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Individual Differences in Humor Processing: A Review of fMRI and ERP Evidence

Bing Yan[1]

[1] School of Foreign Languages, Dalian University of Technology, Dalian, China

Correspondence: Bing Yan, School of Foreign Languages, Dalian University of Technology, Dalian, 116000, China. E-mail: yanbing010418@163.com

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Abstract

Humor plays a crucial role in social interaction and emotional regulation. As a complex psychological phenomenon, the processing mechanism of humor is significantly affected by individual differences. This paper systematically reviews individual differences in verbal humor processing, and integrates fMRI and ERP studies to explore the cognitive neural mechanisms of four key individual factors (gender, age, personality traits, mental state) in the processing of verbal humor. By reviewing the main findings of different studies and analyzing their consistency and controversy, it is found that gender differences are involved in different brain regions activation during humor processing, and age differences are related to the maturation of brain structure and function. Personality traits (such as extraversion and introversion) and mental state factors such as schizophrenia also show significant differences in humor experience and neural mechanisms. This review attempts to provide a more comprehensive perspective on the cognitive neuroscience of verbal humor, points out directions for future research, and emphasizes the importance of considering specific individual differences in future humor processing studies.

Keywords: psycholinguistics, humor processing, individual differences, ERPs, fMRI

1. Introduction

Humor, as a complex psychological phenomenon, requires individuals not only to comprehend the humor but also to appreciate it emotionally[1]. It not only brings pleasant experiences to people but also plays a crucial role in social interaction and emotional regulation. It has attracted extensive attention in fields such as psychology, neuroscience, and linguistics in recent years.

However, it is difficult for traditional psychological research to reveal the cognitive neural processing characteristics of humor processing in time and space, so brain imaging and EEG techniques have been widely used in this field in recent years. Functional magnetic resonance imaging (fMRI) and event-related potentials (ERPs) are two primary methods for exploring the neural mechanism of humor processing[1][2][3]. They are two neuroimaging techniques that offer distinct yet complementary insights into brain function[4]. ERPs provide high temporal resolution, capturing the millisecond-by-millisecond changes in electrical activity associated with cognitive and sensory processing. This makes ERPs ideal for studying the sequence and timing of brain events. fMRI offers high spatial resolution, allowing researchers to pinpoint the exact brain regions that are active during a particular task or in response to a specific stimulus.

Humor processing is not static, and individual differences such as sex/gender, age, personality and psychological factors can significantly impact humor perception and comprehension. Humor varies greatly across individuals, genders[5], as well as over age[6]. In recent years, neuroscience research has increasingly focused on individual differences such as gender and age in humor processing[7][8][9]. These factors are particularly important because they can significantly influence the neural mechanisms and cognitive processes involved in humor comprehension and appreciation. For instance, a study by Prenger et al.[9] highlighted that women may have a more pronounced reward and enjoyment response to humor compared to men. Additionally, research has indicated that men tend to use humor more frequently, especially in aggressive forms, which aligns with cultural expectations and stereotypes. These factors can influence how humor is produced and received, further highlighting the importance of considering gender in humor processing studies. Moreover, the ability to perceive, comprehend, and appreciate humor may change with age, which could be related to the aging of brain structure and function. The inclusion of individual differences such as gender and age in humor processing research provides a more comprehensive

understanding of the neural and cognitive mechanisms involved in humor comprehension and appreciation. These factors not only influence how humor is processed in the brain but also highlight the importance of considering diverse populations in neuroscience studies to ensure the findings are applicable to a broader range of individuals.

This paper will systematically review individual differences in the processing of verbal humor. By integrating fMRI and ERP studies, the cognitive neural mechanism of four key individual factors (gender, age, personality trait, mental state) in processing was explored. It will analyze the neural mechanism of humor processing by considering both the timing (temporal) and brain regions (spatial) involved, to reveal how these individual differences factors impact humor processing. The paper will first review the application of fMRI and ERP techniques in humor processing research, discussing their advantages and limitations. Then, it will delve into the influence of specific individual differences—gender, age, personality traits (extroversion and introversion), and schizophrenia—on humor processing. It will analyze how these factors affect individuals' humor experience and the associated neural mechanism. Finally, the paper will synthesize the findings from previous studies and suggest directions for future research. Through this review, we aim to provide a comprehensive overview of the current understanding of individual differences in humor processing and highlight potential areas for further investigation.

2. Sex Differences in Humor Processing

Humor is a sophisticated phenomenon of human social cognition with large inter-individual variability. Sex differences in emotion processing are a common finding in functional neuroimaging studies, and have been documented in behavioral studies of humor[10].

2.1 fMRI

fMRI studies have consistently shown that the neural correlates of humor appreciation differ between women and men. Azim et al.[11] found that women exhibited greater activation in the left prefrontal cortex and mesolimbic regions than men, suggesting a higher degree of executive processing and reward network response in women. This study did not identify any regions where men showed significantly more activation than women. The authors suggested that these differences may be related to women's greater abilities in language processing and language-based decoding, as well as possible gender differences in reward expectations[11].

Kohn et al.[10] conducted an fMRI experiment using online subjective funniness ratings for parametric modulation. They found that the limbic system, including the amygdala, insula, and anterior cingulate cortex, was more active in women than in men. In contrast, men showed greater activation in the thalamus and the dorsal processing system, including the dorsolateral prefrontal cortex (dlPFC). The study suggested that women process humor through limbic reactivation, involving an appraisal of its emotional features, while men apply more evaluative and executive resources to humor processing[10].

Vrticka et al.[12] investigated gender differences in children using funny, positive, and neutral video footage. The findings indicated that gender differences in brain function are already apparent in childhood, suggesting a biological basis for sex differences that form at an early stage of development. For instance, while watching humorous video clips, girls showed increased activity in the bilateral temporo-occipital cortex, midbrain, and amygdala. These areas are associated with visual processing, the reward system, and emotional responses, suggesting that girls may rely more on these brain regions when processing humor[12]. In contrast, boys showed increased activity in the bilateral inferior parietal lobe, inferior temporal gyrus, and ventromedial prefrontal cortex when watching positive video clips. These areas are associated with cognitive assessment, attention, and emotional regulation, suggesting that boys may rely more on these brain regions to process positive emotions[12]. The study also found that girls showed increased activation in the midbrain when watching humorous videos, which may be related to reward anticipation and experience, while boys exhibited increased activation in the ventromedial prefrontal cortex when watching positive videos, which may be related to reward anticipation and emotional regulation[12].

Based on earlier findings related to joke types[13], Chan[14] analyzed the neural correlates of sex differences in humor processing using a 2 (sex: men and women) × 3 (type: bridging-inference jokes, exaggeration jokes, and ambiguity jokes) factorial design. The study found that for bridging-inference jokes, women showed greater activation than men in the anterior prefrontal cortex (aPFC), temporoparietal junction (TPJ), parahippocampus gyrus, insula, orbitofrontal cortex (OFC), and supplementary motor area (SMA). For exaggeration jokes, women demonstrated greater activation than men in the aPFC, amygdala, midbrain, parahippocampus gyrus, and insula. For ambiguity jokes, women showed greater activation than men in the aPFC. Conversely, men showed greater activation than women in the dlPFC for bridging-inference jokes and the dorsal prefrontal cortex (dPFC) for exaggeration jokes. For ambiguity jokes, men showed greater activation than women in the dPFC and

parahippocampal gyrus. The findings suggest that women rely more on social-emotional processing when processing humor, while men rely more on cognitive control and language processing[14].

Another study by Chan[8] focused on the effective connectivity between brain regions during humor processing using dynamic causal modeling (DCM) and parametric empirical Bayesian (PEB) methods. The study found that women showed stronger effective connectivity from the amygdala to the anterior cingulate cortex when processing conflict-resolution humor, while men showed stronger effective connectivity from the amygdala to the ventromedial prefrontal cortex[8].

In summary, these studies identified some key brain regions with gender differences in humor processing, including the prefrontal cortex, temporoparietal junction, amygdala, insula, anterior cingulate cortex, thalamus, and dorsolateral prefrontal cortex. These differences may be related to fundamental gender differences in emotional processing, reward system responses, cognitive assessment, and language processing.

The differences and similarities between these studies are discussed in detail below. Studies on sex differences in humor processing have identified several key similarities and differences. A common finding across these studies is the universality of gender differences, with all studies confirming that men and women exhibit distinct brain activation patterns during humor processing. For instance, the limbic system, including regions such as the amygdala and insula, shows greater activation in women, which is associated with emotional processing and reward response. Additionally, the prefrontal cortex is consistently highlighted as playing a crucial role in humor processing, particularly in executive control and language processing.

Despite these commonalities, the studies also reveal diverse patterns of brain activation. Azim et al.[11] reported greater activation in the left prefrontal cortex and mesolimbic regions in women, suggesting a higher degree of executive processing and reward network response. In contrast, Kohn et al.[10] found that men exhibited more significant activation in the dorsolateral prefrontal cortex, indicating a greater reliance on cognitive control. Vrticka et al.[12] extended these findings to children and adolescents, observing sex differences in brain regions such as the midbrain, amygdala, and temporo-occipital cortex, which are associated with reward processing and visual-emotional integration.

The choice of research methods, participants, and materials also varied across studies. Azim et al.[11] and Kohn et al.[10] focused on adult samples, while Vrticka et al.[12] examined children and adolescents. The type of humorous material used differed as well, with some studies employing video clips and others using written jokes. Chan[14] provided a detailed classification of joke types, revealing different patterns of gender differences in humor processing based on the specific type of humor. For example, women showed greater activation in the anterior prefrontal cortex and limbic regions for certain joke types, while men exhibited more activation in the dorsolateral prefrontal cortex.

Chan[8] further explored the effective connectivity between brain regions during humor processing, offering new insights into how cognitive and emotional components relate to gender differences. This study highlighted that women demonstrated stronger effective connectivity from the amygdala to the anterior cingulate cortex when processing conflict-resolution humor, while men showed stronger connectivity from the amygdala to the ventromedial prefrontal cortex. These findings suggest that women may rely more on socio-emotional processing, whereas men may engage more in cognitive control and language processing during humor comprehension.

The differences in these studies can be attributed to several factors. First, the developmental stage of participants plays a crucial role. Studies involving children and adolescents[12] show different patterns of brain activation compared to those with adult participants[10][11], likely due to differences in brain development and cognitive abilities. Second, cultural and social factors may influence humor processing, as humor is often context-dependent and shaped by social norms and expectations. Third, the nature of the humorous material used in the studies varies, with some using video clips and others using written jokes, which can affect the pattern of brain activation. Finally, the analysis methods employed in the studies differ, with some using traditional fMRI data analysis techniques and others using more advanced methods such as dynamic causal modeling (DCM) and parametric Empirical Bayesian (PEB) methods[8], which can provide greater insight into the neural mechanism of humor processing.

2.2 ERPs

ERP studies have also provided insights into sex differences in humor processing. Chang et al.[15] used ERPs to investigate sex differences in humor processing, providing preliminary evidence of the neural time-course using difference waves. The study found significant sex differences during the P1000–1300 time window, with men showing more automated processes during the transition from cognitive to emotional processing when reading jokes. In contrast, women recruited more resources to integrate and transition from the late cognitive operation of

humor comprehension to the early emotional response of humor appreciation[15]. This suggests that men may rely more on automated processes during humor refinement, while women invest more resources in integrating cognitive and emotional components, possibly due to their inherent advantages in emotional processing.

Another study, titled "Interhemispheric and gender difference in ERP synchronicity of processing humor"[16], found that women exhibit higher interhemispheric synchronization (IHSS) when processing humor compared to men. This suggests that women have better coordination between the two brain hemispheres during humor processing. The study also investigated the effect of humor type on synchrony, finding that humorous endings resulted in lower average synchronicity scores compared to non-humorous and filler-word endings. This may indicate reduced coordination between the brain's hemispheres when processing humor that requires a shift in mental settings. The research proposes that during humor processing, especially when mental shifts are involved, the right hemisphere may suppress activity in the left hemisphere to increase processing efficiency and reduce cognitive load, contributing to the lower interhemispheric synchronization observed under humorous conditions [16].

These two studies highlight gender differences in humor processing, particularly in the synchrony between brain hemispheres and the integration of cognitive and emotional components. Women appear to rely more on coordinated hemispheric processing and mobilize more mental resources, while men may rely more on automated cognitive processes. These findings help us understand how gender influences the perception and appreciation of humor at both cognitive and emotional levels.

3. Age Differences in Humor Processing

The appreciation and comprehension of humor are not static processes but are shaped by the developmental stages of the brain and its cognitive mechanism[17]. There is a growing body of evidence suggesting that the neural mechanism of humor processing may differ between children and adults, reflecting the dynamic nature of cognitive and emotional development across the lifespan[17][18][19][20]. Understanding these differences is crucial for a comprehensive account of how humor is perceived and processed at various ages, and how it contributes to social cognition and emotional regulation.

Conducting ERP research with young children presents challenges in data collection due to the nature of the tasks and the cognitive demands placed on children. There is a high rate of data loss in child ERP studies, which can be attributed to various factors including children's limited attention spans, difficulty in following complex instructions, and the physical discomfort of wearing EEG caps[7]. Therefore, scholars tend to use fMRI technology to study children's brain cognitive processing, which has lower requirements for children's self-control[7]. The following section will discuss the differences in brain regions activated during humor processing between children and adults, as revealed by fMRI studies.

Neely et al.[17] conducted the first neuroimaging study to examine humor processing in typically developing children (ages 6-12). Children watched video clips while their neural activity was imaged with a 3T GE Discovery MR750 scanner. The videos were categorized into three types: Funny, Positive (enjoyable but not funny), and Neutral (not intended to evoke any emotional response). The study found activation in the Temporoparieto-occipital Junction (TOPJ) and midbrain regions in children's response to humor, suggesting that these regions may form a humor-essential neural network already present in childhood[17]. Additionally, the study found that bilateral TOPJ activation may be specific to humor processing and not part of a general neural activity in response to reward.

Vrticka et al.[12] explored the influence of temperament, age, and IQ on humor processing in children aged 6 to 13 using fMRI. The researchers found that emotionality, shyness, and sociability were associated with brain activity related to humor processing. Emotionality was positively associated with brain activity related to both cognitive and emotional humor components, while shyness was negatively associated. Additionally, shyness and sociability were positively related to activity in the periaqueductal gray region during humor processing[12]. The study also found that increasing age and IQ were linked with stronger activity in brain areas implicated in the cognitive component of humor, suggesting that humor processing undergoes developmental changes and is moderated by higher IQ scores.

Chan et al.[21] aimed to separate the neural substrates of incongruity detection and resolution during the comprehension of verbal jokes within the framework of Wyer and Collin's comprehension-elaboration theory of humor processing. Using an event-related fMRI design with three conditions (unfunny, nonsensical, and funny), the study examined distinct brain regions associated with the detection and resolution of incongruities. The results showed that the detection of incongruities was associated with greater activation in the right Middle Temporal Gyrus (MTG) and right Medial Frontal Gyrus (MFG), and the resolution of incongruities with greater activation

in the left Superior Frontal Gyrus (SFG) and left Inferior Parietal Lobule (IPL). The study proposed a three-stage neural circuit model of verbal humor processing: incongruity detection and resolution during humor comprehension and the inducement of the feeling of amusement during humor elaboration[21].

Prenger et al.[9] investigated the roles of the Dorsal Striatum (DS) and Ventral Striatum (VS) in humor comprehension (understanding jokes) and appreciation (enjoying jokes) using fMRI. The researchers found that the DS and VS play distinct roles in humor processing. The DS is associated with working memory, ambiguity processing, and cognitive flexibility, which are crucial for accurately recognizing humorous stimuli. The VS plays a key role in reward processing and enjoyment. The study demonstrated that humor comprehension involves both the DS and VS, while humor appreciation engages only the VS. This research establishes the role of the DS in humor comprehension and emphasizes the role of the VS in humor processing in general[9].

Based on the results of the above studies, we can make a rough analysis of the brain regions activated in adults and children during humor processing. For children, humor comprehension and appreciation primarily activated the Temporoparieto-occipital Junction (TOPJ) and midbrain regions, which may form a basic neural network for humor processing already present in childhood[17]. Emotionality is positively correlated with brain activity related to cognitive and emotional humor components, while shyness is negatively correlated. Shyness and sociability are positively correlated with activity in the periaqueductal gray region[12].

For adults, incongruity detection is associated with increased activation in the right Middle Temporal Gyrus (MTG) and right Medial Frontal Gyrus (MFG), and incongruity resolution with increased activation in the left Superior Frontal Gyrus (SFG) and left Inferior Parietal Lobule (IPL)[8]. Humor comprehension involves both the Dorsal Striatum (DS) and Ventral Striatum (VS), while humor appreciation involves only the VS[9]. The DS is associated with working memory, ambiguity processing, and cognitive flexibility, while the VS is key in reward processing and enjoyment.

The midbrain is consistently activated in both children and adults during humor processing, suggesting its integral role in the reward aspect of humor. This region, which includes the ventral tegmental area (VTA) and the substantia nigra, is part of the mesolimbic dopamine system, known to be involved in the experience of pleasure and reward[9][17]. The activation of the midbrain in humor processing indicates that the neural circuitry underlying the appreciation of humor and the experience of reward is present across different age groups, highlighting the universality of this aspect of humor processing.

In addition, there are different brain regions activated by adults or children during the process of humor processing. The specific brain regions that were activated in the adults focused on in these studies were the Dorsal and Ventral Striatum (DS and VS). The distinction between the DS and VS is not explicitly mentioned in studies focusing on children, suggesting that adults may engage more complex reward and cognitive control mechanism during humor processing[9]. The DS, particularly, is implicated in higher-order cognitive functions such as working memory, ambiguity resolution, and cognitive flexibility, which are essential for comprehending humor. The VS, on the other hand, is critical for reward processing and the experience of enjoyment, which is a key component of humor appreciation.

Other regions (like Middle Temporal Gyrus (MTG), Medial Frontal Gyrus (MFG), Superior Frontal Gyrus (SFG), and Inferior Parietal Lobule (IPL)), highlighted in adult studies, are not specifically emphasized in children's studies, possibly due to the increased demand for semantic processing and cognitive control in adult humor processing. The MTG is involved in semantic processing and the detection of incongruity, a fundamental aspect of humor comprehension[22]. The MFG and SFG are associated with cognitive control and the resolution of incongruity, which is necessary for understanding jokes and humorous situations[23]. The IPL is implicated in semantic integration and coherence, which are crucial for resolving the incongruities presented in humor[24].

The specific brain regions that were activated in the adults focused on in these studies were Temporoparieto-occipital Junction (TOPJ). The TOPJ is specifically mentioned in children's studies but not in adults', reflecting the potential greater reliance of children on brain regions that process visual and situational information. This region is involved in the detection and resolution of incongruity and is thought to be important for humor comprehension[17]. The activation of the TOPJ in children may indicate a developmental stage where visual and contextual cues are more heavily relied upon for understanding humor. Studies on children suggest that activity in certain brain regions changes with age, which may be related to cognitive development and neural maturation. As children develop, there is a shift from more diffuse brain activation to more specialized and lateralized activation patterns, reflecting the maturation of cognitive and neural processes[25]. This shift indicates that the neural substrates of humor processing evolve as children grow, with cognitive and neural development playing a significant role in how humor is processed and appreciated.

In summary, there are differences in the brain regions activated during humor processing between children and adults, which may be related to age-related changes in neurodevelopment, cognitive abilities, and emotional regulation capabilities. Adults' humor processing involves more cognitive control and semantic processing regions, while children rely more on brain regions that process visual and situational information. These findings emphasize that humor processing is a complex process with neural underpinnings that change as individuals develop. The distinction in the way humor is processed can be attributed to the ongoing neurodevelopmental changes that occur during childhood and adolescence, which are characterized by alterations in brain structure and function. However, it is important to note that although these studies provide important information about the neural basis of humor processing in children and adults, they do not directly compare differences in neural activity between the two groups of people. Therefore, we cannot draw direct conclusions from the literature that children and adults activate different brain regions during humor processing. More studies, especially those that directly compare neural activity across different age groups in the same humor task, are needed to more accurately understand the neural differences in humor processing between children and adults.

4. Personality Traits in Humor Processing

Personality differences, particularly introversion and extroversion, play a crucial role in humor processing. Studies have shown that extroverted individuals are more likely to perceive and use humor in social interactions, enhancing their social connections and communication skills[26]. Personality traits not only influence cognitive evaluations of humor but also affect the neural mechanism underlying humor processing.

4.1 fMRI

Berger et al.[27] conducted an fMRI study to investigate how personality traits, specifically extraversion and neuroticism, modulate functional connectivity between brain regions during humor appreciation. The researchers examined the brain activity of 19 healthy subjects as they processed standardized humorous and neutral cartoon images. The study found that extraversion was associated with increased functional connectivity between the right amygdala and the bilateral caudate nucleus, while neuroticism was associated with increased functional connectivity between the right amygdala and the right temporal lobe region[27]. These findings suggest that personality traits such as extraversion and neuroticism can modulate functional connectivity between the amygdala and brain regions previously associated with the cognitive and emotional components of humor processing.

The results of this study indicate that the neural mechanism of humor processing are influenced by different personality traits, particularly extraversion. Extroverts showed enhanced connectivity in brain regions associated with reward and emotion processing, suggesting that they may experience humor more intensely and derive greater pleasure from it. This aligns with previous findings that extroverts have a bias towards positive emotional experiences and faster reaction times in both explicit behavior and psychophysiology[28].

4.2 ERPs

ERP studies have provided valuable insights into the differences in humor processing between introverts and extroverts. Xia and Yang[29] used ERP technology to investigate these differences, employing jokes as experimental stimuli. Participants were instructed to read the setup (background information) and punchlines before evaluating the relationship between the presented textual materials. The study examined humor processing by measuring responses to three types of stimuli: incongruent funny (eliciting laughter due to inconsistent background and ending), congruent unfunny (consistent background and ending without humor), and incongruent unrelated (lacking connection between background and ending, resulting in no humor). The study posited that humor processing involves stages of incongruity detection, incongruity resolution, and emotion processing. By comparing different stimuli, distinct stages of humor processing were identified using EEG components (N400, P600) and amplitude analysis to discern differences between introverts and extroverts[29].

The ERP results revealed that the amplitude of N400 was significantly larger under incongruent unrelated conditions compared to congruent unfunny conditions. The amplitude of P600 was significantly smaller in incongruent unrelated conditions than in the other two conditions. After 800ms, the incongruent funny condition induced a larger positive amplitude than the other two conditions[29]. These findings indicate that differences between introverts and extroverts are primarily reflected in the early stages of humor processing. Specifically, extroverts used fewer cognitive resources during the incongruity detection stage, suggesting more automated processing compared to introverts.

In another study, Ku and Chang[30] explored how extroversion influences different stages of humor processing using ERP data. The study analyzed ERP components (P2, N400, and LPP) in extroverts and introverts while they read and rated jokes and non-jokes. The results showed that jokes had a smaller N400 amplitude and a larger late

positive potential (LPP) amplitude compared to non-jokes[30]. The more extroverted group exhibited smaller P2 and N400 amplitudes across all stimuli, suggesting different allocation of attention and cognitive resources when processing external stimuli. Regression analysis revealed a positive correlation between the LPP effect of jokes and the level of extroversion, indicating that extroverts invested more cognitive resources in the emotional processing and reward-related aspects of humor[30].

Having explored the research in humor processing between introverts and extroverts using ERP technology, we now turn to a more detailed examination of the specific neural mechanism and psychological factors that underlie these differences, further highlighting the role of personality traits in humor perception and appreciation.

From the perspective of the relationship between N400 and semantic processing, both studies agree that N400 components are related to semantic integration and incongruity detection stages in humor processing. This suggests that the N400 component is a key neurophysiological indicator of understanding humor, reflecting how individuals process and integrate semantic information in humorous materials. The overall change trend of N400 components is consistent in both studies. Xia's study[29] found that the N400 amplitude was significantly greater for inconsistent irrelevant conditions than for consistent non-joke conditions and inconsistent joke conditions, and that the N400 amplitude was significantly greater for introverts than for extroverts. Ku's study[30] found that jokes show a smaller N400 amplitude than non-jokes, and that more extroverted individuals have a smaller N400 amplitude. Therefore, in both studies, the amplitude caused by joke conditions and extroversion is smaller. This indicates that in the process of humor processing, semantically incongruent sentences require more cognitive resources for semantic integration. In contrast, extroverts show more automated semantic processing during humor comprehension, requiring fewer cognitive resources.

Due to differences in experimental design and focus on EEG components, the two studies differed in their findings related to the P600 and LPP components. Ku's study did not discuss the P600 component. However, Xia's study noted that the P600 amplitude under the incongruent unrelated condition was significantly smaller for both introverts and extroverts compared to the incongruent funny condition and the congruent unfunny condition. This suggests that both personality types require cognitive resources to resolve humorous incongruity, but extroverts may exhibit more automated processing during this stage. In Ku's study, extroverts showed larger amplitude in the LPP component of jokes, indicating that they invest more cognitive resources in emotional processing and reward-related cognitive processing. This suggests that extroverts are more sensitive to the emotional and reward aspects of humor. In contrast, Xia's study found that the incongruent funny condition triggered a larger positive LPP amplitude than the other two conditions after 800ms, indicating a stronger emotional response to jokes. Combining these findings provides a better understanding of the differences in humor processing between introverts and extroverts. Specifically, extroverts exhibit more automated semantic processing (as indicated by smaller N400 amplitude) and invest more cognitive resources in emotional and reward-related aspects (as indicated by larger LPP amplitude). In contrast, introverts engage in more detailed semantic processing and may be more reserved in their emotional responses to humor.

In summary, personality traits, particularly extroversion and introversion, significantly influence humor processing, affecting both cognitive and emotional aspects. Extroverts tend to exhibit more automated semantic processing during humor comprehension, as evidenced by smaller N400 amplitudes in ERP studies, indicating efficient semantic integration. They also show greater engagement in emotional and reward-related processing, reflected in larger late positive potential (LPP) amplitudes, suggesting a stronger emotional response to humor. In contrast, introverts engage in more detailed semantic processing, requiring greater cognitive resources, and may exhibit more reserved emotional responses to humorous stimuli. These differences highlight the role of personality in shaping neural mechanism and cognitive-emotional responses to humor, with extroverts showing more efficient semantic processing and heightened emotional engagement, while introverts demonstrate more introspective and resource-intensive cognitive processing. These findings underscore the importance of considering personality traits when studying humor perception and appreciation.

5. Schizophrenia in Humor Processing

Schizophrenia, a severe mental disorder, also significantly impacts humor processing. Individuals with schizophrenia exhibit unique neural mechanism when processing humor, with distinct activation patterns in brain regions compared to healthy individuals[31]. These differences may be related to the cognitive and emotional deficits associated with schizophrenia, affecting their ability to understand and appreciate humor.

Previous literature has shown that individuals with schizophrenia experience difficulties in humor comprehension and may differ from healthy controls in the appreciation of humor, particularly in perceived funniness[32]. The humor understanding process can be disrupted in schizophrenia, a psychiatric condition characterized not only by

psychotic symptoms and neurocognitive deficits but also by pervasive pragmatic impairments[32]. Individuals with schizophrenia often adhere to literal interpretations of figurative language, including humorous expressions, and struggle to grasp the intended humor. Studying the impact of schizophrenia on the neural mechanism of humor processing can help clarify the dynamics of the neural networks involved in humor processing.

5.1 fMRI

Adamczyk et al.[31] investigated the neural correlates of diminished humor comprehension in schizophrenia using fMRI. The study involved 20 chronic schizophrenia outpatients and 20 matched healthy controls who participated in a punchline-based humor comprehension task. The results showed that, compared to healthy controls, schizophrenia patients exhibited attenuated activation in the right posterior superior temporal gyrus (BA 41) when processing irresolvable incongruities in nonsensical punchlines and in the left dorsomedial middle and superior frontal gyri (BA 8/9) when processing funny punchlines[31].

In another study, Adamczyk et al.[33] focused on the neural substrates of impaired cartoon joke comprehension in schizophrenia outpatients. The study included 25 clinical subjects and 20 healthy controls who underwent an fMRI punchline-based humor comprehension task involving 60 cartoons with funny, nonsensical, and neutral punchlines. The findings revealed that schizophrenia patients exhibited hypofunction of the right Inferior Parietal Lobule (IPL), specifically the Supramarginal Gyrus (BA 40), during incongruity detection and complete humor processing[33].

Jáni et al.[34] further explored the associations between the neural substrates of humor processing, psychopathology, and cognition in schizophrenia. The study involved 25 schizophrenia outpatients assessed via fMRI and 40 participants assessed via EEG using a punchline-based humor comprehension task. The results indicated that more severe positive and disorganization symptoms were associated with impaired humor comprehension and altered temporo-parietal effective connectivity during humor processing. Additionally, better cognitive functioning in schizophrenia outpatients was linked to more accurate humor comprehension, increased fronto-temporo-parietal activation, and effective connectivity[34].

The studies by Adamczyk et al. and Jáni et al. used neuroimaging techniques to reveal neural mechanism disorders in humor processing in schizophrenia, particularly in the anterior temporo-parietal network. Despite differences in focus and specific brain regions examined, all studies identified changes in brain activity when individuals with schizophrenia processed humor, which may relate to their difficulties in humor comprehension. These findings provide a neurobiological basis for understanding social and communication impairments in schizophrenia. Specifically, Adamczyk et al.[31] found reduced fronto-temporal activity in schizophrenia patients during humor processing, with decreased activation in the right posterior superior temporal gyrus (BA 41) when processing absurd and funny punchlines. This suggests a weakening of fronto-temporal activity during the processing of irresolvable incongruities, which may underlie humor comprehension deficits in schizophrenia. Jáni et al.[34] further showed that better cognitive function in schizophrenia patients was associated with increased activation and effective connectivity in the fronto-temporo-parietal regions, leading to more accurate humor comprehension. In contrast, patients with impaired cognitive function exhibited less activity in the anterior temporo-parietal region during humor processing, highlighting the role of cognitive abilities in humor understanding.

The three studies differ in their research focus and findings. Adamczyk et al.[31] assessed neural correlates of reduced humor understanding in chronic schizophrenia patients, focusing on activity changes in the anterior temporo-parietal lobe. Adamczyk et al.[33] examined the role of the right inferior parietal lobe in cartoon joke comprehension, finding that decreased activity in this region was associated with impaired humor understanding. Jáni et al.[34] comprehensively explored the relationship between neural mechanism, psychopathology, and cognitive function, revealing that better cognitive function was linked to more accurate humor comprehension and enhanced activation in the anterior temporal parietal lobe. While the first two studies emphasized reduced activity in specific brain regions, the third study highlighted the connection between cognitive function and humor comprehension, providing deeper insights into the neural mechanism of humor processing in schizophrenia.

5.2 EEG

Adamczyk et al.[35] aimed to explore the neural network dynamics during humor processing in individuals with schizophrenia, particularly focusing on abnormalities in information flow within the fronto-temporal-parietal circuit. The researchers used EEG Directed Transfer Function (DTF) to assess the direction and strength of cortical information flow in 40 schizophrenia outpatients and 40 healthy controls while they processed written and cartoon jokes. The study found that schizophrenia patients showed engagement of alternative neural circuits and a pronounced leftward shift in lateralization, associated with diminished activity in the right hemisphere, particularly in fronto-temporal-parietal regions, during humor processing.

Jani et al.[34] divided participants into two groups for fMRI and EEG DTF analyses. Some of the results were discussed in Section 2.1, where it was noted that schizophrenia patients with better cognitive function exhibited more accurate humor comprehension, associated with increased activation and effective connectivity in the anterior temporo-parietal lobe. Additionally, the study found that more severe positive and dissociative symptoms were associated with impaired humor comprehension and altered temporoparietal effective connectivity. More severe symptoms of arousal and emotional response were associated with increased activation in bilateral frontal and temporo-parietal regions.

Both studies used EEG directed transfer functions (DTF) to assess the neural network dynamics of humor processing in schizophrenia patients. They both identified changes in neural network dynamics, particularly in the anterior temporo-parietal region, during humor processing in individuals with schizophrenia. However, the studies differed in their focus and findings. Adamczyk et al.[35] focused more on the direction and intensity of neural network dynamics and information flow, while Jani et al.[34] comprehensively examined the relationship between neural mechanism, psychopathology, and cognitive function. The latter study provided a more detailed exploration of how psychiatric symptoms and cognitive function influence neural activity and humor comprehension.

In summary, both studies offer valuable insights into the neural network dynamics of humor processing in schizophrenia. Adamczyk et al.[35] provided a foundational description of the changes in neural network dynamics, while Jani et al.[34] further explored the interactions between neural dynamics, psychopathology, and cognitive function. These findings highlight the complex relationship between neural mechanism and cognitive deficits in schizophrenia and suggest that future research should continue to investigate how these factors influence humor processing and social cognition.

6. Conclusion

This review has provided a comprehensive analysis of the neural evidence of individual differences in humor processing, highlighting the significant impact of gender, age, personality traits (extroversion and introversion), and schizophrenia on the neural mechanism involved in humor processing. By integrating findings from various neuroscience studies using fMRI and ERP techniques, this review has identified distinct brain activation patterns associated with these individual differences.

The studies on gender differences consistently show that women and men exhibit distinct brain activation patterns during humor processing, with women relying more on socio-emotional processing and men on cognitive control and language processing. Age differences reveal that children and adults activate different brain regions during humor processing, reflecting the dynamic nature of cognitive and emotional development. Personality traits, particularly extroversion and introversion, significantly influence humor processing, with extroverts showing more automated semantic processing and greater emotional engagement, while introverts engage in more detailed cognitive processing. Schizophrenia patients exhibit unique neural mechanism in humor processing, characterized by reduced activation in key brain regions and altered connectivity, which may relate to their difficulties in humor comprehension.

These findings underscore the complexity of humor processing and highlight the importance of considering individual differences in future research. Future research on humor processing should consider longitudinal designs to track changes across different developmental stages, providing insights into how neural mechanism evolve over time.

Combining fMRI and ERP techniques can offer a more comprehensive spatiotemporal understanding, capturing both the spatial and temporal aspects of brain activity. Therefore, by combining ERPs and fMRI, researchers can leverage the strengths of both methods to gain a more detailed spatio-temporal understanding of brain activation. This combined approach can help elucidate the complex interplay between brain regions and the timing of their activation, offering a more comprehensive view of brain function than either technique alone. This maybe a better choice for future research on humor processing.

Further investigation into the neural mechanism of humor processing in clinical populations, such as individuals with schizophrenia or depression, can elucidate specific impairments and inform potential therapeutic interventions. Additionally, future studies should explore the interplay between cognitive and emotional components in humor processing, particularly how individual differences influence this interplay. Finally, research should consider the impact of cultural and contextual factors on humor processing, as these can significantly influence the perception and appreciation of humor.

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