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Neural responses to one's own name under mortality threat

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ABSTRACT

Recent behavioral research has shown evidence for greater inclination to avoid symbolic cues of mortality threats in nonbelievers than Christians. However, the neurocognitive mechanisms underlying religious influences on behavioral tendency to avoid mortality threats remain unknown. We tested the hypothesis of distinct arousal/attention-related brain responses to self-related information under mortality in nonbelievers and Christians. We recorded event-related brain potentials (ERPs) from Christians and nonbelievers while they viewed their own names and a stranger's name (i.e., Zuma) that flashed around a cue word (i.e., *death*, *pain* or *life*) located at the center of a screen. While own name vs. a stranger's name induced faster responses and larger P3 amplitudes, the P3 amplitudes to own name showed distinct patterns of modulations by the cue words in nonbelievers and Christians. Specifically, own name elicited larger P3 amplitudes in the *death* than *pain/life* cue conditions in nonbelievers but not in Christians. Moreover, the differential P3 amplitude to own names in the *death* vs. *life* cue conditions predicted greater inclination to avoid mortality threats in nonbelievers but not in Christians. Our findings provide a neurocognitive account of increased behavioral tendency to avoid mortality threats in nonbelievers than in Christians.

1. Introduction

It has been long acknowledged that a major function of religious beliefs is to reduce individuals' fear of death (Grogh-Marnat, 1992). This proposition has been examined empirically by extensive studies of terror management theory (TMT) (Greenberg et al., 1986, 1990; Pyszczynski et al., 1999; Rosenblatt et al., 1989). TMT proposes that our awareness of inevitable death and desire for continued existence produce fear and anxiety, which, however, can be dampened by cultural worldviews and self-esteem. Cultural worldview refers to a large-scale system of beliefs regarding the nature of reality and future, including religious beliefs. A prediction of TMT is that religious believers relative to nonbelievers have a lower level of death fear/anxiety due to their religious beliefs such as a good afterlife.

One line of TMT research revealed evidence for this prediction (see Vail et al., 2010 for review) by showing that affirmation of religious beliefs decreased death-thought accessibility following mortality salience (Jonas and Fischer, 2006) and that challenging individuals' religious beliefs increased their anxiety and death-related thoughts (Greenberg et al., 1995; Schimel et al., 2007). Another line of TMT research based on questionnaire measures, however, has shown inconsistent results (see Ellis and Wahab, 2013 for review). Regarding the relationship between religiosity and death fear/anxiety, there have been studies that reported negative (e.g., Clements, 1998; Daaleman and Dobbs, 2010; Henrie and Patrick, 2014), positive (e.g., Dezutter et al., 2009; Ellis et al., 2013; Swanson and Byrd, 1998), curvilinear (e.g., Cohen et al., 2005; Wink and Scott, 2005), or no (e.g., Azaiza et al., 2010) associations between religiosity and death fear/anxiety.

While the previous research focused on the relationship between religiosity and death fear/anxiety, we recently investigated the relationship between religious beliefs and inclination to avoid symbolic mortality threats (IASMT) (Fan et al., In preparation). We first developed and validated a word-position (WP) task to estimate IASMT. The WP task required participants to write target words (e.g., self, family, a stranger's name) in a circle with a cue word (e.g., *death, life,* or *pain*) located at the center of the circle. The distance between target and cue words was measured as an index of target-related behavioral tendencies to avoid death. We then showed evidence that, relative to nonbelievers, religious believers exhibited decreased IASMT, and the difference in IASMT between nonbelievers and believers including Christians, Muslims, Hindus and Buddhists was evident across samples with ethnic and age diversities from different sociocultural environments. In addition, we found that exposing nonbelievers to religious afterlife beliefs reduced their IASMT, further suggesting a causal relationship between religious afterlife beliefs and decreased IASMT. While the behavioral findings shed new light on the influences of religious afterlife beliefs on

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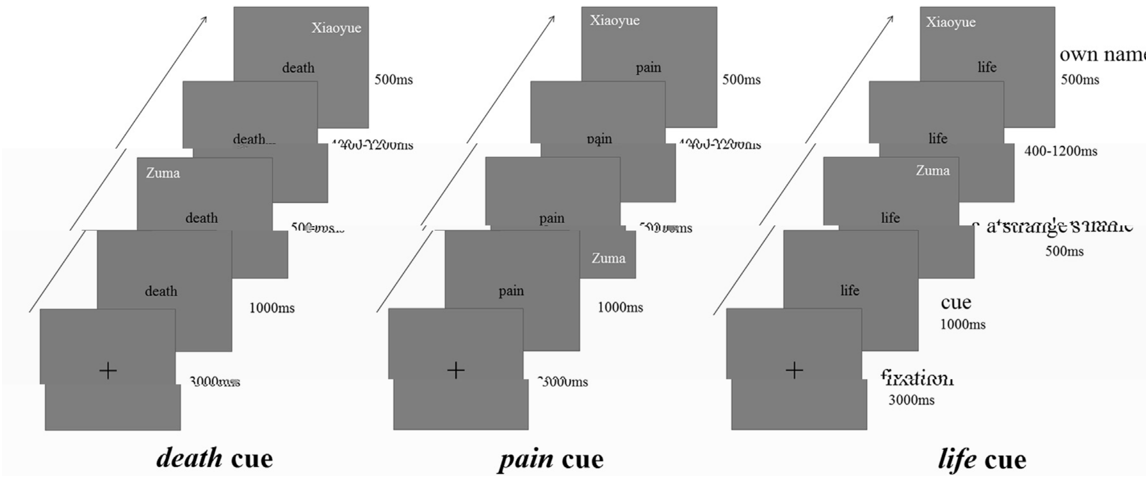

Fig. 1. Illustration of the stimuli and procedure of EEG recording. The *death/life/pain* cues were used in separate blocks of trials. Own name and Zuma were flashed randomly at one of the four positions and in a random order.

IASMT in adults, the neurocognitive underpinnings of distinct IASMT in religious believers and nonbelievers remain unresolved.

A possible cognitive mechanism underlying the increased IASMT in nonbeliever vs. religious believers is enhanced attention/arousal in responses to self-related information under mortality threat, as self-focused attention and psychological arousal have been proposed to play an important role in avoidance behavior (Clark and Wells, 1995). Individuals under conditions of social threat reported increased self-focused attention and heightened arousal which in turn drive avoidance of external threatening cues (Mansell et al., 2003). It is likely that, relative to religious believers, nonbelievers showed enhanced self-focused attention and arousal when viewing stimuli that remind the self (i.e., self-related information) under mortality threat.

The present study tested this hypothesis by recording electroencephalogram (EEG) in a task to identify one's own name and a stranger's name (i.e., Zuma) that flashed around the *death, pain, or life* cue at the center of a monitor (Fig. 1). Previous event-related potential (ERP) studies have shown that the amplitude of a parietal positive ERP component with a long peak latency (i.e., P3) is enlarged by highly arousing stimuli (Cuthbert et al., 2000; Olofsson et al., 2008) due to enhanced attention to emotionally salient information (Polich, 2007). In the current work, the P3 amplitude elicited by one's own name in the death cue condition was a key measure for assessing attention/arousal in association with self-related information. Brain activity in the pain cue condition was recorded as a baseline that allowed us to clarify whether and how nonbelievers or Christians were different in brain responses to own name in the death (vs. pain) cue conditions. Such a comparison also allowed us to exclude possible effects of negative but death-unrelated emotion on brain activity in response to own name. In addition, brain activity to Zuma was recorded as a second control condition which allowed us to examine whether any effect of the death (vs. pain) cue on brain activity was specific to own name and to clarify the self-specific death-cue effect on brain activity. Finally, we included a life-cue condition to examine whether the fundamental, genetically based human need and propensity to affiliate with other living organisms, or biophilia (Wilson, 1984) – the other aspect of human desires for survival – also modulates self-specific brain activity.

If our hypothesis is correct, one would expect that one's own name would elicit a larger P3 when flashing around the *death* cue than *pain/life* cues and this effect should be stronger in nonbelievers than in religious believers. We recorded ERPs to own name and the stranger's name flashing around the *death, life,* or *pain* cues from two independent subject groups who self identified as nonbelievers and Christians, respectively. After EEG recording all participants were asked to complete the WP task with the *death* cue. We were interested in whether nonbelievers but not Christians showed enlarged P3 amplitudes in responses to own name in the *death* (vs. *life/pain*) cue conditions and whether the P3 amplitude can predict how far participants positioned the self in relation to the *death* cue in the WP task.

2. Methods

2.1. Participants

Sixty Chinese undergraduate and graduate students participated in this study as paid volunteers, including 30 self-identified Christians (15 males, 15 females, 23.30 ± 2.76 years) and 30 self-identified non-believers (15 males, 15 females, 22.80 ± 2.34 years) who were not affiliated with any religion. Christians and non-religious participants were matched in age and education.

Christian participants were members of local Protestant communities. Their religious attitudes were evaluated using a questionnaire containing 10 religious items derived from Minnesota Multiphasic Personality Inventory (Butcher et al., 1989). All Christian participants reported believing in God and the second coming of Christ. 96.7% reported believing in a life hereafter and 90.0% believing there was only one true religion. 96.7% reported praying several times a week. 80.0% reported going to church every week. 96.7% reported reading the Bible several times a week. 96.7% reported believing Christ performed miracles.

All participants had normal or corrected-to-normal vision and reported no neurological or psychiatric history. Informed consent was obtained prior to the experiment. All participants were debriefed by explaining the purpose of this study after data collection. This study was approved by the local ethics committee at the School of Psychological and Cognitive Sciences, Peking University.

2.2. Stimuli and procedure during EEG recording

Stimuli used during EEG recording consisted of 3 cue words (i.e., *death*, *pain* and *life*) and 2 target words (i.e., a participant's own name and Zuma (the president of South Africa)). All words were presented against a gray background on a computer monitor. Each cue word was displayed in black at the center of the screen. Each target word was presented in white on the gray background and randomly displayed at one of the four positions along the diagonal of the monitor with a distance of 6 cm from the center of the monitor (Fig. 1). Each word subtended a visual angle of 1.90° × 0.95° (width × height) at a viewing distance of 120 cm.

EEG was recorded in 12 blocks of 64 trials. Each block started with a fixation of 3000 ms at the center of the screen, which was then replaced by a cue word that stayed at the center of the screen until the end of the block of trials. Each of the three cue words (i.e., *death, life,* and *pain*) was presented in 4 blocks of trials and blocks of trials with different cues were presented in a random order. In each block, a participant's own name was presented on 32 trials and Zuma was presented on 32 trials in a random order. The target words (i.e., a participant's own name and 'Zuma') were randomly displayed at one of the four positions around the cue. Each target word was presented for 500 ms followed by an interstimulus interval that varied randomly between 400 and 1200 ms. Before EEG recording, participants were instructed to fixate at the cue word and to identify own name vs. Zuma by pressing one of two keys using the left or right index finger. The association between the target words and responding hand was counterbalanced across participants.

2.3. The word-position task

After EEG recording participants were asked to finish the WP task adopted from our previous work (Fan et al., In preparation) to estimate an individual's IASMT. In the WP task participants were asked to write 7 target words (e.g., self, family, friend, a favourable celebrity's name, an unfavourable celebrity's name, Zuma (the president of South Africa as a stranger to participants), stone) in a circle on a piece of A4 paper, with a cue word (*death*) located at the center of the circle. The order to write the target words was random across all participants. Participants were asked to mark their favourable and unfavourable celebrities' names with "+" and "-", respectively. The radius of the circle was 9.5 cm. Participants were asked not to position all target words in a row or a column. The distance between a target word and the central cue word was measured as an index of target-related behavioral tendencies to avoid death. A longer target-(*death*)cue distance reflects greater IASMT.

2.4. Questionnaire measures

After EEG recording participants were asked to complete the Death Attitudes Profile-Revised (DAP-R) (Wong et al., 1994) which consists of 32 items rated on a 7-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree). There are 7 items for estimating fear of death (e.g., "The prospect of my own death arouses anxiety in me", "Death is no doubt a grim experience") with an alpha-value of 0.86; 5 items for estimating death avoidance (e.g., "I avoid death thoughts at all costs", "I always try not to think about death") with an alpha of 0.88; 5 items for estimating neutral acceptance (e.g., "Death is a natural aspect of life", "Death should be viewed as a natural, undeniable, and unavoidable event") with an alpha of 0.65; 10 items for estimating approach acceptance (e.g., "I believe that I will be in heaven after I die", "I look forward to life after death") with an alpha of 0.97; and 5 items for estimating escape acceptance (e.g., "Death will bring an end to all my troubles", "I see death as a relief from the burden of this life") with an alpha of 0.84.

Because self-esteem has been suggested to serve as a buffer of the existential anxiety in humans (Pyszczynski et al., 1999), we estimated participants' self-esteem using the Self-Esteem Scale (Rosenberg, 1965). This scale consists of 10 items such as "On the whole, I am satisfied with myself." All items were scored on a 4-point Likert scale varying between 1 (strongly agree) and 4 (strongly disagree). A larger score indicates greater self-esteem. To control potential influences of cultural orientation, each participant was asked to complete the Self-Construal Scale (Singelis, 1994) to estimate their cultural orientations (i.e., interdependence and independence). This questionnaire consists of 24 items with 12 items for estimation of independence and 12 items for estimation of interdependence that require ratings on a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree).

2.5. EG data recording and analysis

EEG was continuously recorded using a Neuroscan system from 62 scalp electrodes that were mounted on an elastic cap according to the extended 10–20 system with the addition of two mastoid electrodes. The mean of the left and right mastoid electrodes was used as reference during online EEG recording. The electrode impedance was kept less than 5 kΩ. Eye blinks and vertical eye movements were monitored with electrodes located above and below the left eye. The horizontal electro-oculogram was recorded from electrodes placed 1.5 cm lateral to the left and right external canthi. The EEG was amplified (band pass 0.01–100 Hz) and digitized at a sampling rate of 250 Hz. A band-pass filter of 0.01–40 Hz was applied during offline EEG processing. The ERPs in each condition were averaged separately offline with an epoch beginning at 200 ms before stimulus onset and continuing for 1000 ms. Trials contaminated by eye blinks, eye movements or muscle potentials exceeding ± 50 μV at any electrode were excluded from the average, resulting in rejection of about 16.1% trials from further data analysis. The baseline for ERP measurements was the mean voltage of a 200 ms pre-stimulus interval.

The mean amplitudes of the N1, P2 and N2 components over the frontal-central area were calculated from the frontal-central electrodes (FC3, FCZ, FC4). The mean amplitudes of P1and N170 over the posterior area were calculated from the posterior electrodes (PO5, POZ, PO6). The mean amplitudes of N2 over the posterior area were calculated from the posterior electrodes (PO3, POZ, PO4). The mean amplitudes of P3 over the parietal area were calculated from the parietal electrodes (P3, P4, PZ, POZ).[1] Behavioral performance and the mean amplitude of each ERP component were subject to ANOVAs with Target (own name vs. Zuma) and Cue (*death, life, pain*) as within-subjects variables and Group (Christians vs. nonbelievers) as a between-subjects variable.

3. Results

3.1. Behavioral performances

The results of questionnaire measures of self-esteem, death attitudes and self-construals are shown in Table 1. Independent sample *t*-tests revealed higher self-esteem, greater fear of death and death avoidance, and greater independence in nonbelievers than in Christians (see Table S1 for statistical details).

Table 2 shows the mean reaction times (RTs) and response accuracies in response to own name and Zuma during EEG recording. ANOVAs of RTs only showed a significant main effect of target ($F(1,58) = 31.624$, $P < 0.001$, $\eta_p^2 = 0.353$) due to faster responses to own name than Zuma. ANOVAs of accuracies showed a significant interaction of Cue × Group ($F(2,116) = 5.596$, $P = 0.005$, $\eta_p^2 = 0.088$). Post hoc analyses revealed that nonbelievers responded to targets less accurately in the *death* than *pain* cue conditions (mean difference = 0.012, 95% CI = [0.000, 0.023], P = 0.05), whereas Christians responded to targets less accurately in the *pain* than *life* cue conditions (mean difference = 0.012, 95% CI = [0.004, 0.021], P = 0.006).

3.2. ERP results

Visual inspection of the grand average ERP waveforms identified a negative going component at 120–168 ms (N1), a positive wave at 192–248 ms (P2) and a negative deflection at 252–332 ms (N2) over the frontal-central area. Stimuli also elicited a positive wave at 112–152 ms (P1), a negative deflection at 164–204 ms (N170) and a negative going component at 244–312 ms (N2) over the posterior

[1] As requested by one reviewer, we provided statistical details of the amplitudes of different ERP components in Supplementary results.

Table 1
Rating scores (Mean ± SD) of self-esteem, death attitudes and cultural orientation.

	Self-esteem	Death attitude profile-revised					Self-construal scale	
		Fear of death	Death avoidance	Neutral acceptance	Approach acceptance	Escape acceptance	Independence	Interdependence
Nonbelievers (N = 30)	29.83 ± 4.17	3.32 ± 1.32	3.72 ± 1.39	5.98 ± 0.98	3.20 ± 1.00	3.64 ± 1.06	4.90 ± 0.61	5.02 ± 0.75
Christians (N = 30)	27.47 ± 3.21	2.26 ± 1.18	2.52 ± 1.36	4.77 ± 1.59	4.96 ± 0.83	3.52 ± 1.59	4.54 ± 0.65	5.23 ± 0.57
t-score	2.45*	3.29**	3.37**	3.52**	−7.33***	0.34	2.20*	1.25

Note:
* $P < 0.05$.
** $P < 0.005$.
*** $P < 0.001$.

Table 2
RTs and accuracies (Mean ± SD) to identification of own name vs. Zuma during EEG recording.

		Self			Zuma		
		Death	Pain	Life	Death	Pain	Life
Reaction time (ms)	Non-believers	505 ± 60	501 ± 53	503 ± 55	521 ± 52	515 ± 46	517 ± 44
	Christians	504 ± 44	500 ± 51	502 ± 48	521 ± 51	516 ± 52	519 ± 47
Accuracy (%)	Non-believers	0.93 ± 0.08	0.94 ± 0.07	0.93 ± 0.06	0.92 ± 0.07	0.94 ± 0.05	0.93 ± 0.07
	Christians	0.93 ± 0.04	0.92 ± 0.04	0.93 ± 0.03	0.93 ± 0.04	0.92 ± 0.05	0.93 ± 0.03

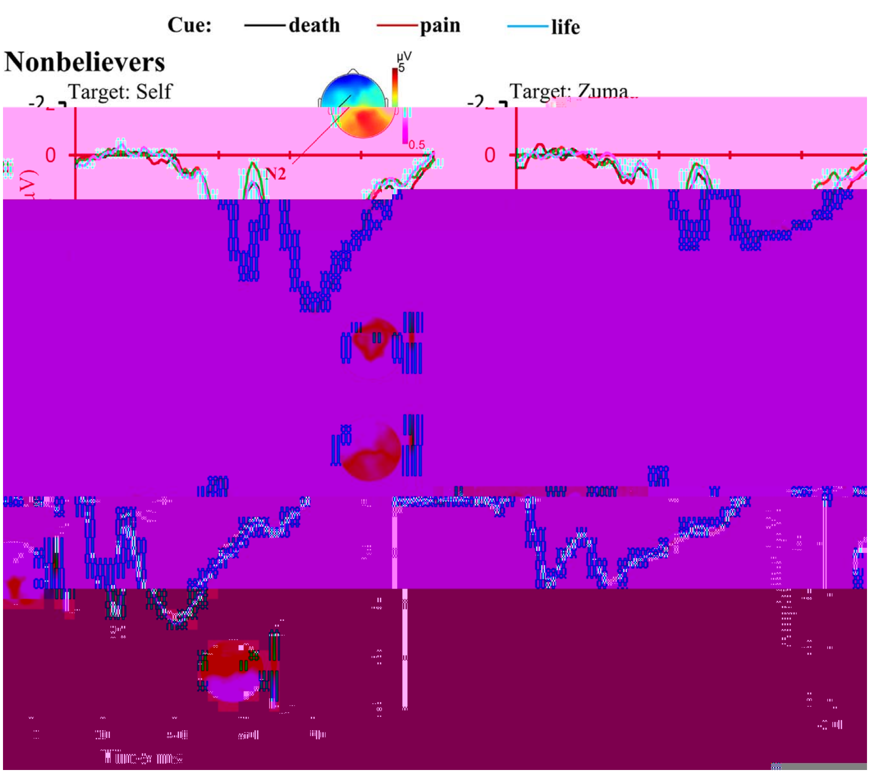

Fig. 2. Illustrations of ERPs to own name and Zuma in different cue conditions over an anterior electrode FCZ.

electrodes. These were followed by a long-latency positivity at 340–500 ms (P3) over the occipitoparietal region (Figs. 2 and 3).

3.2.1. *Anterior N1 and P2 components*

We first analyzed whether and how targets and cues influenced the amplitudes of ERP components over the frontal-central regions. ANOVAs of the N1 amplitudes at 120–168 ms over the frontal-central electrodes showed a significant main effect of Target (FC3, FCZ, FC4: $F(1, 58) = 7.620, 9.364, 10.857$; $Ps = 0.008, 0.003, 0.002$; $\eta_p^2 = 0.116, 0.139, 0.158$), suggesting smaller N1 amplitudes to own name than Zuma. There were also significant main effects of Group (FC3, FCZ, FC4: $F(1, 58) = 13.624, 13.804, 8.946$; $Ps < 0.001, < 0.001, = 0.004$; $\eta_p^2 = 0.190, 0.192, 0.134$), due to smaller N1 amplitudes in non-believers than Christians (Fig. 2). ANOVAs of the P2 amplitudes at 192–248 ms over the frontal-central electrodes only showed a significant main effect of Target (FC3, FCZ, FC4: $F(1, 58) = 74.018, 78.182, 82.321$; $Ps < 0.001$; $\eta_p^2 = 0.561, 0.574, 0.587$), as own name elicited larger P2 amplitudes than Zuma (Fig. 2).

3.2.2. *Anterior N2 component*

ANOVAs of the N2 amplitudes at 252–332 ms over the frontal-central electrodes showed a significant main effect of Cue (FC3, FCZ,

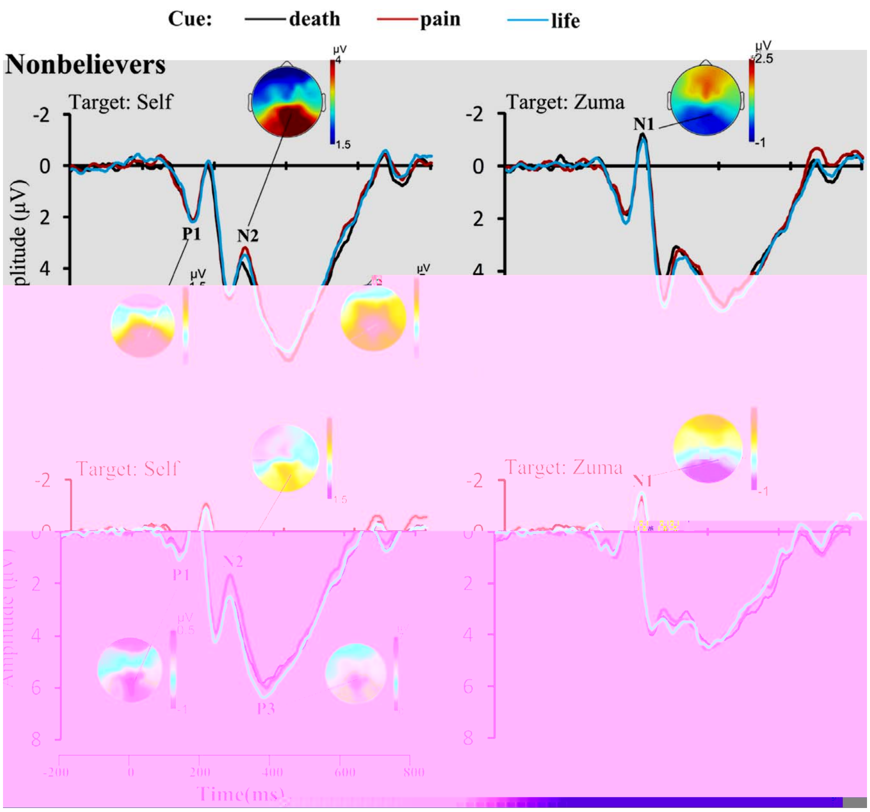

Fig. 3. Illustrations of ERPs to own name and Zuma in different cue conditions over a posterior electrode POz.

FC4: F(2, 116) = 6.887, 5.499, 5.556; Ps = 0.001, 0.005, 0.005; η_p^2 = 0.106, 0.087, 0.087), suggesting smaller N2 amplitudes to the stimuli in the *death/life* than *pain* cue conditions. Interestingly, there was a significant interaction of Group × Target (FCZ, FC4: F(1, 58) = 4.022, 5.924; Ps = 0.05, 0.018; η_p^2 = 0.065, 0.093) as own name tended to elicit smaller N2 amplitudes than Zuma in nonbelievers but not in Christians (Fig. 2).

3.2.3. Posterior N2 component

Next we analyzed whether and how targets and cues influenced the amplitudes of ERP components over the posterior regions. ANOVAs of the N2 amplitudes at 244–312 ms over the posterior electrodes revealed significant a main effect of Cue (PO3, POZ, PO4: F(2, 116) = 7.416, 4.683, 4.571; Ps = 0.001, 0.011, 0.012; η_p^2 = 0.113, 0.075, 0.073), suggesting a larger N2 amplitude (more negative) in the pain cue than death/life cue conditions. There were also significant interactions of Target × Cue × Group (PO3, POZ, PO4: F(2, 116) = 0.845, 3.151, 4.604; Ps = 0.432, 0.046, 0.012; η_p^2 = 0.014, 0.052, 0.074), suggesting distinct patterns of modulations of the N2 amplitudes to targets by cues in Christians and nonbelievers (Figs. 3 and 4). Thus we further analyzed the N2 amplitudes with Target (own name vs. Zuma) and Cue (*death, life, pain*) as within-subjects variables for Christians and nonbelievers, respectively.

ANOVAs of the N2 amplitudes in nonbelievers revealed a significant interaction of Target × Cue (PO3, POZ, PO4: F(2, 116) = 3.867, 5.345, 6.369; Ps = 0.027, 0.007, 0.003; η_p^2 = 0.118, 0.156, 0.180), suggesting distinct N2 responses to own name and Zuma in the three cue conditions. Post hoc pairwise comparisons confirmed that the N2 amplitude to Zuma did not differ significantly across the three cue conditions (Ps > 0.05). However, one's own name elicited larger N2 amplitudes in the *pain* than *death* cue conditions (PO3, POZ, PO4: mean differences = 0.543, 0.445, 0.466, 95% CIs = [0.198, 0.887], [0.005, 0.885], [0.062, 0.869], Ps = 0.003, 0.048, 0.025). One's own name also tended to elicit larger N2 amplitudes in the *life* than *death* cue conditions (PO4: mean differences = 0.365, 95% CI = [0.060, 0.669], Ps = 0.021).

ANOVAs of the N2 amplitudes in Christians also showed a significant interaction of Target × Cue (POZ, PO4: F(2, 116) = 3.519, 4.405; Ps = 0.036, 0.017; η_p^2 = 0.108, 0.132), indicating distinct N2 responses to own name and Zuma in the three cue conditions. Post hoc pairwise comparisons again confirmed that the N2 amplitude to Zuma did not differ significant across the three cue conditions (Ps > 0.05). By contrast, own name in the *pain* cue condition elicited larger N2 amplitude than in the *death* cue condition (PO3, POZ, PO4: mean differences = −0.630, −0.711, −0.616, 95% CIs = [−0.957, −0.302], [−1.089, −0.332], [−0.991, −0.241], Ps < 0.005). One's own name also evoked larger N2 amplitudes in the *pain* than in the *life* cue conditions (PO3, POZ, PO4: mean differences = −0.540, −0.818, −0.836, 95% CIs = [−0.860, −0.219], [−1.229, −0.407], [−1.275, −0.397], Ps < 0.005).

To further examine potential influences of self-esteem, death attitude and cultural trait on the distinct patterns of N2 amplitudes in nonbelievers and Christians, the N2 amplitudes over the posterior electrodes were further subject to a repeated measures analysis of covariance (ANCOVA) with self-esteem, death attitudes and independence/interdependence as covariates. ANCOVAs of the N2 amplitudes with Target (own name vs. Zuma) and Cue (*death, life, pain*) as within-subjects variables and Group (Christians vs. nonbelievers) as a between-subjects variable and self-esteem, death attitudes and cultural trait as covariates also showed a significant interaction of Target × Cue × Group over the posterior electrodes (PO3, POZ, PO4: F(2, 100) = 4.837, 6.532, 7.643; Ps = 0.010, 0.002, 0.001; η_p^2 = 0.088, 0.116, 0.133), further confirming distinct patterns of modulations of N2 amplitudes to own name and Zuma by cues in nonbelievers and Christians when controlling the potential influences of self-esteem, death attitudes and independence/interdependence.

3.2.4. P3 component

ANOVAs of the P3 amplitudes at 340–500 ms over the parietal electrodes showed significant main effects of Target (POZ, P4, P3, PZ: F(1, 58) = 111.45, 113.15, 82.58, 128.75; Ps < 0.001, η_p^2 = 0.658,

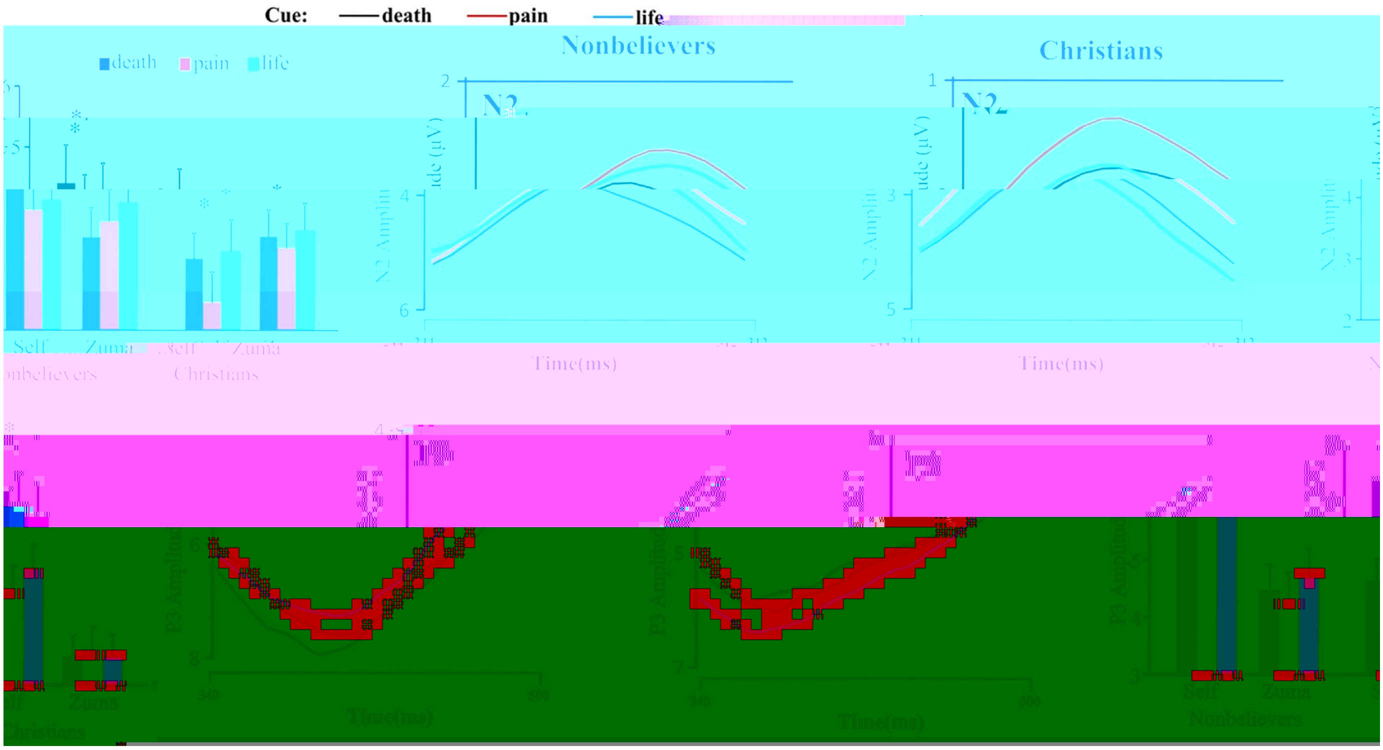

Fig. 4. Illustrations of the P3 and posterior N2 amplitudes elicited by own name and Zuma in different cue conditions over a posterior electrode POz. The left panel shows the P3 and posterior N2 components in different conditions. The right panel illustrate the mean amplitudes of the P3 and posterior N2 components in different conditions. The error bars represent standard errors.

0.661, 0.587, 0.689), suggesting larger P3 amplitudes to own name than Zuma (Figs. 3 and 4). Interestingly, there was a significant interaction of Target × Cue × Group over the middle and right parietal electrodes (POZ, P4: $F(2, 116) = 4.187, 4.754$; $P = 0.018, 0.010$, $\eta_p^2 = 0.067, 0.076$, marginally significant at PZ: $F(2, 116) = 2.607$, $P = 0.078$, $\eta_p^2 = 0.043$), suggesting different patterns of modulations of the P3 amplitudes to name stimuli by cues in Christians and nonbelievers. Thus we further analyzed the P3 amplitudes with Target (own name vs. Zuma) and Cue (*death, life, pain*) as within-subjects variables for Christians and nonbelievers, respectively.

ANOVAs of the P3 amplitudes in nonbelievers revealed a significant main effect of Target (POZ, P4, P3, PZ: $F(1, 29) = 57.312, 59.060, 44.916, 62.22$; $Ps < 0.001$; $\eta_p^2 = 0.664, 0.671, 0.608, 0.682$), suggesting a larger P3 amplitude to own name than Zuma. There were also significant interactions of Target × Cue at the middle and right parietal electrodes (POZ, P4: $F(2, 58) = 4.342, 5.148$; $P = 0.017, 0.009$, $\eta_p^2 = 0.130, 0.151$, marginally significant at PZ: $F(2, 58) = 2.790$, $P = 0.070$, $\eta_p^2 = 0.088$). Post hoc pairwise comparisons showed that the P3 amplitude to Zuma did not differ significantly across the three cue conditions ($Ps > 0.05$). However, as expected, the P3 amplitude to own name was enlarged in the death than pain cue conditions (P4, P3, PZ, POZ: mean differences = 0.284, 0.377, 0.353, 0.281, 95% CIs = [0.001, 0.568], [0.086, 0.667], [0.034, 0.673], [−0.019, 0.581], $Ps = 0.049, 0.013, 0.032, 0.065$). Own name also elicited a larger P3 amplitude in the death than life cue conditions (P4, P3, PZ, POZ: mean differences = 0.418, 0.334, 0.492, 0.489, 95% CIs = [0.033, 0.803], [−0.031, 0.699], [0.075, 0.909], [0.082, 0.896], $Ps = 0.034, 0.072, 0.022, 0.020$).

ANOVAs of the P3 amplitudes in Christians only showed a significant main effect of Target (POZ, P4, P3, PZ: $F(1, 29) = 56.99, 55.90, 38.12, 75.11$; $Ps < 0.001$, $\eta_p^2 = 0.663, 0.658, 0.568, 0.721$) due to larger P3 amplitudes to own name than Zuma. The P3 amplitudes tended to be larger in the *life* cue condition than in the *death/pain* cue conditions but these effects failed to reach significance ($Ps > 0.05$).

To further examine potential influences of self-esteem, death attitude and cultural trait on the distinct patterns of P3 amplitudes in nonbelievers and Christians, the P3 amplitudes were further subject to ANCOVAs with self-esteem, death attitude and independence/interdependence as covariates. ANCOVAs of the P3 amplitudes with Target (own name vs. Zuma) and Cue (*death, life, pain*) as within-subjects variables, Group (Christians vs. nonbelievers) as a between-subjects variable, and self-esteem, death attitude and independence/interdependence as covariates also showed a significant interaction of Target × Cue × Group at the middle and right parietal electrodes (POZ, P4: $F(2, 100) = 8.570, 8.566$; $Ps < 0.001$, $\eta_p^2 = 0.146, 0.146$). This further confirmed distinct patterns of modulations of the P3 amplitudes to own name and Zuma by cues in nonbelievers and Christians when controlling self-esteem, death attitude and cultural trait.

3.2.5. P1 and N170 components

ANOVAs of the P1 amplitudes at 112–152 ms over the posterior electrodes showed a significant main effect of Group (PO5, POZ, PO6: $F(1, 58) = 22.434, 7.371, 12.784$; $Ps = 0.001, 0.009, 0.001$; $\eta_p^2 = 0.279, 0.113, 0.181$), suggesting larger P1 amplitudes to name stimuli in nonbelievers than Christians (Fig. 3). Since a recent ERP study reported modulations of the N170 amplitude by one's own name and others' names (Shi, 2016), we also analyzed the N170 amplitudes in response to target words. ANOVAs of the N170 amplitudes at 164–204 ms over the posterior electrodes showed a significant main effect of Target (PO5, POZ, PO6: $F(1, 58) = 20.607, 44.755, 8.936$; $Ps = 0.001, 0.001, 0.004$; $\eta_p^2 = 0.262, 0.436, 0.133$), as own name elicited smaller N170 amplitudes than Zuma. There was also a significant interaction of Group × Target at (POZ: $F(1, 58) = 5.033$; $Ps = 0.029$; $\eta_p^2 = 0.080$), suggesting greater modulations of the N170 amplitudes by own name vs. Zuma in nonbelievers than in Christians (Fig. 3).

3.2.6. Relationship between the P3 amplitude and intention to avoid mortality threats

Finally, we assessed whether and how brain activity to own name under mortality threat could predict individuals' WP-task measures of

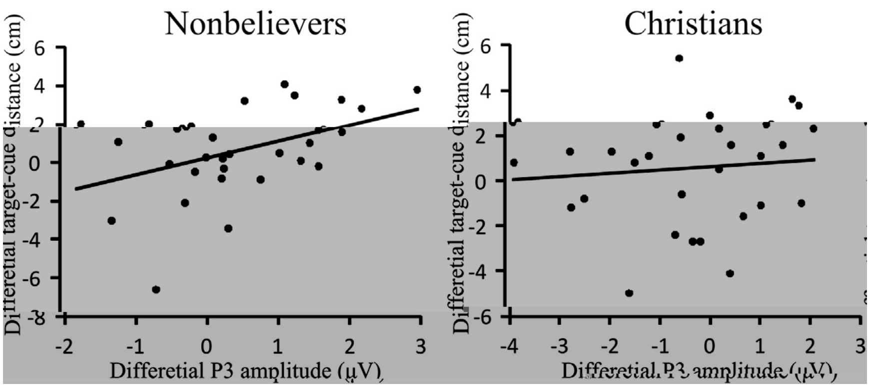

Fig. 5. Illustrations of the correlation between the differential P3 amplitude to own names in the *death* vs. *life* cue conditions was significantly correlated with the differential (self vs. Zuma)target-(*death*)cue distance measured in the WP task. The correlation was significant for nonbelievers but not Christians.

IASMT. We calculated the differential P3 amplitude by subtracting the P3 amplitude to own name in the life cue condition from that in the death cue condition and calculated the differential target cue distance by subtracting (Zuma)target-(death)cue distance from (self)target-(death)cue distance. We found that the differential P3 amplitude to own names in the death vs. life cue conditions was significantly correlated with the differential (self vs. Zuma)target-(*death*)cue distance measured in the WP task for nonbelievers ($r = 0.425$, $P = 0.019$) but not Christians ($r = 0.099$, $P = 0.603$, Fig. 5). Nonbelievers with larger differential P3 amplitudes positioned self further away from death, suggesting that attention/arousal to self-related information under mortality threat may contribute to nonbelievers' BTAMT.

4. Discussion

The present study sought to examine the neurocognitive processes that underlie the difference in IASMT between nonbelievers and Christians and mediate the WP-task measure of IASMT in nonbelievers. We recorded both behavioral and neural responses to one's own name and a stranger's name in the *death/life/pain* cue conditions from nonbelievers and Christians. We found that own name vs. a stranger's name induced faster behavioral responses and larger P3 amplitude over the parietal regions in both nonbelievers and Christians. The P2 amplitude over the frontal/central regions was also enlarged by own name compared with a stranger's name. These results replicated the previous behavioral and ERP findings that, relative to control stimuli, self-relevant stimuli (e.g., own name and photos of own face) elicited faster behavioral responses (e.g., Ma and Han, 2009, 2010; Tacikowski and Nowicka, 2010), and larger P3 amplitude (Fischer et al., 2008; Ninomiya et al., 1998; Sui et al., 2006, 2009; Tacikowski and Nowicka, 2010; Tacikowski et al., 2014), and larger P2 amplitudes (Chen et al., 2011, 2013; Fan et al., 2013; Hu et al., 2011; Liu et al., 2013; Mu and Han, 2010). These results provide consistent evidence for enhanced processing of self-relevant cues at multiple stages of the processing stream in both nonbelievers and Christians. The results were evident even though Christians relative to nonbelievers showed lower self-esteem, suggesting that the enhanced processing of stimuli with personal-relevance seems to be independent of individuals' levels of self-esteem.

In consistent with our hypothesis, we found that the P3 amplitude to own name (but not the stranger's name) was modulated by *death/life/pain* cues and such modulations differed significantly between nonbelievers and Christians. Specifically, for nonbelievers, the P3 amplitude to own name was significantly larger in the *death* than *life/pain* cue conditions. By contrast, the P3 amplitude to own name in Christians was not modulated by *death/life/pain* cues. The discrepant patterns of modulations of neural responses to own name by *death* vs. *life/pain* cues were also evident in the posterior N2 amplitude which was decreased in response to the *death* cue than *life/pain* cues in nonbelievers. For Christians, however, the posterior N2 amplitude was enlarged by the *pain* relative to *death/life* cues. The distinct patterns of modulations of the P3 and posterior N2 amplitudes by *death/life/pain* cues were also evident when controlling self-esteem, death attitudes, cultural trait (i.e., self-construals) as co-variants, suggesting that the distinct patterns of modulations of the P3 and posterior N2 amplitudes by *death/life/pain* cues cannot be interpreted by the group differences in self-esteem, death attitudes and cultural trait. The distinct patterns of the modulations of the P3 and posterior N2 amplitudes by *death/life/pain* cues cannot be simply explained as reflecting influences of negative affect (e.g., both *death* and *pain* cues may be linked to negative affect) because, for nonbelievers, the P3 and posterior N2amplitudes in response to own name did not differ between the *life* cue and the *pain* cue although the *pain* cue produced negative affect compared with the *life* cue. Taken together, our ERP results indicate that brain activities to self-relevant cues in multiple time windows are more sensitive to mortality threat in nonbelievers than in Christians.

There has been ample evidence that the P3 amplitude was increased by high-arousing (vs. low-arousing) emotional stimuli and the effect was evident for both pleasant/positive and unpleasant/negative stimuli (Pollatos et al., 2005; Olofsson and Polich, 2007; Rozenkrants et al., 2008; Rozenkrants and Polich, 2008) and for both pictures and words (Naumann et al., 1992; Olofsson et al., 2008). Because the arousal level governs the amount of processing capacity available for attention allocation that further determines P3 amplitude (Polich, 2007), it has been further suggested that emotionally arousing stimuli elicit a sustained increase in attention and receive increased processing resources (Hajcak et al., 2010). In addition, attentional resources for arousing stimuli have motivational significance for responses to emotional stimuli events (Olofsson et al., 2008). On the ground of the functional significance of the P3 component related to attention/arousal demonstrated in the previous studies, one may suggest that, for nonbelievers, the presence of the *death* cue relative to the *life/pain* cues enhanced their attention/arousal in response to self-relevant items (as indexed by the enlarged P3 amplitude) because self-relevant items under mortality threat may increase nonbelievers' anxiety or fear of death. The increased attention/arousal in response to self-relevant items then in turn motivates avoidance behavior in response to mortality threat.

The previous behavioral studies of the relationship between mortality threat and self-awareness found that participants remained in an exam cubicle that contained a large mirror for less time to think about their mortality than exams (Arndt et al., 1998). This result suggests that mortality threat made participants to avoid exposure of themselves in a mirror. Wisman et al. (2015) also reported that participants low in self-esteem were more likely to choose to write about others than themselves in response to mortality reminders. The behavioral findings imply avoidance of seeing or thinking about the self under mortality threat. The enhanced attention/arousal in response to self-related information under mortality threat proposed in the current study provide a possible mechanism that drives the avoidance of seeing and thinking about the self under mortality threat. The previous fMRI studies showed that viewing death-related (vs. death-unrelated) words decrease the anterior insular activity that is related to self-awareness (Han et al., 2010; Shi and Han, 2012). The decreased insular activity may provide a neural basis of a low threshold for attention/arousal in response to self-related information under mortality.

The increased attention/arousal in response to self-relevant items under mortality threat can also explain the difference in behavioral tendency to avoid mortality threat between nonbelievers and Christians. Our previous work revealed increased IASMT (i.e., positioning own name further away from the *death* cue) in nonbelievers than in Christians and this finding was replicated in both Chinese and Americans (Fan et al., In preparation). In parallel with the behavioral results, the current work showed evidence for increased P3 amplitude in response to self-relevant items, which is supposed to be associated with enhanced attention/arousal. If this analysis is correct, one would expect an association between the P3 amplitude in response to own name and behavioral tendency to avoid mortality threat. Indeed, we found evidence for a significant correlation between the differential P3 amplitude to own names in the *death* vs. *life* cue conditions and the differential (self vs. Zuma)target-(*death*)cue distance of the WP task for nonbelievers. These results together suggest that the enhanced attention/arousal in response to self-relevant information may mediate both group and individual differences in behavioral tendency to avoid mortality threat.

Interestingly, the anterior and posterior N2 amplitudes in response to own name showed different patterns of modulations by *death/life/pain* cues. For Christians both the anterior and posterior N2 amplitude was decreased by the *death/life* relative to *pain* cues. For nonbelievers, however, the anterior N2 amplitude was decreased by the *death/life* than *pain* cues whereas the posterior N2 amplitude was decreased by the *death* than *life/pain* cues. Previous ERP studies of empathy found that the anterior N2 amplitude was decreased in response to cues announcing negative compared with neutral targets when viewing others' body parts receiving painful vs. non-painful stimulations (e.g., Carretié et al., 2001; Fan and Han, 2008; Sheng and Han, 2012), reflecting a greater capacity of nonaversive stimuli to generate expectancy-related attention. Similarly, if both tendencies to avoid death and to approach life reflect human desire for survival, the presence of the *death* and *life* cues might induce greater attention to self than the presence of the *pain* cue, providing a possible account of the decreased N2 amplitude over the anterior electrodes in the *death/life* than *pain* cue conditions for both nonbelievers and Christians. Alternatively, since the anterior N2 following a response or stimulus is supposed to originate from the dorsal region of the ACC (Van Veen and Carter, 2002) – a brain region engages in conflict monitoring and cognitive control (Kerns et al., 2004), the larger anterior N2 in response to own name in the *pain* than *death/life* cue conditions might reflect the requirement for monitoring and controlling of negative affect related to the association between physical pain with oneself due to simultaneous presentation of the *pain* cue and own name.

The posterior N2 component is also supposed to reflect the degree of attention related to visual specific information processing during target detection tasks (Suwazono et al., 2000). The posterior N2 amplitude is augmented for emotionally arousing compared to neutral stimuli and reflects selective processing of emotional stimuli (Kissler et al., 2009; Schupp et al., 2004). If the larger posterior N2 amplitude reflected enhanced selective processing of own name in the *pain* than *death* cue conditions, nonbelievers and Christians similarly engaged enhanced attentional processing of own name in the *pain* then *death* cue conditions. However, the *life* cue also increased the posterior N2 amplitude relative to the *death* cue in nonbelievers (but not in Christians), suggesting that the *life* cue may also generate enhanced attention to own name in nonbelievers. This results can also be interpreted as decreased attention to own name in the *life* cue condition in Christians compared with nonbelievers. The proposed distinct attentional processing of own name in Christians and nonbelievers helps us to understand the different behavioral responses to self in response to the *life* cue in the WP task in which nonbelievers relative to Christians tended to position self closer to the *life* cue (Fan et al., In preparation). It is likely that increased attention to own name in the *life* cue condition due to the fundamental, genetically based human need and propensity to affiliate with other living organisms (Kellert, 1996; Wilson, 1984) drove nonbelievers to position self close to the *life* cue. By contrast, a good afterlife belief may also reduce Christians' intention to position self close to the *life* cue (Fan et al., In preparation).

Most of the previous ERP studies failed to show evidence for modulations of the N170 amplitude by own vs. others' names (e.g., Zhao et al., 2011; Tacikowski et al., 2011; Tacikowski et al., 2014) except that one ERP study found larger N170 amplitudes to own name than familiar and unfamiliar others' names in a task to identify the color of the name stimuli (Shi, 2016). Interestingly, the present study observed modulations of the N170 amplitude by own name vs. the stranger's name in an opposite pattern, as own name vs. the stranger's name elicited smaller N170 amplitudes. Moreover, this effect was stronger in nonbelievers than in Christians. In our study participants were asked explicitly discriminate own name vs. a stranger's name. Thus implicit vs. explicit identification may differentially modulate the N170 amplitude in response to own name. More relevant to our hypothesis, the N170 results in our work suggest that Christians compared with nonbelievers were less sensitive to own name during the early processing of names. This ERP result is in agreement with the findings of our previous behavioral study that showed self-face advantage (i.e., faster responses to own face than a familiar other's face) was significantly reduced in Christians than nonbelievers (Ma and Han, 2012).

The present study is not without limitations. Our hypothesis was tested mainly by examining the P3 amplitude in response to own name in the *death/life/pain* cue conditions. We did not measure other physiological indices of attention/arousal related to the processing of own name in different cue conditions. Future research can measure skin conductance that reflects general activation of the autonomic nervous system and is a well-established measure of biological arousal. The current work only recorded ERPs to own name. If the distinct patterns of modulations of the P3 amplitudes by *death/life/pain* cues in Christians and nonbelievers reflect the influences of religious beliefs on attentional processing of self-related information, one would expect that the P3 amplitudes in response to own face should also exhibit distinct patterns of modulations by *death/life/pain* cues in Christians and nonbelievers. This should be examined in future research. Finally, since our previous behavioral study revealed that religious believers including Christians, Muslims, and Hindus similarly showed reduced IASMT compared with nonbelievers (Fan et al., In preparation), it would be interesting to further test whether believers of different religions show similar reduced brain activity in response to own name under mortality threat in future research.

In conclusion, by recording ERPs in response to own name under mortality threat, the current study revealed neurocognitive processes that underlie the difference in IASMT between nonbelievers and Christians and mediate the WP-task measure of IASMT in nonbelievers. Our ERP fi

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.neuropsychologia.2017.11.026.

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