-making becomes smaller and smaller, while the immoral decision-making could create a greater activation degree[19, 30, 31]. We believe that is because emotional processing becomes more stable at this time, and cognitive processing in immoral decision-making is more active and dominant. Therefore, there are two effects of processing present in the interaction, resulting in a greater degree of activation.

Sarlo believed that the P2 component has a positive connection with negative emotion processing in moral judgment [25], but the P2 component is also found in ordinary moral phrase judgment. We believe that the moral evaluation of the experimental materials (integrity management) used in this study involves less negative emotion, and it is an evaluation of the moral behavior of others, with more positive emotion generated during the evaluation. Therefore, simply considering the P2 component as negative emotion processing is yet to be confirmed.

V. CONCLUSION

The following conclusion can be drawn from the above experiment and analysis: 1) Moral decision-making processing and immoral decision-making processing have a rather similar neural time processing. 2) Moral decision-making activates more brain areas. 3) Moral decision-making is relatively more complicated. However, there are different interpretations of the P2 component in the study, probably because Sarlo's study required individuals to make decisions in the experiment, that is, the subjects had to make choices when facing a moral dilemma. In this process, more emotional processing would be activated. Therefore, this study pre-uses a method similar to Sarlo’s to analyze one’s moral decision-making, as well as moral processing differences under increased cognitive load.

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