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Identifying Cognitive Preferences for Attractive Female Faces: An Event-Related Potential Experiment Using a Study-Test Paradigm

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In this experiment, sensitivity to female facial attractiveness was examined by comparing event-related potentials (ERPs) in response to attractive and unattractive female faces within a study-test paradigm. Fourteen heterosexual participants (age range 18–24 years, mean age 21.67 years) were required to judge 84 attractive and 84 unattractive face images as either "attractive" or "unattractive." They were then asked whether they had previously viewed each face in a recognition task in which 50% of the images were novel. Analyses indicated that attractive faces elicited more enhanced ERP amplitudes than did unattractive faces in judgment (N300 and P350–550 msec) and recognition (P160 and N250–400 msec and P400–700 msec) tasks on anterior locations. Moreover, longer reaction times and higher accuracy rate were observed in identifying attractive faces than unattractive faces. In sum, this research identified neural and behavioral bases related to cognitive preferences for judging and recognizing attractive female faces. Explanations for the results are that attractive female faces arouse more intense positive emotions in participants than do unattractive faces, and they also represent reproductive fitness and mating value from the evolutionary perspective. © 2011 Wiley-Liss, Inc.

Key words: female faces; attractiveness; ERP; cognitive preferences

Recent brain imaging studies have shown that several brain areas are differentially responsive to attractive vs. attractive faces (Aharon et al., 2001; O'Doherty et al., 2003; Senior, 2003; Chatterjee et al., 2009). For example, O'Doherty et al. (2003) found that medial prefrontal regions, including the medial orbitofrontal cortex and lateral regions, were more responsive to attractive than to unattractive faces. Chatterjee et al. (2009) found that the fusiform face area (FFA), lateral occipital cortex (LOC), and medially adjacent regions were activated automatically by beauty and may be a neural trigger for pervasive effects of attractiveness in social interactions, regardless of the task in which participants are engaged. Although brain areas responsive to attractive vs. unattractive faces have been extensively investigated, little is known about the time course of brain responses to these stimuli.

Numerous studies have reported early ERP effects in face perception-related time periods, such as N1, P1, N170, and P170 components (Pizzagalli et al., 1999, 2002; Halit et al., 2000). Pizzagalli et al. (1999) found ERP that difference responses to a likable and nonlikable Szondi portrait were modulated between 100 and 160 msec. Pizzagalli et al. (2002) showed that responses to likable vs. neutral or nonlikable Szondi portraits can modulate face processing at a latency of about 160 msec. Moreover, Werheid et al. (2007) revealed that attractive as opposed to unattractive target faces elicited an early posterior negativity (EPN; ~230–280 msec) during an

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TABLE I. Ratings of Female Chinese Face Images by Chinese College Students (n = 80)

Rating dimension	Attractive faces, mean (SD)	Unattractive faces, mean (SD)	Average faces, mean (SD)	F(2, 333)	P
Attractiveness	7.92 (0.82)	2.71 (0.99)	5.35 (1.33)	761.141	0.001
Happiness	6.36 (0.68)	2.78 (0.60)	4.36 (0.48)	879.517	0.001
Arousal	6.44 (0.71)	6.32 (0.83)	6.26 (0.92)	1.343	0.263
Dominance	4.70 (0.46)	4.81 (0.66)	4.77 (0.38)	0.996	0.370
Emotion valence	2	2	2	0.001	

attractiveness classification task. Recent evidence also suggests a comparatively larger occipitotemporal negativity for attractive faces at about 300 msec (Werheid et al., 2007; Schacht et al., 2008). However, other studies have shown that attractive faces elicit larger amplitudes of the parietocentral LPC between 400 and 600 msec after target onset (Johnston and Oliver-Rodriguez, 1997; Oliver-Rodriguez et al., 1999).

Although these studies point to clear effects in processing attractive faces, some of them did not control for the expression of attractive faces. Marzi and Viggiano (2010) reported that, independently of facial expression, facial attractiveness modulates face processing from encoding through recognition. Unfortunately, however, these authors did not separate female faces from male faces, so it is not clear whether responses differ for female vs. male faces stimuli. This issue is important because one previous study revealed that attractive female faces activate reward regions more strongly than attractive male faces or unattractive faces of either gender (Aharon et al., 2001). Therefore, to elucidate responses to different degrees of facial attractiveness further, we assessed the temporal course of neural responses to attractive and less attractive female facial stimuli via ERP within a study–test paradigm. We hypothesized that attractive female faces would elicit more enhanced ERP components and amplitude than unattractive faces during both judgment and recognition tasks.

MATERIALS AND METHODS

Participants

As paid volunteers, 14 Chinese participants (seven females, seven males) aged 18–24 years (mean age 21.67 years) participated in the experiment. All were heterosexual, were right-handed, and had normal hearing and no self-reported history of neurological or psychiatric disorder. Each participant signed an informed consent form for the experiment. The study was designed in accordance with tenets of the Declaration of Helsinki. Approval was granted from the Research Ethics Committee, School of Psychology, Southwest University, Chongqing, China.

Stimuli

Unfamiliar face photographs of young Chinese women (n = 490) were collected from the Google website in 2009; all featured a neutral emotional expression. Search keywords were: images (照片/证件照 in Chinese). Standardized facial stimuli were developed and validated within a recently published study (Zhang et al., 2010). For 346 stimulus images selected by two specialists, nine-step rankings were made on dimensions of attractiveness, happiness, arousal, and dominance and a three-step rating on emotional valence (1, positive; 2, neutral; 3, negative) by 80 Chinese university students (39 males, 41 females, mean age 21.98 years). Finally, 84 attractive face images (rating range 7–9), 84 less attractive face images (rating range 1–3), and 168 average face images (rating range 4–6) were employed in the ERP experiment. One-way analyses of variance (ANOVA) were performed on the dimensions described above (see Table I), and post hoc analyses assessed specific differences among the three face categories (all $P < 0.01$). To examine the consistency of attractiveness categorizations between the current sample and prior samples, research participants also rated the experimental images on nine-step scales immediately after the ERP measurement was finished. The t-test results revealed no differences between preexperimental and postexperimental ratings ($P > 0.05$), as reflected in Table II.

TABLE II. Pre- and Postexperimental Ratings of Facial Attractiveness Categories

Rating dimension	Attractive faces, mean (SD)	Unattractive faces, mean (SD)	Average faces, mean (SD)
Preexperimental ratings (N = 80)	7.92 (0.82)	2.71 (0.99)	5.35 (1.33)
Postexperimental rating (N = 14)	8.08 (0.69)	2.47 (0.98)	4.95 (1.23)
t (df = 92)	−0.77	0.84	1.13
P	0.446	0.403	0.263

Procedure

Participants were seated in a comfortable chair in a soundproof, electrically shielded, dimly lit room, at a distance of 80 cm from the computer screen. Next, electrodes were placed, and the participants were instructed to limit movements and eye blinks during testing. Judgment and recognition tasks were then completed sequentially using the same sequence of events (see Fig. 1). The stimuli were presented in randomized order. The response-to-hand assignment was counterbalanced across participants.

For the study phase, participants had to classify each target face as "attractive" or "unattractive" as quickly and accurately as possible by pressing one of two horizontally arranged keys. There were 168 trials covering 84 attractive and 84 unattractive female face images divided into two blocks of 84 trials featuring 42 attractive and 42 unattractive face images. The duration of the experiment was about 15 min.

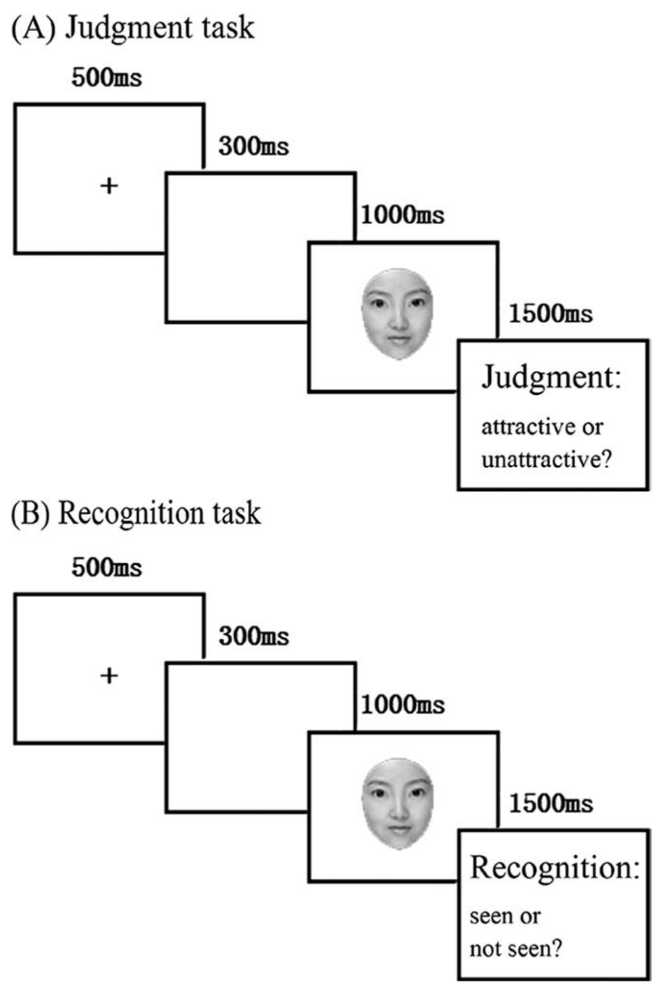

Fig. 1. Experimental procedure. Attractiveness judgment was performed during the study phase (**A**; judgment task) followed by recall of familiar vs. novel faces in a test phase (**B**; recognition task).

For the test phase, participants were asked whether they recognized face images from the judgment task based on Rugg et al.'s (1998) ''new/old'' paradigm. There were 336 trials divided into two blocks that included 168 previously viewed, familiar images and 168 novel images. Each block consisted of 168 trials, including 42 familiar attractive faces, 42 familiar less attractive faces, and 84 novel face images. The duration of the experiment was about 25 min.

ERP Recording and Data Processing

The electroencephalogram (EEG) was recorded from 64 scalp sites using tin electrodes mounted in an elastic cap (Brain Products, Munich, Germany), with the references on the left and right mastoids (average mastoid reference; Luck, 2005). The ground electrode was on the medial frontal aspect. The vertical electrooculogram (EOG) was recorded with electrodes placed above and below the left eye. The horizontal EOG was recorded from the left vs. the right orbital rim. EEG and EOG were amplified using 0.01–100-Hz bandpass and continuously sampled at 500 Hz/channel. Impedances were kept below 5 kΩ. Averaging of ERPs was computed off-line, rejecting those trials with eye movements, blinks, motion, or other artifacts at any of the channels. Trials contaminated with EEG artifacts (mean voltage exceeding ±80 mV) or those with artifacts resulting from amplifier clipping, bursts of electromyographic (EMG) activity, or peak-to-peak deflection exceeding ±80 mV were excluded from averaging. For the ERP analysis, epochs of 1,000 msec were generated offline from the continuous ERP records, starting 200 msec before target stimulus onset. Furthermore, incorrect behavioral classifications had to be rejected from further data processing. ERPs were aligned to a 200-msec baseline. The remaining 50+ trials in two tasks were averaged separately for each channel and experimental condition and recalculated to average reference, excluding the vertical EOG channels. Average ERP waveforms were calculated separately for each of the conditions described above in two tasks.

Data Analysis

Behavior. For the study phase, repeated-measures ANOVAs were performed on accuracy (ACC) and reaction times (RTs) for correct classifications. Attractiveness (attractive vs. unattractive) was the independent variable. For the test phase, attractiveness level differences in mean recognition ACC and RTs for correct responses of familiar (hits) faces were analyzed with repeated-measures ANOVAs (Fig. 2).

ERP. ERP amplitudes of early components (N1, N2, P1, P2, N3) and mean amplitudes in selected time periods (see below) were assessed via repeated-measures ANOVA, with attractiveness (attractive vs. unattractive) and location (frontal/frontocentral/central/centroparietal/parietal) as factors. For all analyses, P values were corrected for deviation from sphericity according to the Greenhouse-Geisser method.

RESULTS

Behavioral Responses

For the study phase, no significant effects emerged for ACC [$F(1, 13) = -0.9$, $P = 0.4$], but RTs yielded a significant effect of attractiveness [$F(1, 13) = 5.3$, $P < 0.001$]. Longer RTs were found when participants judged faces to be attractive rather than unattractive [$t(13) = 5.3$, $P < 0.001$; Fig. 2].

ANOVA for the test phase revealed a main effect for ACC [$F(1, 13) = 8.9$, $P < 0.01$], with greater accuracy in recognizing attractive than unattractive faces [$t(13) = 7.6$, $P < 0.001$]. The ANOVA for RTs revealed a main effect [$F(1, 13) = 21.3$, $P < 0.001$], in which longer RTs were observed in recognizing attractive than unattractive faces [$t(13) = 5.0$, $P < 0.001$; Fig. 2].

ERP Results

Study phase. Visual inspection revealed that early ERP components following target faces were markedly elicited, including N1 (N60–120), P2 (P140–180), N2 (N180–250), and N3 (N250–350) components, independently of whether faces were attractive or unattractive. Latencies were not significantly different.

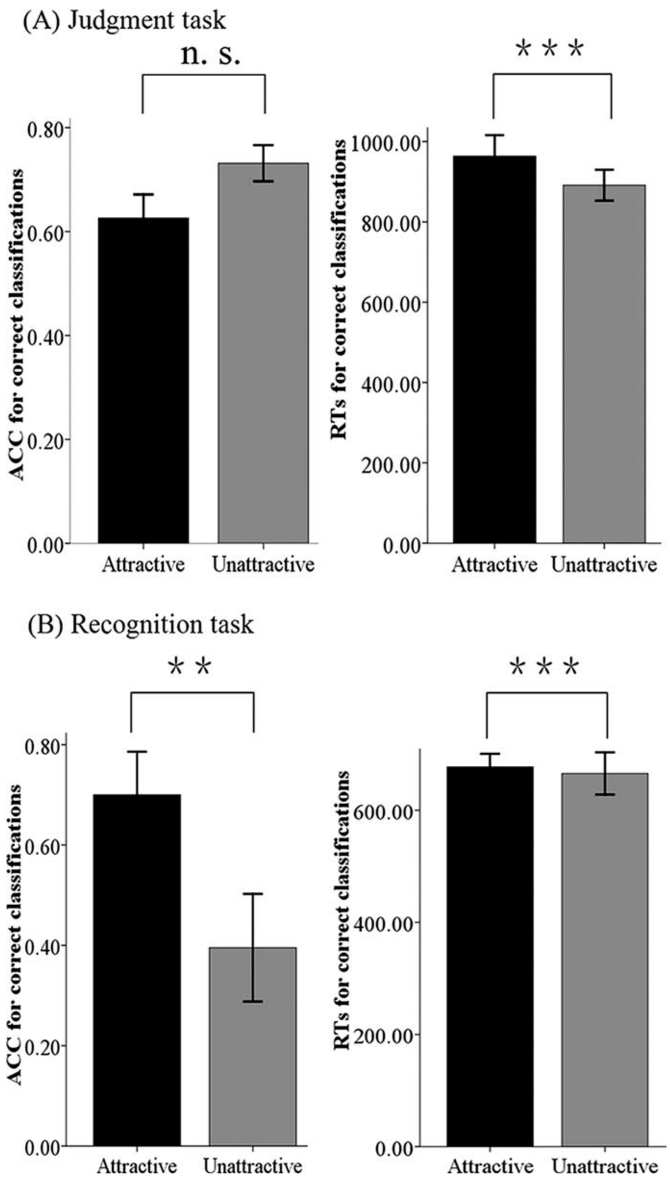

Fig. 2. Accuracy rate (ACC) and mean reaction times (RTs) for correct classification in the judgment (**A**) and recognition (**B**) of attractive vs. unattractive faces.

For the peak and amplitudes, there were no attractiveness differences on N1, P2, or N2 components. However, distinct ERP waveforms emerged for attractive vs. unattractive faces on the N300 component and within the LPC (350–550 msec) time range (Fig. 3). The topographies of the ERP difference curves (attractive vs. unattractive) were clearly different at about 300 msec posttarget and within the LPC time range (350–550 msec; Fig. 4).

Early anterior negative component (N300). The attractiveness × location ANOVA revealed effects for attractiveness [$F(1, 13) = 5.1$, $P < 0.05$], location [$F(1.3, 16.9) = 12.4$, $P < 0.01$], and their interaction [$F(1.6, 20.5) = 3.9$, $P < 0.05$]; attractive faces yielded greater negativity than did unattractive faces at frontal sites [$F(1, 13) = 6.6$, $P < 0.05$], frontocentral sites [$F(1, 13) = 5.8$, $P < 0.05$], and central sites [$F(1, 13) = 6.4$, $P < 0.05$]. Figure 3 illustrates representative electrode sites in these locations (frontal sites, Fz; frontocentral sites, FCz; central sites, Cz).

Late positive component (LPC; 350–550 msec). In the early time window from 350 to 550 msec, significant main effects for attractiveness [$F(1, 13) = 4.8$, $P < 0.05$] and location [$F(1.4, 17.5) = 19.8$, $P < 0.001$] reflected larger amplitudes for attractive than unattractive faces at central sites [$F(1, 13) = 6.0$, $P < 0.05$].

Test phase. Visual inspection revealed that early ERP components following target faces were markedly elicited regarding N1 (N60–120), P2 (P140–180), and N2 (N180–250), independent of attractiveness level, whereas latencies were not significantly different. For the peak and amplitudes, there were no significant attractiveness differences on N1 or N2 ERP components. However, distinct ERP waveforms emerged for attractive vs. unattractive faces on the P160 component, 250–400 msec, and within the LPC (400–700 msec) time range (Fig. 3). As shown in Figure 4, topographies of the ERP difference curves (attractive vs. unattractive) were clearly different.

Early anterior positive component (P160). The 2 × 2 ANOVA revealed main effects for attractiveness [$F(1, 13) = 7.0$, $P < 0.05$] and location [$F(1.3, 17.2) = 41.8$, $P < 0.001$], with attractive faces eliciting enhanced positivity compared with unattractive faces, at frontal sites [$F(1, 13) = 5.4$, $P < 0.05$], at frontocentral sites [$F(1, 13) = 7.1$, $P < 0.05$], and at central sites [$F(1, 13) = 12.6$, $P < 0.01$].

Late negative potential (~250–400 msec). From 250 to 400 msec, the main effect for attractiveness [$F(1, 13) = 6.4$, $P < 0.05$] and location [$F(1.3, 16.7) = 17.2$, $P < 0.001$] indicated greater negativity for attractive faces than unattractive faces at frontal sites [$F(1, 13) = 5.0$, $P < 0.05$], at frontocentral sites [$F(1, 13) = 5.0$, $P < 0.05$], and at central sites [$F(1, 13) = 10.4$, $P < 0.01$].

LPC (~400–700 msec). In the time window 400–700 msec, a main effect was found for attractiveness [$F(1, 13) = 4.9$, $P < 0.05$] and location [$F(2.3, 30.6) = 4.201$, $P < 0.05$], with attractive faces yielding greater positivity than unattractive faces at central sites [$F(1, 13) = 4.8$, $P < 0.05$].

Summary of the Results

In sum, attractive faces elicited more enhanced ERP amplitudes than did unattractive faces in judgment (N300 and P350–550 msec) and recognition (P160, N250–400 msec and P400–700 msec) tasks on anterior locations. Moreover, higher ACC rates and longer RTs were found for attractive than for unattractive faces.

DISCUSSION

Effects of Facial Attractiveness on Behavioral Responses

More time taken in judging attractive bvs. unattractive female faces might have reflected more attention

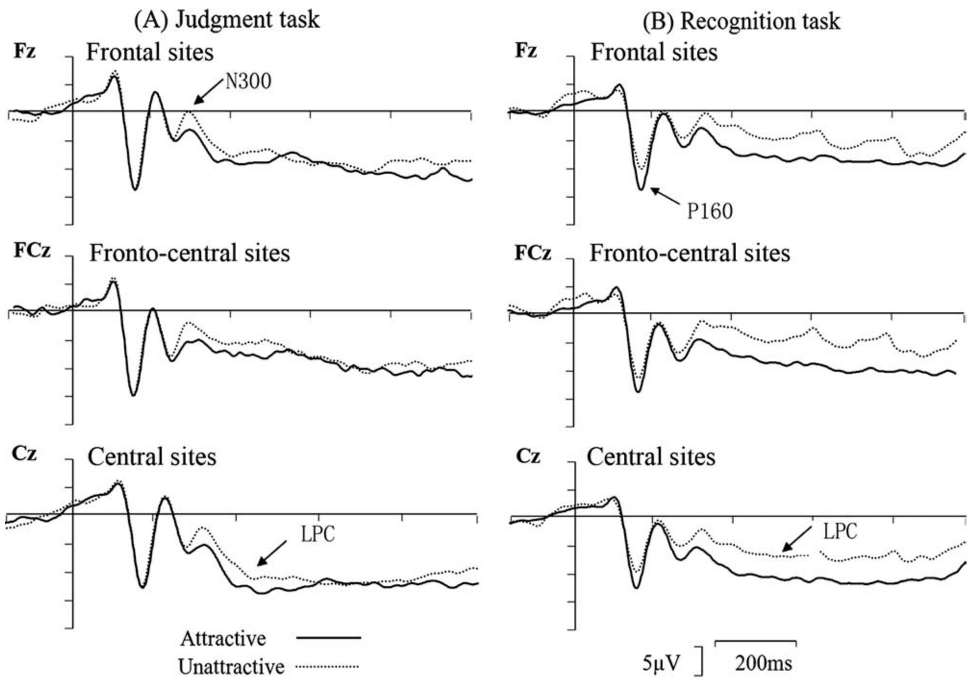

Fig. 3. Grand-mean event-related potentials at representative electrode sites at three locations (frontal sites, Fz; frontocentral sites, FCz; and central sites, Cz) during the judgment (**A**) and recognition (**B**) of attractive vs. unattractive faces.

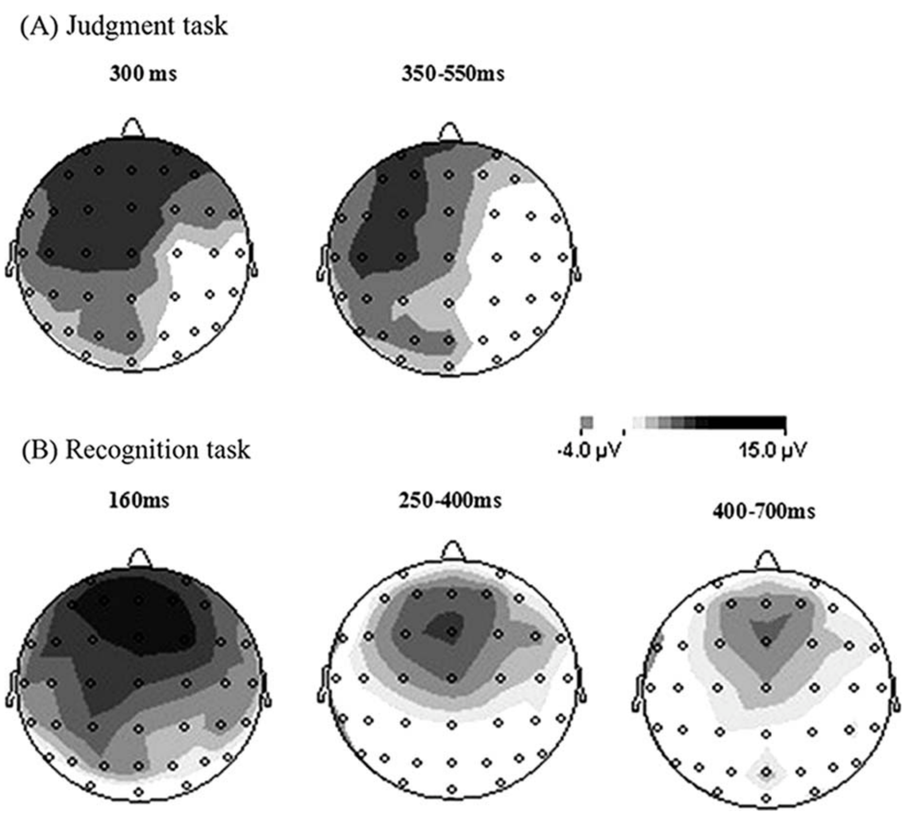

Fig. 4. Topographies of differences curves (attractive minus nonattractive faces) during judgment (**A**) and recognition (**B**).

devoted to processing beautiful facial features. Furthermore, participants might have been more cautious in judging attractive faces, based on evidence that more effort is exerted by the key press procedure in rating beautiful females as attractive compared with attractive males (Aharon et al., 2001).

Accordingly, participants were also significantly slower and more accurate in recognizing the attractive faces. Perhaps attractive faces made comparatively deeper impressions on participants during the judgment task, and participants were more deliberate and accurate in remembering these compared with unattractive faces. These findings are somewhat consistent with those of Marzi and Viggiano (2010), who found a greater accuracy in retrieving highly attractive faces than faces of medium or low attractiveness or unattractive faces. Accuracy in detecting attractive faces may be facilitated because attractive features more closely match cultural preferences for facial beauty. Also, reinforcing properties of attractive faces might have enhanced recognition accuracy. This interpretation is in accordance with research indicating that attractive female faces lead men to discount higher future rewards against smaller immediate rewards (Wilson and Daly, 2004).

Effects of Facial Attractiveness on ERP Results

Importantly, the current behavioral results are consistent with observed patterns of ERP response. Specifically, attractive and unattractive female faces elicited significant differences in early and late ERPs components in judgment and recognition. When participants made explicit evaluations of attractiveness, N300 was more sensitive to attractive than unattractive female faces. N300 is considered to relate to the picture stimulus classification processing (Hamm and Blake, 2002). Because of its frontal distribution, the N3 difference wave might reflect the occurrence of conflict detection (Nieuwenhuis et al., 2003; Yeung and Cohen, 2006) consistent with differences in judgment task properties (i.e., judging female faces as attractiveness vs. unattractiveness).

In addition, consistently with previous ERP research (Johnston and Oliver-Rodriguez, 1997; Oliver-Rodriguez et al., 1999) concluding that the LPC is sensitive to facial attractiveness, the most enhanced late positivity (LPC) activity (P350–550 msec) elicited by attractive faces was produced in frontal-central locations. N300 and LPC in the judgment task could reflect different cognitive functions, including perceptual closure, stimulus evaluation, decision-making, and working memory updating (Polich, 2003). Overall, analogously to behavioral results, ERP evidence supports a judgment preference for facial attractiveness.

Attractive faces also elicited a comparatively more positive P160 component in the recognition task from the frontal to the central cortex. Some investigators have suggested that facial attractiveness recognition processing begins prior to the LPC time window (Werheid et al., 2007). For example, Schacht et al. (2008) showed that facial attractiveness can modulate face processing starting as early as 150 msec. The brain's capacity to implement rapid perception-related stimulus detection supports this view (Olson and Marsheutz, 2005). Early ERP effects in processing attractive faces reflect the detection of perceptual features or facial configurations that are associated with stimulus-driven frontal attention mechanisms (Chen et al., 2007). Thus, our findings supported the view of Halit et al. (2000) that these very early ERP effects represent, in part, processing of facial features. In concert with other work, we can conclude that P160 is related to stimulus-driven rather than evaluative processes and reflects precategorical perceptual encoding of faces in face-specific ventral visual areas that provide structural representations utilized in subsequent stages of face recognition (Bentin et al., 1996; Eimer, 1998, 2000).

Moreover, Chatterjee and colleagues (Chatterjee, 2004; Chatterjee et al., 2009) found that specific regions within visual association cortices continue to respond to facial attractiveness. This region may be involved in visual processing before object identification, such as the apprehension of symmetry and grouping, processes that also occur automatically and influence aesthetic judgment. These hypotheses require further investigations.

Attractive Faces as Reward Value Evoked Early ERP Effect

An alternate explanation for ERP patterns is that attractive faces are more emotionally rewarding to process and activate regions related to emotion arousal. Previous studies have implicated more activation in the amygdala when observing attractive vs. unattractive faces (Aharon et al., 2001; O'Doherty et al., 2003). Our results were consistent with those of Aharon et al. (2001), who reported that beautiful faces have variable reward value in both fMRI and behavioral experiments. On the other hand, Senior (2003) suggested that people focus predominantly on attractive faces, possibly because of the higher intrinsic reward value that they elicit. It is also possible that the high reward value of attractive faces evoked enhanced LPC amplitudes (Oliver-Rodriguez et al., 1999; Herbert et al., 2006). Within this framework, attractive faces constitute reward motivation and promote simultaneous activation of emotion and reward systems. Together, these systems could facilitate enhanced perceptual processing and memory formation. Prolonged reaction times in the recognition task as well as greater accuracy in classifying attractive faces relative to unattractive faces are consistent with this view.

Preferences for Attractive Female Faces From the Evolutionary Perspective

On the whole, our results point to cognitive preferences for processing attractive faces. From an evolutionary perspective, attractive female faces can affect mate choice and reproductive success (Thornhill and Gangestad, 1999a; Rhodes, 2006). Good-genes theories have suggested that face preferences are adaptations for mate choice (Kirkpatrick, 1996; Thornhill and Gangestad, 1999a; Grammer et al., 2003), because attractive features represent genetic health and immunocompetence of prospective mates (Perrett et al., 1998; Thornhill and Gangestad, 1999b; Grammer et al., 2003). Indeed, select research has linked facial attractiveness with health and reproductive potential (Perrett et al., 1998; Thornill and Gangestad, 1999a,b). Mate-quality theories have also proposed that attractive features, such as ''averageness,'' symmetry, and feminine traits signal health and other aspects of mate quality so that such preferences may be adaptations for finding good mates (Rhodes, 2006).

CONCLUSIONS

In conclusion, results of this experiment identified possible processing preferences in the judgment and recognition of attractive female faces. Plausible reasons for these findings include higher intrinsic reward value and more intensive positive emotional responses aroused in relation to attractive rather than unattractive female faces. Attractive female faces also represent reproductive fitness and mating value from the evolutionary perspective.

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REFERENCES

Aharon I, Etcoff N, Ariely D, Chabris CF, O'O Connor E, Breiter HC. 2001. Beautiful face shave variable reward value: fMRI and behavioral evidence. Neuron 32:537–551.

Bentin S, Allison T, Puce A, Perez E, McCarthy G. 1996. Electrophysiological studies of face perception in humans. J Cogn Neurosci 8:551–565.

Chatterjee A. 2004. Prospects for a cognitive neuroscience of visual aesthetics. Bull Psychol Arts 4:55–59.

Chatterjee A, Thomas A, Smith SE, Aguirre GK. 2009. The neural response to facial attractiveness. Neuropsychology 23:135–143.

Chen A, Luo Y, Wang Q, Yuan J, Yao D, Li H. 2007. Electrophysiological correlates of category induction: PSW amplitude as an index of identifying shared attributes. Biol Psychol 76:230–238.

Eimer M. 1998. Does the face-specific N170 component reflect the activity of a specialized eye detector? Neuroreport 9:2945–2948.

Eimer M. 2000. The face-specific N170 component reflects late stages in the structural encoding of faces. Neuroreport 11:2319–2324.

Google.com. 2009. Facial image search.http://www.google.com.hk/images? q=%E8%AF%81%E4%BB%B6%E7%85%A7&hl=zh-CN&newwindow=1&safe=strict&client=aff-cs-360se&hs=RyH&source=lnt&tbs=isch:1,itp:photo&prmd=ivnsu&source=lnt&sa=X&ei=OFUQTdGrLYaGvAP-q-jIDQ&ved=0CA8QpwU,dates: 9-July-2009.

Grammer K, Fink B, Moller AP, Thornhill R. 2003. Darwinian aesthetics: Sexual selection and the biology of beauty. Biol Rev 78:385–407.

Halit H, de Haan M, Johnson MH. 2000. Modulation of event related potentials by prototypical and atypical faces. Neuroreport 11:1871–1875.

Hamm JP, Blake W. 2002. Comparison of the N300 and N400 ERPs to picture stimuli in congruent and incongruent contexts. Clin Neurophysiol 1138:1339–1350.

Herbert C, Kissler J, Junghofer M, Peyk P, Rockstroh B. 2006. Processing of emotional adjectives: evidence from startle EMG and ERPs. Psychophysiology 43:197–206.

Johnston VS, Oliver-Rodriguez JC. 1997. Facial beauty and the late positive component of event-related potentials. J Sex Res 34:188–198.

Kirkpatrick M. 1996. Good genes and direct selection in the evolution of mating preferences. Evolution 50:2125–2140.

Luck SJ. 2005. An introduction to event-related potentials and their neural origins. In: Luch S, editor. An introduction to the event-related potential technique. Cambridge, MA: MIT Press. p107.

Marzi T, Viggiano MP. 2010. When memory meets beauty: Insights from event-related potentials. Biol Psychol 84L:192–205.

Nieuwenhuis S, Yeung N, van den Wildenberg W, Ridderinkhof KR. 2003. Electrophysiological correlates of anterior cingulate function in a go/no-go task: effects of response conflict and trial type frequency. Cogn Affect Behav Neurosci 3:17–26.

O'Doherty J, Winston J, Critchley H, Perrett D, Burt DM, Dolan RJ. 2003. Beauty in a smile: the role of medial or bitofrontal cortex in facial attractiveness. Neuropsychologia 41:147–155.

Oliver-Rodriguez JC, Guan Z, Johnston VS. 1999. Gender differences late positive components evoked by human faces. Psychophysiology 3:176–185.

Olson IR, Marshuetz C. 2005. Facial attractiveness is appraised in a glance. Emotion 54:498–502.

Perrett DI, Lee KJ, Penton-Voak IS, Rowland DR, Yoshikawa S, Burt DM, et al. 1998. Effects of sexual dimorphism on facial attractiveness. Nature 394:884–887.

Pizzagalli D, Regard M, Lehmann D. 1999. Rapid emotional face processing in the human right and left brain hemispheres: an ERP study. Neuroreport 10:2691–2698.

Pizzagalli D, Lehmann D, Hendrick AM, Regard M, Pascual-Marqui RD, Davidson RJ. 2002. Affective judgments of faces modulate early activity 160ms within the fusiform gyri. Neuroimage 16:663–677.

Polich J. 2003. Theoretical overview of P3a and P3b. In: Polich J, editor. Detection of change: event-related potential and fMRI findings. Boston: Kluwer Academic Press. p 83–98.

Rhodes G. 2006. The evolutionary psychology of facial beauty. Annu Rev Psychol 57:199–226.

Rugg MD, Mark RE, Walla P. 1998. Dissociation of the neural correlates of implicit and explicit memory. Lett Nat 392:595–598.

Schacht A, Werheid K, Sommer W. 2008. The appraisal of facial beauty is rapid but not mandatory. Cogn Affect Behav Neurosci 8:132–142.

Senior C. 2003. Beauty in the brain of the beholder. Neuron 38:525–528.

Thornhill R, Gangestad SW. 1999a. Facial attractiveness. Trends Cogn Sci 3:452–460.

Thornhill R, Gangestad SW. 1999b. The scent of symmetry: a human sex pheromone that signals fitness? Evol Hum Behav 20:175–202.

Werheid K, Schacht A, Sommer W. 2007. Facial attractiveness modulates early and late event-related brain potentials. Biol Psychol 761:100–108.

Wilson M, Daly M. 2004. Do pretty women inspire men to discount the future? Biol Lett 271:177–179.

Yeung N, Cohen JD. 2006. The impact of cognitive deficits on conflict monitoring: predictable dissociations between the error-related negativity and N2. Psychol Sci 17:164–171.

Zhang Y, Kong FC, Chen H, Xiang YH, Gao X, Chen MY. 2010. Cognitive bias toward female facial attractiveness in males: evidences from an ERP study. Acta Psychol Sin 11:1060–1072.