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Sex differences in humor processing: An event-related potential study

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ABSTRACT

Numerous behavioral studies and a handful of functional neuroimaging studies have reported sex differences in humor. However, no study to date has examined differences in the time-course of brain activity during multi-stage humor processing between the sexes. The purpose of this study was to compare real-time dynamics related to humor processing between women and men, with reference to a proposed three-stage model (involving incongruity detection, incongruity resolution, and elaboration stages). Forty undergraduate students (20 women) underwent event-related potential recording while subjectively rating 30 question-answer-type jokes and 30 question-answer-type statements in a random order. Sex differences were revealed by analyses of the mean amplitudes of difference waves during a specific time window between 1000 and 1300 ms poststimulus onset (P1000–1300). This indicates that women recruited more mental resources to integrate cognitive and emotional components at this late stage. In contrast, men recruited more automated processes during the transition from the cognitive operations of the incongruity resolution stage to the emotional response of the humor elaboration stage. Our results suggest that sex differences in humor processing lie in differences in the integration of cognitive and emotional components, which are closely linked and interact reciprocally, particularly in women.

1. Introduction

Humor comprehension is a set of implicit cognitive processes involving the detection and resolution of embedded ambiguities in contexts, leading to positive feelings of mirth or reward feedback that are produced through humor appreciation. The following joke, which was obtained from the Internet (https://www.rd.com/jokes/customer-service/), can illustrate the underlying process:

I was at the customer-service desk, returning a pair of jeans that was too tight.
"Was anything wrong with them?" the clerk asked.
"Yes," I said.
"They hurt my feelings."

The punch-line "They hurt my feelings" disrupts the expected outcome and conflicts with reality (because jeans would not actively "hurt" a person's feelings), thereby inducing a sense of surprise. To fit the punch line to the developing context, a strategy of searching stored mental scripts for possible resolutions of this cognitive conflict is activated. The ambiguities must (at least partially) be resolved through cognitive logic and appear plausible to some degree with respect to the setup context, thus inducing the subsequent positive emotional response or laughter phenomenon. According to Wyer and Collins' comprehension–elaboration theory of humor (1992), the following processes contribute to humor comprehension: detecting incongruent information, experiencing surprise, and reestablishing coherence when incongruent information is reinterpreted using various schema. Additionally, humor comprehension and humor appreciation have been regarded as a sort of cognitive problem-solving ability, as proposed in Suls' incongruity resolution theory (1972). Thus in combination, these two established theories suggest a process of detection of incongruity between a prediction and reality, resolution of incongruity through comprehending a situation, and, finally, a feeling of mirth or reward. These three components constitute an integrated processing of humor, with the first two stages functioning as the premise that leads to the final stage of humor elaboration.

1.1. Sex differences in humor processing: behavioral aspects

Behavioral studies have determined sex differences with regard to humor appreciation. For example, regarding *humor content*, men appreciate humor involving erotic or violent content more than women do (Brodzinsky, Barnet, & Aiello, 1981), as is evident from the larger erotic priming effect and faster response to erotic targets seen in males (Geer & Melton, 1997; Mussweiler & Forster, 2000). With respect to *humor structure*, women enjoy nonsensical or absurd humor more than men do

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(Brodzinsky & Rubien, 1976; Brodzinsky et al., 1981; Terry & Ertel, 1974). Considering the *social roles* and *social functions* of humor, men have been found to be more likely to act as humor creators to gain self-esteem or achieve superiority (Bressler & Balshine, 2006; Crawford & Gressley, 1991; Martin, 2007). In contrast, women are more likely to act as humor appreciators and tend to laugh more in social interactions (Bressler & Balshine, 2006; Chan, 2016; Li et al., 2009; Martin, 2007; Vrticka, Black, & Reiss, 2013). So far, sex differences in humor have mostly been elucidated through the evolutionary perspective of Darwin's sexual selection theory (1871), indicating that the two sexes may have different preferences for specific types and social roles of humor. More specifically, Miller's evolutionary theory of humor (1998, 2000) proposes that a "sense of humor" may be an indicator of "good genes" and thus of desirability as a potential mate, particularly for women choosing their male mate (Martin, 2007).

As mentioned, humor appreciation is the end product of complex humor comprehension. Thus, it is reasonable to doubt that the observed sex differences in humor appreciation originate from the cognitive processing of the premise of a joke. Albeit, behavioral studies reporting sex differences in humor comprehension are scant. This is because providing proper explanations of questions exploring implicit cognitive processing, such as humor comprehension, according to explicit behavioral performances is difficult. Hence, investigating integrative humor processing at the neural level may help clarify whether humor comprehension contributes to the underlying mechanisms of sex differences regarding humor appreciation. Furthermore, neuroscientific investigations may provide a new perspective beyond the evolutionary in understanding sex differences in relation to humor processing.

1.2. Neural evidence of sex differences in humor processing

Recently, the topic of how people comprehend and appreciate humor is getting more attention in the field of neuroscience. On the basis of the comprehension-elaboration theory (Wyer & Collins, 1992), Chan et al. (2013) proposed a three-stage neural circuit model of verbal humor processing which they developed based on functional magnetic resonance imaging (fMRI) data. These data demonstrated corresponding neural correlates for each prerequisite stage of the integrative humor process (e.g., activation of the right middle temporal gyrus and right middle frontal gyrus was responsible for identifying semantic incongruities at the incongruity detection stage). Other neuroimaging studies have identified a key role for the temporo-parietal junction (TPJ) and anterior cingulate cortex (ACC) during the humor process (Azim, Mobbs, Jo, Menon, & Reiss, 2005; Kohn, Kellermann, Gur, Schneider, & Habel, 2011; Mobbs, Greicius, Abdel-Azim, Menon, & Reiss, 2003; Moran, Wig, Adams, Janata, & Kelley, 2004; Vrticka et al., 2013; Watson, Matthews, & Allman, 2007). In a review article, Vrticka et al. (2013) noted that in the humor process, the TPJ region appears to be the main region associated with the cognitive component, whereas the mesocorticolimbic dopaminergic pathways and the amygdala appear to be dominant for the emotional component.

Specific neural correlates of sex differences in humor processing have been reported in a small number of studies. For example, Azim et al. (2005) used fMRI to examine sex differences in brain activation elicited by humorous cartoons. The results showed that the left temporal–occipital junction (BA 37), which is part of the ventral-stream involved in visual processing, was activated in both sexes, representing semantic processing occurring during the coherence development process of joke comprehension. However, women exhibited higher neural activity in the left prefrontal cortex (PFC) and mesolimbic regions than men. The authors therefore suggested that, for women, humor processing involves a greater degree of executive processing regarding coherence and language-based decoding. In a later study also involving watching humorous cartoons, Kohn et al. (2011) reported that women showed a stronger association between subjective affective ratings and brain areas involved in the ventral emotion processing system (e.g., amygdala, insula, ACC), suggesting that women process humor through limbic reactivity, involving the appraisal of its emotional features. In contrast, in men, both the ventral and dorsal processing systems were activated. The authors therefore concluded that men apply more evaluative, executive resources to humor processing than women do, a perspective that contrasts with the interpretation of Azim et al. (2005). In a recent study, Chan (2016) applied fMRI to differentiate the neural correlates of humor processing between the sexes and provided evidence that, regardless of the joke type (bridging-inference joke, exaggeration joke, or ambiguity joke), greater activation was elicited in the anterior prefrontal cortex (aPFC) of women than of men, corresponding to neural processing within the ventral stream. In contrast, men exhibited greater activation in the dorsolateral prefrontal cortex (dPFC), corresponding to neural processing within the dorsal stream. The divergent topographical results from such studies have led to diverse conclusions regarding differences in humor processing between the sexes.

Collectively, these small number of studies have indicated that women and men share extensive overlapping activation in brain areas implicated in cognitive humor processing. Existing findings on sex differences in brain activation have primarily identified the role of the differential processing of emotion, which is evident in the stronger engagement of emotion-related brain areas in women than in men. This occurs irrespective of whether significant behavioral differences in subjective funniness rating are demonstrated between the sexes (Azim et al., 2005; Chan, 2016; Kohn et al., 2011; Vrticka et al., 2013). However, such a conclusion lacks neural evidence focusing on temporal dynamics to strengthen its validity. Since both cognitive processing and emotional humor processing follow a sequential flow (i.e., you will not perceive the humor without first realizing that something is "wrong"), examining real-time neural dynamics in light of the three-stage neural circuit model of humor could contribute further empirical evidence about how different processing from humor comprehension to humor appreciation occurs in the brains of men and women.

1.3. Examining humor processing through real-time dynamics

To date, no study has examined real-time dynamics to analyze the differences in humor processing between the sexes. However, a few studies have found corresponding event-related potential (ERP) effects in line with the proposed three stages of the integrative humor process. These studies have either involved reading verbal jokes (Du et al., 2013; Feng, Chan, & Chen, 2014; Ku, Feng, Chan, Wu, & Chen, 2017; Mayerhofer & Schacht, 2015; Shibata et al., 2017) or watching humorous cartoons (Tu et al., 2014). The most consistent finding across these studies is of an enhanced N400 for funny items compared with unfunny and unrelated items (Coulson & Kutas, 2001; Du et al., 2013; Feng et al., 2014; Mayerhofer & Schacht, 2015; Tu et al., 2014). This may be indexing the registration of surprise in humor comprehension (Du et al., 2013; Tu et al., 2014), or the semantic integration difficulties (Mayerhofer & Schacht, 2015) during the preliminary stage of incongruity detection.

Following the N400 effect, starting at approximately 500 ms, a sustained positive deflection is observed at multiple areas, representing the incongruity resolution stage in humor processing. This has been associated with the posterior P600–800 (Du et al., 2013), the central-posterior P600 (500–700 ms, Feng et al., 2014; Ku et al., 2017; 500–800 ms, Shibata et al., 2017), the central-anterior P800–1000 (Tu et al., 2014), or the P1000–1600 without specified regions (Tu et al., 2014). In addition, some studies have observed enhanced negativities for jokes during a similar time interval, such as the frontocentral N600–800 (Du et al., 2013), or left-lateralized sustained negativities (500–900 ms, Coulson & Kutas, 2001). Despite these polarities, the salient positive or negative deflection following N400 indicates the cognitive operation of incongruity resolution during humor processing, comprising the reconstruction of convergent meaning from novel

associations or the frame-shifting involved in re-establishing coherence in a given context (Coulson & Kutas, 2001).

As humor processing concludes at the cognitive level, the moment of "getting" the joke approaches. The unconscious or conscious positive feeling of amusement contributes to the third stage of humor processing, namely humor elaboration, which indexes the feeling state related to amusement, mirth, or reward feedback during the affective stage (Chan, 2016). Neural evidence corresponding to the third stage of humor elaboration after incongruity resolution has been indexed by a centro-parietal late positive potential (800–1500 ms, Feng et al., 2014; 700–1000 ms, Ku et al., 2017), a P1250–1400 over anterior and posterior scalp regions (Du et al., 2013), a P1600–2000 without specified areas (Tu et al., 2014), or frontal late positivities (700–1000 ms, Mayerhofer & Schacht, 2015). These results imply that the affective response to comprehending humorous materials is generated in the ventromedial prefrontal cortex, bilateral amygdalae, and bilateral parahippocampal gyri (Chan, Chou, Chen, & Liang, 2012).

To date, despite the application of techniques with high temporal or spatial resolution, neural evidence regarding differences in humor processing between the sexes diverges considerably. Notably, no studies so far have applied a temporal perspective to obtain neural evidence of sex differences in humor processing. In the current study, we used the high temporal resolution of the ERP technique to examine the time phase at which sex differences in neural processing of linguistic jokes arise. Accordingly, the present study is the first to examine whether the differences between the sexes in humor processing observed in fMRI studies can also be distinguished through on-line ERP recording. Examining sex differences in humor processing provides a greater understanding of how the cognitive and emotional components of humor are processed in the two sexes. Exploring and clarifying these differences might be relevant to understanding differences in emotional responses, cognitive interpretations, and consequent coping strategies between the two sexes in the face of emotional events, as proposed in previous studies (Bradley, Codispoti, Sabatinelli, & Lang, 2001; Howerton & Van Gundy, 2009; Tamres, Janicki, & Helgeson, 2002).

We developed our hypothesis on the basis of the generally reported significant sex difference observed in emotion-related areas during humor processing, predicting that women will exhibit a larger positive effect than men at the third stage (emotional response). The present study therefore focused on processes during humor comprehension (i.e., incongruity detection and resolution) and humor appreciation (i.e., indexing humor elaboration). Humor production, such as the expression of laughing, which was discussed by Chan (2016) in her proposal of the Tri-Component Theory of Humor, is excluded from further discussion.

2. Methods

2.1. Participants

Forty undergraduate students (20 women) aged 20–27 years (mean age 22.5 years, SD = 1.95) from National Taiwan Normal University, Taiwan, participated in our study. The ages of the women (mean = 22.45, SD = 2.04) and men (mean = 22.50, SD = 1.91) were not significantly different. All participants were right-handed, native Chinese speakers. At the time of participating in this study, they had no history of current or past neurological or psychiatric disorders. They had either normal or corrected-to-normal vision. Informed consent was obtained from all the participants. Each participant received a sum of NT$500 for participating in the experiment as compensation. The present study was approved by the Institutional Review Board of National Taiwan University (201208HS012, Taipei, Taiwan).

2.2. Materials

Thirty Chinese question-answer-type jokes with embedded amusing endings were collected from the riddle database of Feng et al. (2014) and defined as the *joke* condition in this study (e.g., Question: "Who goes to the hospital most often?" Answer: "Doctors."). In addition, 30 Chinese question-answer-type statements without embedded amusing endings, namely common problem-solving questions, were collected from the same database and defined as the *nonjoke* condition in this study (e.g., Question: "What do we call the planet we live on?" Answer: "The Earth."). To block the potential priming effect of the proposed sex-dominant word categories on word processing in the two sexes, jokes and nonjokes involving erotic or threatening words were eliminated (Daltrozzo, Wioland, & Kotchoubey, 2007). The numbers of words of the setup questions and the punchline answers were controlled to between 11 and 14 and between 2 and 4, respectively. Lexical properties such as word frequency, number of strokes, and word length in the characters of the setup questions and punchlines between conditions were comparable (all $p > .05$). A total of 60 trials were presented to the participants in a random order.

Before the formal testing, all the experimental stimuli were rated by a separate group using a 9-point Likert scale, which ranged from '1' (totally not surprised, totally incomprehensible, and not funny at all), through '5' (neutral response for each domain), to '9' (totally surprised, totally comprehensible, and very funny), to investigate the degree of surprise, comprehensibility, and funniness of each. In line with our expectations, significantly higher surprise and funniness scores were assigned for joke than nonjoke conditions (mean ± SD of surprise rating: 6.27 ± 0.71 for the joke condition, 3.61 ± 0.74 for the nonjoke condition, $p < .01$; mean ± SD of funniness rating: 6.76 ± 0.37 for jokes, 3.75 ± 0.40 for non-jokes, $p < .01$). A similar level of comprehensibility was reported for both conditions (mean ± SD of comprehensibility rating: 8.05 ± 0.41 for the joke condition, 8.06 ± 0.62 for the nonjoke condition, $p = .98$).

2.3. Procedure

Participants were seated at a distance of approximately 110 cm in front of a computer monitor in a dimly lit, sound-proofed room. Each participant received 10 trials for practice and 60 randomized experimental trials to complete the experiment. Pauses were allowed when requested. For each trial, the presentation order was as follows: (1) a central fixation mark first appeared at the center of the monitor for 1000 ms; (2) the setup question appeared and lasted for 4000 ms; (3) a central fixation was displayed for 4000 ms; and (4) the answer punch line appeared for 2000 ms. Participants were asked to silently read the stimuli, and after they finished reading, they were asked to judge the level of (a) surprise (whether the punch line surprised them after reading each trial), (b) comprehensibility (how well they understood the punch line's meaning in relation to the corresponding setup), and (c) funniness (how funny they considered each trial) for each trial without time limitation, according to a 4-point Likert scale (1 for totally not surprised, totally incomprehensible, and not funny at all; 2 for not surprised, incomprehensible, and not funny; 3 for surprised, comprehensible, and funny; 4 for totally surprised, totally comprehensible, and very funny). Brain activity was recorded simultaneously during the whole procedure.

2.4. Data recording and analysis

Electroencephalogram (EEG) data were recorded from 32 channel-sintered Ag/AgCl electrodes located in a standard 10–20 system (QuickCap, Neuromedical Supplies, Sterling, Texas, USA) on the following nine sites: F3, FZ, F4, C3, CZ, C4, P3, PZ, and P4. All electrodes were re-referenced to the average of the bilateral mastoids for off-line analysis. The EEG signal was continuously recorded and digitized at a sampling rate of 500 Hz and was amplified using SynAmps2 (Neuroscan Inc., El Paso, Texas, USA) with a bandpass filter of 0.05–70 Hz. Vertical electrooculograms were recorded using electrodes placed on the

Table 1
Subjective ratings for surprise, comprehensibility, and funniness in women and men.

	Surprise		*Comprehensibility*		*Funniness*	
	Women	Men	Women	Men	Women	Men
Joke	2.63(0.38)	2.46(0.44)	3.32(0.34)	3.22(0.37)	2.64(0.49)	2.58(0.43)
Non-joke	1.78(0.40)	1.68(0.30)	3.44(0.36)	3.30(0.61)	1.79(0.39)	1.80(0.35)

Notes. Values are mean (SD) from the 4-point Likert scales.

supraorbital and infraorbital ridges of the left eye, and horizontal electrooculograms by electrodes placed lateral to the outer canthi of the right and left eyes. Impedances were maintained below 5 kΩ.

For off-line analysis, EEG data were analyzed using Neuroscan 4.4 (Compumedics Neuroscan, 2003). The continuous waveforms were time-locked to the onset of the punch line and segmented into epochs, including 100 ms of the prestimulus baseline and 2000 ms after the target onset. All epochs were filtered with a band-pass filter of 0.1–30 Hz and a notch filter of 60 Hz. Trials contaminated by eye blinks or with voltage variations greater than ± 100 μV were excluded from further analysis. After this processing, at least 22 trials were retained for each condition. Average waves were separated according to condition and sex.

On the basis of a literature review and on visual inspection of our grand average ERP data, we analyzed the mean amplitudes of three ERP components: N400 (300–520 ms), P500–1000 (500–1000 ms), and P1300–1500 (1300–1500 ms). The mean amplitudes were calculated as the averaged amplitude of the selected electrodes for six regions of interest: “anterior” (F3, FZ, F4), “central” (C3, CZ, C4), “posterior” (P3, PZ, P4), “left” (F3, C3, P3), “midline” (FZ, CZ, PZ), and “right” (F4, C4, P4). Three-way mixed design repeated-measures analyses of variance (ANOVAs) were then performed, including the factors Sex (women and men) as the between-subject factor and Condition (joke and non-joke) and Regions of Interest (hereafter, Region) as the within-subject factors. Notably, the third time window of P1300–1500 was identified mainly in reference to the men’s grand average data, because the sustained positivities after 500 ms in women were continuously expanded until 1500 ms or later, hindering isolation of the second and third major components in the women’s data. The grand average waveform patterns were reflective of individual differences between women and men.

Because of the essentially different trends between women and men after approximately 1000 ms, and the extensive overlap in waveform pattern particularly evident in women after 500 ms, the identified time window may be problematic. This is due to the “defined” time window possibly containing overlapped components that might differ in terms of their functional meaning (especially as the processing time lengthens). This may consequently lead to inaccuracy and misinterpretation when comparing the two sets of data. To address these issues, we used an additional approach, namely difference waves, to more precisely examine the potential sex differences during humor processing. The method of analyzing difference waves has been advocated by Luck (2005) because it offers advantages in dealing with the temporal overlap problem, enabling experimental effects to be revealed more clearly. We therefore applied this method to examine differences between the sexes in this study. Another potential overlap problem arose because the setting of both the joke and nonjoke conditions resembles a problem-solving process that involves extensive language processing. Thus, to address this, we initially computed the difference waves, subtracted the grand average waveforms elicited by the nonjoke condition from those elicited by the joke condition, and then compared the resulting difference waves (joke-minus-non-joke waveforms) between the sexes. We considered that this method (regarding the *nonjoke condition* as the baseline) would highlight the unique characteristics (such as the feeling of surprise and mirth) involved in comprehending the jokes, thereby revealing the core differences between the sexes with regard to humor processing. In addition, using difference waves reduces the number of factors in the ANOVA, decreasing the number of p values to be calculated and thereby decreasing the familywise error rate (Luck, 2005).

Accordingly, based on visual inspection of the grand average ERP data of the resulting difference waves (joke-minus-non-joke waveforms in women and in men), the mean amplitudes of the difference waves in the given time window of 1000–1300 ms (P1000–1300) were examined using two-way, mixed-design repeated-measures ANOVAs, including the factors Sex (women and men) as the between-subject factor and Region as the within-subject factor.

In summary, four time windows were examined through the application of three-way mixed design repeated-measures ANOVAs to the mean amplitudes of N400, P500–1000, P1300–1500, and the application of two-way mixed design repeated-measures ANOVAs to the mean amplitude of the difference wave of P1000–1300. Behavioral rating scores were analyzed using two-way mixed-design repeated-measures ANOVAs. Additionally, correlation tests were applied to examine the relationships across the subjective ratings of surprise, comprehensibility, and funniness in women and in men. Greenhouse-Geisser corrections were applied to the ANOVAs as necessary. The Bonferroni correction was used for post hoc comparisons as necessary. All statistical differences were considered significant at a threshold of $p < .05$.

3. Results

3.1. Subjective ratings

The average rating scores of surprise, comprehensibility, and funniness for both conditions in women and men are listed in Table 1. Statistical analysis from two-way mixed-design ANOVAs revealed a nonsignificant interaction for each rating score (all $p > .05$). There were significant main effects of Condition for surprise ratings [$F(1, 38) = 135.20$, $p < .01$] and funniness ratings [$F(1, 38) = 191.28$, $p < .01$]. This reconfirmed the discriminative validity between the joke and nonjoke materials used in this study. However, no main effect of Sex was found. In other words, women and men provided similar ratings for the surprise, comprehensibility, and funniness of joke and nonjoke stimuli.

However, analysis of the correlations between the subjective ratings revealed a distinction between the two sexes. In men, there were moderately significant correlations between subjective ratings of surprise and comprehensibility ($r = 0.53$, $p < .01$), and between ratings of comprehensibility and funniness ($r = 0.69$, $p < .01$). In contrast, none of the pairwise correlations between the subjective ratings were significant in women (all $p > .05$).

3.2. Mean amplitudes of N400, P500–1000, and P1300–1500

Fig. 1A illustrates the grand average ERPs of the joke and nonjoke conditions in women and men. Three-way mixed design ANOVAs showed no three-way interaction of Sex, Condition, and Region for any of the three components. Likewise, no main effect of Sex or interaction effect involving the factor Sex was found for any of the three components. Means and standard deviations of the amplitudes of N400,

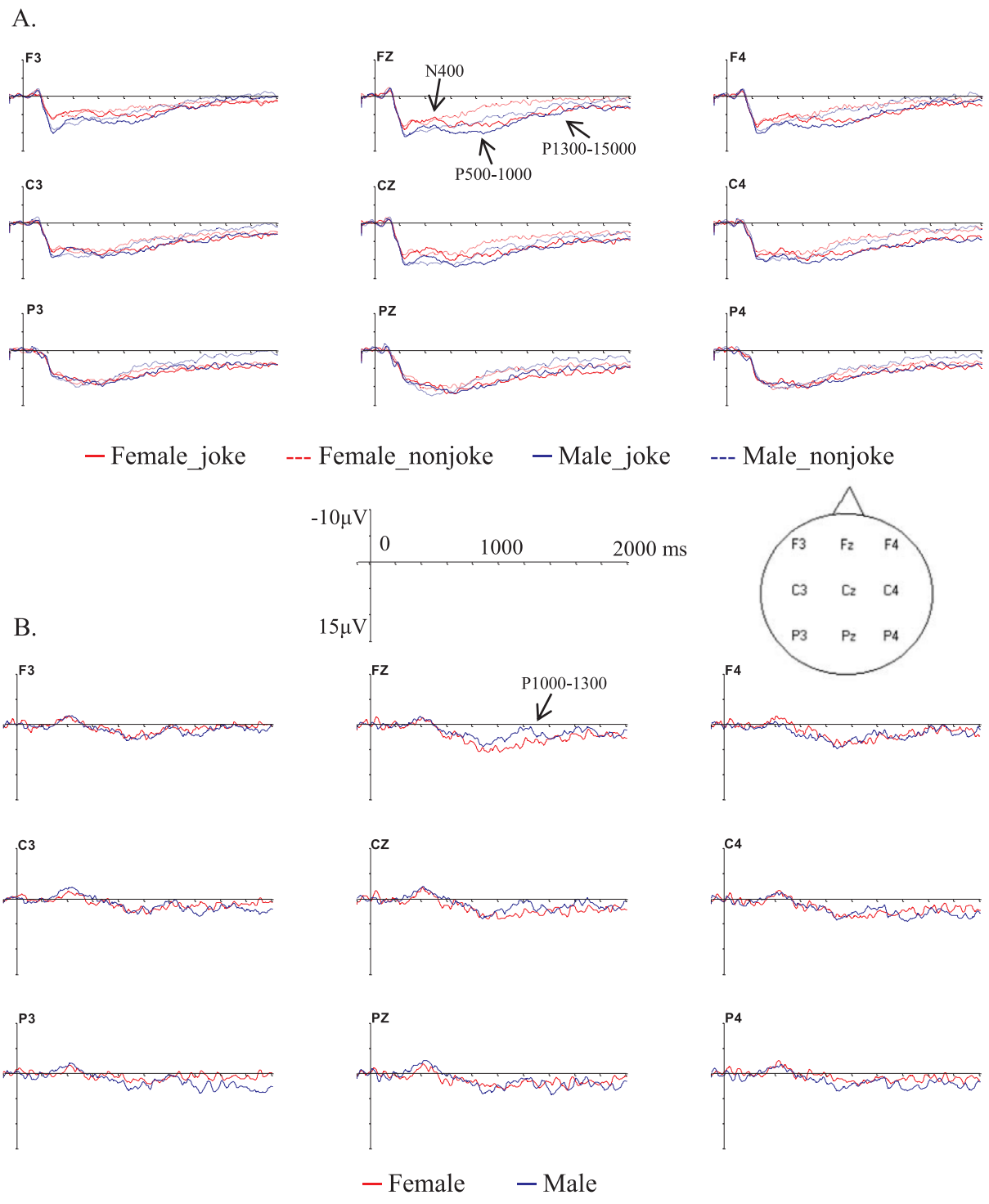

Fig. 1. Grand averaged ERPs over the 20 women and 20 men to the (A) joke and non-joke conditions, and (B) difference waves for each EEG channel. Negative potentials are plotted upward (unit: μV).

P500–1000, and P1300–1500 are listed in Table 2.

For N400, the data revealed significant main effects for Condition [$F(1, 38) = 8.07$; $p < .01$] and Region [$F(5, 190) = 13.50$; $p < .01$]. No interaction effect was found. The joke condition elicited a more negative N400 than the nonjoke condition (mean ± SD: 7.67 ± 0.66 for the joke condition; 8.77 ± 0.61 for the nonjoke condition). Post hoc tests showed that the strongest N400 effect was found at anterior sites, followed in sequence by central sites and then posterior sites (all $p < .05$). Moreover, a stronger N400 effect was found on the left side than in the midline position ($p < .01$).

For P500–1000, a significant interaction effect between Condition and Region was reported [$F(5, 190) = 3.91$; $p < .01$]. Both conditions elicited increased P500–1000 at the posterior and central sites relative to the anterior sites (all $p < .01$). During the joke condition, the strongest neural activity was observed at the midline sites, followed by the right sites, and, finally, the left sites (all $p < .05$). During the nonjoke condition, stronger neural activity was observed at midline sites compared to left sites (all $p < .05$). A post hoc analysis indicated that in each of the six regions of interest, the joke condition elicited a more positive P500–1000 than the nonjoke condition (all $p < .05$).

Table 2
Mean amplitudes of N400, P500–1000 and P1300–1500 in women and men.

		Joke		Non-joke	
	Region	Women	Men	Women	Men
Mean amplitudes of ERP effect (μV)					
N400	Anterior	4.85(7.66)	7.43(4.50)	5.89(4.45)	8.08(5.07)
	Central	7.34(4.53)	8.49(4.25)	8.32(4.22)	9.90(4.23)
	Posterior	8.85(3.75)	9.03(3.35)	9.94(3.72)	10.52(3.68)
	Left	5.87(7.24)	7.14(3.17)	6.93(4.00)	8.58(3.81)
	Midline	7.76(4.41)	9.20(4.94)	8.71(4.34)	10.70(4.59)
	Right	7.41(4.01)	8.60(3.74)	8.51(3.57)	9.21(3.84)
P500–1000	Anterior	6.42(4.01)	8.31(4.05)	4.22(2.93)	5.92(3.27)
	Central	8.35(3.57)	9.43(4.70)	6.57(3.66)	8.13(3.49)
	Posterior	8.90(3.18)	9.28(4.27)	7.87(3.54)	7.73(3.41)
	Left	6.88(3.81)	7.85(3.94)	5.84(2.88)	6.47(3.09)
	Midline	8.87(3.51)	10.08(4.98)	6.52(3.79)	8.47(4.15)
	Right	7.91(3.37)	9.09(3.87)	6.30(3.13)	6.84(2.62)
P1300–1500	Anterior	3.62(5.27)	3.98(3.23)	1.75(3.17)	1.88(3.72)
	Central	5.52(4.32)	5.91(4.45)	3.35(2.29)	3.55(4.28)
	Posterior	5.72(4.93)	5.45(4.07)	4.66(3.25)	3.19(4.06)
	Left	4.00(5.26)	4.18(3.54)	3.34(3.15)	2.25(3.44)
	Midline	5.78(4.48)	5.97(4.74)	3.26(2.90)	3.87(5.29)
	Right	5.09(4.68)	5.19(3.39)	3.15(2.13)	2.51(3.58)

Notes. Values are mean (SD).

For P1300–1500, a significant interaction effect between Condition and Region was found [$F(5, 190) = 2.53$; $p < .05$]. The joke condition elicited more positive waveforms than the nonjoke condition at the anterior, central, midline, and right sites (all $p < .01$). Within each condition, stronger P1300–1500 waveforms were observed at the posterior and central sites than at the anterior sites (all $p < .01$).

3.3. Mean amplitudes of difference waves of P1000–1300

In contrast to the statistical results of the three-way ANOVAs, which indicated no main effect of Sex or any interaction effect involving the factor Sex for the major components of N400, P500–1000, and P1300–1500, a two-way mixed-design ANOVA indicated a significant main effect of Sex [$F(1, 38) = 7.16$; $p < .01$, $\eta^2 = 0.158$] on the mean amplitudes of difference waves. Higher amplitude difference waves were found in women (mean ± SD: 4.22 ± 0.46) relative to men (mean ± SD: 2.46 ± 0.46) in the 1000–1300 ms time window poststimulus onset (Fig. 1B). There was no main effect of Region or any interaction effect (both $p > .05$).

We conducted the two-way ANOVAs as a supplementary analysis to check the mean amplitudes of the difference waves of N400, P500–1000, and P1300–1500. The statistical results revealed no main effect or interaction effect for these components (all $p > .05$).

4. Discussion

The present study is the first to use ERPs to examine the real-time dynamics of differences in how men and women process linguistic jokes based on the three-stage model of humor processing (Chan et al., 2013; Suls, 1972; Wyer & Collins, 1992). In the behavioral domain, we found that women and men provided similar subjective ratings of surprise, comprehensibility, and funniness to the materials used in the study. However, the results for men showed significant correlations between the subjective ratings of surprise, comprehensibility, and funniness, whereas all of the correlations for women were nonsignificant. In the neural domain, our data revealed an activation pattern of more negative N400 at anterior sites and more positive P500–1000 and P1300–1500 at central and posterior sites for the joke condition, compared with the nonjoke condition; this activation pattern is markedly similar to previous ERP findings (Du et al., 2013; Feng et al., 2014; Ku et al., 2017; Mayerhofer & Schacht, 2015; Shibata et al., 2017; Tu et al., 2014). However, these results failed to support our hypothesis that women would show larger positivities during the humor elaboration stage. Rather, the enhanced joke-minus-non-joke mean amplitudes in women relative to men were revealed by using difference wave analysis to examine the 1000–1300 ms (P1000–1300) time window.

4.1. The functional meaning of P1000–1300

Applying difference waves provides a relatively pure measure of the difference in the brain responses between women and men during humor processing. Notably, the timing of the significant sex differences found during the difference waves of P1000–1300 was anchored approximately between the second and the third visually prominent components in reference to men's grand average ERP data. These are the two ERP components which have been interpreted as the incongruity resolution stage and the humor elaboration stage in previous studies, respectively. Moreover, when the grand average waveforms of the mean amplitudes were examined, neither women nor men showed a prominent ERP effect during this period. Thus, we conjecture that the P1000–1300 difference waves are unlikely to represent a pure measure of the third stage of humor elaboration. Rather, they may represent the interplay between the cognitive processes of the incongruity resolution stage and the emotional processes of the humor elaboration stage. We infer that during this intersectional time phase, men recruited more automated processes during the transition from cognitive to emotional processing when reading jokes. In contrast, women recruited more resources than men to integrate and transition from the late cognitive operation of humor comprehension to the early emotional response of humor appreciation.

Based on difference waves analysis, the results from this study appear to support the proposal of Azim et al. (2005) and Shibata, Terasawa, and Umeda (2014), namely that the different aspects of humor processing should not be overemphasized with respect to the reciprocal interaction between cognitive and emotional processes at the neural level. According to our results, this proposal may be more applicable specifically to humor processing in women. Furthermore, our ERP findings reconfirm that women and men exhibit extensive overlapping activation during cognitive humor processing, with the difference waves being nearly identical for women and men before 1000 ms poststimulus onset.

4.2. Differences in pairwise correlations between surprise, comprehensibility, and funniness ratings in women and in men

In this study, men showed stronger interrelationships between the subjective ratings of surprise, comprehensibility, and funniness levels in response to the humorous materials. Specifically, the more men comprehend the jokes, the funnier they feel them to be, and vice-versa. Conversely, the extent to which women feel the jokes are amusing has no connection to their understanding of them (at least presumably, in this study). That is, along the processing flow from humor comprehension to humor appreciation, men appear to follow a relatively regular pattern, whereas women do not. The reported irrelevance of subjective ratings for women presented by our data may provide an explanation for why women enjoy nonsensical or absurd humor more than men, as suggested by previous studies (Brodzinsky & Rubien, 1976; Brodzinsky et al., 1981; Terry & Ertel, 1974). Collectively, the findings from the subjective ratings in our study indicate that comprehensibility modulates the development of humor appreciation for men but not for women. We conjecture that this might be because women and men possess different expectations and goals in the context of joke processing.

4.3. Underlying mechanisms leading to sex differences in humor processing

A review of the differential social roles and functions associated

with humor in women and men is appropriate here. As mentioned, men have been reported to be more likely to act as humor creators (Bressler & Balshine, 2006; Crawford & Gressley, 1991; Martin, 2007), and women to be more likely to act as humor appreciators (Bressler & Balshine, 2006; Chan, 2016; Li et al., 2009; Martin, 2007; Vrticka et al., 2013). Specifically, in the social context of joke processing, women often play a passive role involving being amused, considering themselves to be the recipients in humorous situations, whereas men are usually actively involved in creating humor to show their superiority or gain self-esteem. In this regard, although Azim et al. (2005) suggested a greater reward network response but possibly less reward expectation in women, we suggest that there is a greater reward expectation in women in the context of the social meaning, based on an evolutionary perspective. Differential social roles involving being active or passive participants may contribute to the differential coping strategies that women and men use in humorous scenarios, resulting in differential activation patterns in brain activity between the two sexes during humor processing.

Notably, it has been well established that women and men have different styles of coping (Tamres et al., 2002). When coping with emotional events, men are more likely to employ more problem-focused coping behaviors (Pearlin & Schooler, 1978; Stone & Neale, 1984; Vingerhoets & Van Heck, 1990), whereas women use more emotion-focused regulation strategies (Nolen-Hoeksema & Jackson, 2001). That is, when processing emotional stimuli, women and men assign differential weightings to cognition and emotion. In a meta-analysis that combined 65 neuroimaging studies on emotion and reported gender differences in brainstem and cortical regions, Wager, Phan, Liberzon, and Taylor (2003) argued that men might direct more attention to the implications of required actions, whereas women might direct more attention to the feeling state. In other words, men tend to adopt more goal-directed actions when confronting emotional events, whereas women tend to immerse themselves in the experiential state caused by emotional events.

Because joke scenarios are evidently emotional events waiting to be resolved, we assumed that the underlying mechanisms leading to sex differences in the integrated humor process might be similar to those underlying mechanisms leading to the differential coping strategies adopted by women and men in the context of emotional events. We propose that, acting as active participants, when men saw the setup questions (the “problems”), they attempted to engage in a goal-directed action, expecting to “solve the problems.” That is, in the context of joke processing, men may be inclined to apply problem-solving strategies, primarily for the purpose of finding possible resolutions. Additionally, as evident from the moderately strong correlations between the subjective ratings in men, it appears that the prerequisites of the integrated humor process, namely the three stages of incongruity detection, incongruity resolution, and humor elaboration, did follow some rules in a time-sensitive manner in men. Thus, compared with women, the derived neural evidence of a significant decrease in P1000–1300 in men indicates that men exert less effort to integrate the cognitive and the emotional components into a whole during the intersectional time phase. It also reveals that men recruit more automated processes to transition from the cognitive to the affective stage during humor processing (as evident from the more clearly discriminated second and third major components revealed in the men’s grand average data). Hence, it appears that collectively integrating the cognitive and emotional components at a later stage is unnecessary for men to develop their appreciation of the jokes; indeed, in comparison with women, men’s appreciation is more correlated with their comprehensibility. This finding is also consistent with the findings of Kohn et al. (2011) and their interpretation of more automatic emotion regulation in men.

Women have been found to be focused on emotional responses and inclined to use more emotion-focused strategies when confronting emotional events. In this sense, we assume that when reading jokes, women—who, as suggested, act in the passive role of humor appreciators—may place more emphasis on the emotional responses that are going to be induced by the humorous materials, rather than on searching for possible resolutions for the incongruities embedded in the jokes, as men do. The emotional response itself appears to be an end in itself for women during the humor process. On the basis of our results, we interpret the enhanced P1000–1300 as implying that women recruited more mental resources to integrate the cognitive and emotional components of the jokes. The underlying mechanism contributing to the enhanced effect in this particular time window may be twofold: first, a greater preference in women to immerse themselves in the experiential state during joke processing; and second, the inherent superiority of women in terms of semantic and emotional processing.

Previous studies have indicated that women appear to recruit more automated semantic processing than men (Whittle, Yücel, Yap, & Allen, 2011; Wolff, Hurwitz, Imamura, & Lee, 1983). In addition, women have been reported to be more emotionally perceptive and more reactive to emotional stimuli (Whittle et al., 2011). We conservatively conjecture that, because women place more emphasis on induced emotional responses, the original more automated semantic processing is then postponed in order to collectively integrate the emotional responses into a whole; moreover, the inherent advantage in their processing of emotion-related information may accelerate their induced emotional responses relative to men. In a study by Schirmer, Kotz, and Friederici (2002) that investigated sex differences regarding emotional prosody using a lexical decision task, women showed priming effects with a small interstimulus interval (ISI of 200 ms) between the prosodic prime and the visual target word. In men, similar effects of emotional prosody on word processing occurred only for a longer interval between the prime and the target (ISI of 750 ms). The authors further underlined that women “might profit from shorter neuronal connections between areas that process language and areas that process emotional prosody,” implying an intimate bond between cognitive and emotional functions in women (pp. 232 in Schirmer et al., 2002). This account is in line with our interpretation based on the results revealed for women in the present study. On the basis of the significantly larger P1000–1300 difference waves shown in the present study, we suggest that humor comprehension and humor appreciation are more functionally connected in women, which is also more consistent with the perspectives of Kohn et al. (2011) and Chan (2016) based on their neural activity findings from fMRI.

4.4. *Difference waves: A more effective means of exploring sex difference in humor processing*

Findings from previous studies regarding ERP components which correspond to the three-stage model indicate that the specified time window and reported scalp sites become more varied as processing time proceeds (Du et al., 2013; Feng et al., 2014; Ku et al., 2017; Mayerhofer & Schacht, 2015; Tu et al., 2014). In other words, the evoked neural responses for comprehending humorous stimuli become increasingly diverse and complex as the process proceeds from the initial incongruity detection at the perceptual level to the resolution process at the cognitive level, and finally to affective elaboration at the emotional level. In addition, prior research suggests that the end product of the humor process, namely the sense of amusement or humor appreciation, is influenced by individual differences such as sex and personality traits (Bressler & Balshine, 2006; Samson, Hempelmann, Huber, & Zysset, 2009). It is plausible that, as the processing time lengthens, the subjective involvement of cognitive and emotional processes gradually increases. This would lead to a substantially increased divergence between individuals’ brain activity patterns toward the later stage of humor processing, which is in line with our grand average data for women and men. However, this could hinder the identification of a suitable time window for all subjects, and present a particular difficulty for the present study, which was focused on the proposed potential sex difference in emotional responses at the later stage. In this regard, the

use of difference waves can circumvent this problem.

This study indicates that difference waves are effective tools for our study hypothesis and research purpose. Because humor processing is a complex phenomenon composed of the interaction between cognitive and emotional resources on the basis of extensive language processing, implicit sex differences may be relatively minute and difficult to reveal. However, prior studies have noted inherent sex differences in many cognitive and emotional domains, such as in semantic processing or in emotional perceptiveness and responses, which are also involved in integrated humor processing (Bradley et al., 2001; Daltrozzo et al., 2007; Schirmer et al., 2002; Whittle et al., 2011). By subtracting the mean amplitudes of conditions, specific neural signatures of humor processing for each sex can thereby be rendered more prominent. Thus, the use of difference waves can overcome problems due to overlap in time and minimize para-effects that are less relevant to core of humor processing (e.g., language processing of semantics, or the problem-solving process involved in both joke and nonjoke conditions). This leaves only brain activity that reflects task-induced differential processing, in other words, the "real" and implicit sex differences during humor processing.

As mentioned in the Introduction section, we were particularly focused on identifying the time phase during which a sex difference in neural processing of linguistic jokes would emerge. Hence, it was irrelevant whether the activities in the joke-minus-non-joke difference waves could be clearly categorized according to their functional role, as in the N400, P600, or some other later components. Regardless of the functional meanings of these components, by using difference waves it was possible to effectively demonstrate that the brains of women and men do process humor differently, particularly in the 1000–1300 ms period poststimulus onset.

In summary, the present study advances our understanding of sex differences in humor processing. Four key contributions have been made. First, the results support the idea that women and men show extensively overlapping activation patterns during humor comprehension. Second, based on neural evidence of temporal dynamics in brain activity, we determined that for humorous scenarios (or generally speaking, in the context of emotional events), the processing of cognitive and emotional components should not be discussed separately; this is because these processes are closely linked and interact reciprocally, particularly in women. Third, we discovered that sex differences in humor processing involve the integration of humor comprehension and humor appreciation, not simply each in isolation. Fourth, the present study provides a new insight, namely that examining the mean amplitudes of difference waves, rather than the mean amplitudes themselves, is a more efficient means of uncovering subtle but critical differences between the sexes regarding brain activity involved in humor processing. In this study, multiple perspectives were integrated to explain such differences between the two sexes: differences in social roles from an evolutionary perspective; differences in neural correlates from a neural perspective; differences in coping strategies from a behavioral perspective; and the inherent superiority of women in semantic and emotional processing. Based on the present findings, we hope that a more comprehensive view, from both biological and social–cultural perspectives, can aid our comprehension of how and why women and men differ when it comes to humor.

4.5. Limitations

This study has some limitations. First, the familiarity (or the predictability) of materials may diminish behavioral responses and consequent responses in the brain. Applying familiarity as the fourth behavioral index may facilitate the selection of more effective stimuli. Second, although the term *sex* is defined by biological differences, some have argued that *sex* is founded on social constructs and that it is unwise to divide the population by biology when measuring psychological traits. The traits of masculinity and femininity appear to be more applicable now than in preceding eras. In such a context, applying psychological traits of gender identity such as masculine, feminine, androgynous, or undifferentiated, as in Brodzinsky et al. (1981), may be effective in better understanding brain activities associated with gender identity and humor appreciation. In future research aimed at examining sex differences regarding humor, or indeed on any other issue, further methodological considerations will be necessary to allow the innate brain mechanisms distinguishing the sexes to be clarified.

5. Conclusions

The current study presented neural evidence on the time-course of integrated humor processing in men and women. Although no obvious effects were apparent in subjective ratings at the behavioral level, underlying sex-based differences in humor processing still emerged at the neural level, as indexed by the enhanced mean amplitudes of P1000–1300 difference waves (joke-minus-non-joke waveforms) in women compared to men. During this particular time window between 1000 and 1300 ms poststimulus onset, women appear to devote more mental resources to integrating the interdependent cognitive and emotional components of humor. Therefore, the interplay between cognitive and emotional components in the context of joke processing seem to be more influential in women. In contrast, a more automated transition from humor comprehension to humor appreciation was observed in men. Correlation analyses revealed that, when comprehending jokes, men conformed to certain temporal relationships between the three stages of the integrated humor process, whereas women did not. Comprehensibility acted as a modulator of the feeling of mirth for men, but such an effect was lacking for women. We suggest that the underlying mechanism leading to sex differences in humor processing may relate to the different social roles of men and women, as explained by the evolutionary perspective and as apparent in the differential coping strategies men and women exhibit when confronting emotional events such as joke processing. The present study provides preliminary evidence of the neural time-course derived using difference waves to confirm the emergence of sex differences during humor processing. Our findings highlight the importance of considering interactions between cognitive operations and emotional responses during humor comprehension and humor appreciation when discussing sex differences in humor processing.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.bandc.2017.11.002.

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