

available at www.sciencedirect.comwww.elsevier.com/locate/brainres

**BRAIN
RESEARCH**

Research Report

The neural correlates of reasoning about prosocial–helping decisions: An event-related brain potentials study

Ivy Chiu Loke^{a,*}, Angela D. Evans^a, Kang Lee^{a,b,*}

^aInstitute of Child Study, University of Toronto, 45 Walmer Road, Toronto, ON, M5R 2X2, Canada

^bUniversity of California, San Diego, CA, USA

ARTICLE INFO

Article history:

Accepted 31 October 2010

Available online 12 November 2010

Keywords:

Prosocial reasoning

ERP

Helping decision

Neural correlate

ABSTRACT

Providing help to others is a highly valued social practice. This study used neurophysiological methods to explore the neural correlates of individuals' reasoning about prosocial–helping behaviors and the relation between these correlates and self-reports of prosocial personality. Event-related potentials (ERP) were recorded while individuals reasoned about others' decisions to provide help or not provide help in situations where help was either obviously needed or not necessarily needed. Specific examination of the relation between self-reports of prosocial personality and the peak amplitude and latency of the P3, an ERP component considered to represent the perception and processing of a salient response, revealed that individuals' self-ratings of prosocialness were related to their ERPs. The findings from this study suggest that there are neural correlates for reasoning about prosocial–helping decisions and that there is a relation between these neural correlates and individuals' prosocial personality.

© 2010 Elsevier B.V. All rights reserved.

1. Introduction

Providing help to others is a highly valued social practice in all societies. Social psychologists have long theorized about and studied different factors that influence people's decisions to help or not to help others in situations of need. Forms of prosocial behaviors underpin all societies. As a result, humans have a motivation to understand the moral and social factors associated with helping others.

Respect for others is a valued quality that people in Europe and North America would like their children to develop ([World Values Survey, 2006](#)). Also, providing service to others is considered to be an important aspect in people's lives ([World Values Survey, 2006](#)). These findings suggest that the value of prosocial responses is shared and articulated among different populations. However, it has been demonstrated that despite

the value placed on prosocial responses, people do not always behave prosocially ([Bersoff, 1999](#); [Darley and Latané, 1968](#); [Darley and Baston, 1973](#); [Fritzsche et al., 2000](#)). Previous research has examined the behavioral correlates of prosocial reasoning and helping behavior, investigating factors such as personal moral values ([Neff et al., 2002](#)), social contexts ([Darley and Latané, 1968](#); [Levine et al., 2005](#)), socio-cultural upbringing ([Eisenberg et al., 2001](#)), personality traits ([Carlo et al., 2003](#); [De Cremer et al., 2001](#)), cognition ([Carlo et al., 2003](#)), development ([Eisenberg et al., 2005](#)), and experience with social norms ([Epley and Dunning, 2000](#)). This research has largely used behavioral methods, often combining various elements of moral values, personality dispositions, contextual factors, and experience with social norms in the analyses. Importantly, the neural correlates of prosocial reasoning have not yet been investigated. Presumably, expressed values and

* Corresponding authors. Fax: +1 416 934 4565.

E-mail addresses: i.chiuloke@utoronto.ca (I. Chiu Loke), kang.lee@utoronto.ca (K. Lee).

socio-moral behaviors have a direct relation with underlying neural mechanisms.

The present study captured individuals' brain-based event-related potentials (ERPs) to investigate the neural correlates of people's reasoning about others' decisions to engage in prosocial-helping behaviors, and the relation between these brain-based potentials and individuals' prosocial personality. Although there has been some study of the neurophysiological processes underlying moral judgment using functional magnetic resonance imaging (fMRI) (e.g., Fiddick et al., 2005; Finger et al., 2006; Greene and Haidt, 2002; Greene et al., 2001; Lamm et al., 2007; Young et al., 2007), no study has assessed the neural correlates of reasoning about prosocial-helping. The present study, with the use of ERP methodology, aimed to bridge this gap in the literature.

ERPs are useful for providing information about differential activation in response to stimuli and the temporal dynamics between the different stimuli events and neural responses. Although ERP methods have not been used to investigate the neural correlates of prosocial reasoning, they have been used to explore cognitive reasoning processes. One component used to examine cognitive processes is the P3 (Fabiani et al., 2000; Segalowitz and Davies, 2004), which refers to a positive inflection in EEG amplitude occurring at or after approximately 300 ms after the stimulus and is suggested to reflect a time period during which the ERP represents the perception and processing of stimulus valence, or stimulus probability and violations of expectation (Fabiani et al., 2000; Segalowitz and Davies, 2004). The latency of the P3 component, which is the time period between the stimulus presentation and the peak of the P3 response (Luck, 2005), is thought to be proportional to the time required to process or evaluate the stimuli (Fabiani et al., 2000; Polich, 2007). The P3 can be further described as consisting of the subcomponents P3a, which is suggested to refer to earlier occurring attention mechanisms in the frontal brain areas during stimulus processing, and P3b or late positive potential (LPP; Cacioppo et al., 1996), which is suggested to refer to later occurring attention mechanisms related to subsequent memory processing in the temporal-parietal brain areas (Polich, 2007). Previous ERP studies have found differences in P3b amplitude evoked by the evaluation of inconsistent versus consistent stimuli (Cacioppo et al., 1996; Cunningham et al., 2005). Further, these studies found that P3b or LPP amplitudes were larger in the right brain regions for negative evaluations and for evaluative categorizations compared with non-evaluative categorizations (Cacioppo et al., 1996; Cunningham et al., 2005). Thus, the P3 component and more specifically, the P3b, were examined in this study to capture information about the saliency and expectation of moral decisions about helping others.

Although many studies have elicited the P3 component using an oddball paradigm, more recent research has extended the investigation of the P3 component to other paradigms, including those that examine naturally existing disparity where valence differences can be elicited by the relative saliency of events (e.g., Cuthbert et al., 2000; Johnston and Wang, 1991; Schupp et al., 2000). In these paradigms, the P3 component is evoked using stimuli that appear with equal probability in random sequences. Thus, the criteria for the P3 component being examined are positive inflections defined in

the temporal dimension. The goal of this study was to investigate the saliency of decisions to help or not to help for different individuals by examining the P3 component elicited in individuals' natural responses to decisions about prosocial-helping actions. Also, because of the evaluative nature of the task, this study focused on the later occurring P3b, which has been shown to be differentially evoked by evaluations of inconsistent versus consistent, and negative versus positive, stimuli.

Participants were asked to read and reason about four story conditions. One condition described a situation where help was obviously needed and the character decided to help. In another condition, help was not necessarily needed and the character decided not to help. In a third condition, help was obviously needed and the character decided not to help. A final condition described a situation where help was not necessarily needed and the character decided to help. The characters' decisions in the first two conditions were congruent with the respective situations, and the characters' decisions in the latter two conditions were incongruent with the respective situations. This manipulation ensured that participants' responses were not dependent on detecting simple congruencies but rather on assessing helping decisions in two different situations. Participants were asked to judge the character's decision as "good" or "bad" and then to evaluate "how good" or "how bad" the decision was (scored on a scale of +4 to -4). EEG activation was recorded while participants were reasoning about the stories. After completion of the EEG task, participants were asked to rate their prosocial personality characteristics on a paper and pencil questionnaire.

We hypothesized that there would be differences in P3 peak amplitude and latency in response to a story character's decision to help or not to help another character when help is obviously needed or unnecessary. More specifically, we expected higher P3 amplitudes and shorter P3 peak latencies in response to decisions not to help when help is needed as this scenario was hypothesized to be the most unexpected. We expected differences to appear in right-hemispheric brain regions but were mindful of the novelty of this study's topic and thus also examined medial and left-hemispheric brain regions. Furthermore, we hypothesized that differences in these brain-based activities would be related to differences in individuals' prosocial personality traits.

2. Results

2.1. Behavioral results

The behavioral results showed that participants judged helping when help was obviously needed to be generally "good" ($M=3.19$, $SD=0.52$) and not helping when help was obviously needed to be generally "bad" ($M=-3.18$, $SD=0.37$). However, judgments were more neutral for helping when help was not necessary ($M=0.98$, $SD=0.76$) and not helping when help was not necessary ($M=-0.14$, $SD=0.80$). A situation (prosocial, neutral) by action (help, not help) analysis of variance (ANOVA) revealed a main effect of situation, $F(1,17)=21.88$, $p<0.01$, $\eta_p^2=0.56$, a main effect of action, $F(1,17)=252.64$, $p<0.01$,

$\eta_p^2=0.94$, and an interaction between situation and action, $F(1,17)=339.08$, $p<0.01$, $\eta_p^2=0.95$. Simple effects analyses (LSD, $p<0.05$) showed that for prosocial situations, participants judged helping to be more positive than for neutral situations but judged not helping to be more negative than for neutral situations. These results indicate that participants did in fact judge helping and not helping actions differently based on whether help was obviously needed or not necessarily needed.

2.2. ERP results

Table 1 shows the mean P3 amplitudes and latencies for the frontomedial, left parietal, and right parietal regions. A main effect for gender at the frontomedial, $F(1,16)=15.41$, $p<0.01$, $\eta_p^2=0.49$, left parietal, $F(1,16)=7.62$, $p=0.01$, $\eta_p^2=0.32$, and right parietal sites, $F(1,16)=12.42$, $p<0.01$, $\eta_p^2=0.44$, indicated that females had significantly higher P3 amplitudes as compared with males. A situation (prosocial, neutral) by action (help, not help) effect was significant for the P3 amplitudes in the right parietal region, $F(1,16)=4.87$, $p=0.04$, $\eta_p^2=0.23$ (Fig. 1). Post hoc tests comparing the actions for each situation (LSD, $p<0.05$) showed that the simple effects were not significant. However, an investigation of the significant interaction suggests a trend where higher P3 amplitudes were evoked by decisions not to help as opposed to decisions to help when help was obviously needed and by decisions to help as opposed to decisions not to help when help was not necessarily needed (Fig. 2). A main effect of action was also found for P3 latency for the frontomedial, $F(1,16)=11.56$, $p<0.01$, $\eta_p^2=0.42$, and left parietal, $F(1,16)=5.35$, $p=0.03$, $\eta_p^2=0.25$, regions. These effects were a result of shorter latencies recorded for stories in which the character decided not to help, regardless of whether help was needed.

The relation between individuals' ERP recordings and their scores on the Prosocialness Scale for Adults was examined through a series of regression analyses. The analyses revealed

a significant effect of gender on individuals' prosocial personality scores, $F(1,16)=10.43$, $p<0.01$, $R^2=0.40$. Consistent with the general literature (Skoe et al., 2002), females ($M=64.91$, $SD=5.75$) were more prosocial than males ($M=54.43$, $SD=8.06$). Using the forward step method, P3 amplitudes and latencies recorded for each story type, grouped by region, were used as predictors for individuals' prosocial personality scores, with the effect of gender controlled for in the first step of the analyses. After the effect of gender was partialled out, P3 latencies in the right parietal region elicited by prosocial-helping decisions were significantly related to prosocial personality scores, ($\beta=0.05$, $t=2.86$, $p=0.01$, $r_{\text{part}}=0.46$), $F(1,15)=8.19$, $p=0.01$, $\Delta R^2=0.21$ (Fig. 3). The longer P3 latencies elicited by the character's decision to help when help was obviously needed were predictive of higher prosocial personality scores. In other words, the more prosocial the person, the longer it took to evaluate an unexpected decision to help when help was needed.

For the cortical source analysis, an ANOVA revealed a main effect of action in the right limbic ROI between 250 and 300 ms after the stimulus presentation, $F(1,16)=5.02$, $p=0.04$, $\eta_p^2=0.24$, between 300 and 350 ms, $F(1,16)=8.93$, $p<0.01$, $\eta_p^2=0.36$ and between 350 and 400 ms, $F(1,16)=6.93$, $p=0.02$, $\eta_p^2=0.30$ (see Fig. 4). These findings were a result of higher levels of activity when individuals were reasoning about stories where the character decided not to help regardless of whether help was necessary. In the left temporal ROI, interactions between action and gender were significant between 350 and 400 ms after the stimulus presentation, $F(1,16)=4.91$, $p=0.04$, $\eta_p^2=0.24$, between 400 and 450 ms, $F(1,16)=11.59$, $p<0.01$, $\eta_p^2=0.42$, and between 450 and 500 ms, $F(1,16)=6.48$, $p=0.02$, $\eta_p^2=0.29$. Whereas males had higher levels of activity for the stories in which the character decided not to help than when the character decided to help, females had higher levels of activity for the stories in which the character decided to help than when the character decided not to help.

Table 1 – Measure of P3 amplitudes and P3 latencies.

Story types	Amplitude (in μV)		Latency (in ms)	
	Male	Female	Male	Female
Frontomedial				
Prosocial–helping	2.04 (1.90)	5.23 (1.30)	447.29 (71.02)	391.05 (66.20)
Prosocial—not helping	1.98 (1.74)	4.84 (3.22)	376.79 (63.64)	367.55 (60.89)
Neutral–helping	2.09 (1.68)	5.13 (1.54)	407.79 (66.83)	401.86 (66.64)
Neutral—not helping	1.60 (1.70)	4.97 (2.11)	424.14 (94.20)	368.45 (42.81)
Right parietal				
Prosocial–helping	2.03 (2.32)	4.75 (1.31)	396.29 (78.10)	389.73 (81.55)
Prosocial—not helping	2.67 (1.52)	5.50 (2.21)	371.00 (79.38)	394.32 (69.68)
Neutral–helping	2.76 (1.79)	5.44 (1.96)	360.21 (53.28)	398.27 (59.96)
Neutral—not helping	2.14 (1.65)	5.10 (2.21)	422.57 (97.26)	403.14 (81.11)
Left parietal				
Prosocial–helping	1.95 (2.13)	4.44 (2.37)	428.43 (78.63)	421.45 (59.47)
Prosocial—not helping	2.55 (.88)	4.48 (2.17)	352.21 (67.93)	388.77 (78.70)
Neutral–helping	2.14 (1.84)	4.50 (2.19)	387.36 (84.10)	401.55 (49.82)
Neutral—not helping	1.52 (1.75)	3.89 (1.90)	425.79 (103.90)	372.00 (64.44)

Mean (\pm standard deviations) P3 amplitudes (in μV) and mean (\pm standard deviations) P3 latencies (in ms) recorded in response to each story condition for each gender separated by region.

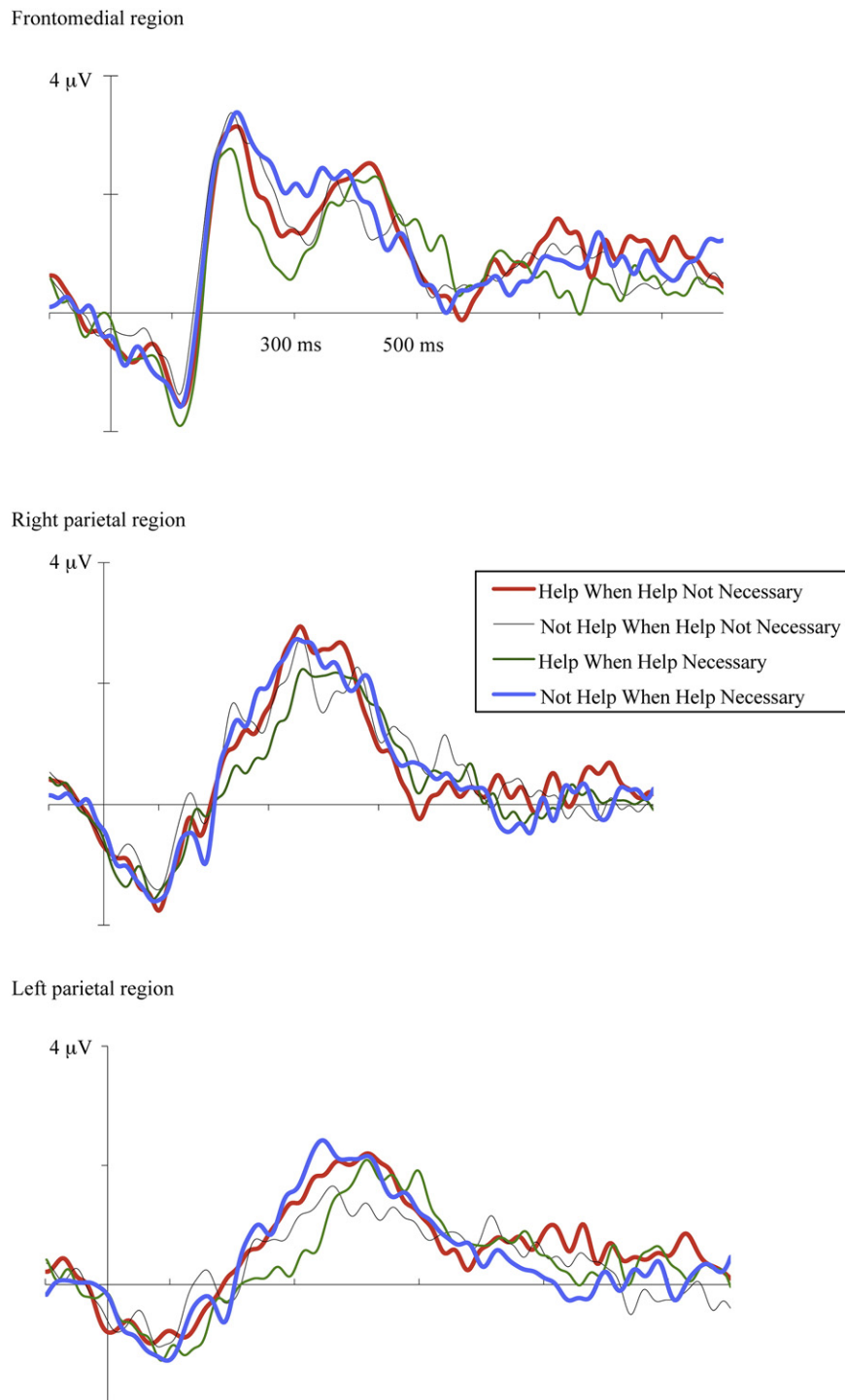


Fig. 1 – Averaged ERP waveforms illustrating the P3 component recorded in each of the three montages. Averaged P3 amplitudes recorded in the right parietal region in response to decisions not to help when help was needed and decisions to help when help was not necessarily needed were greater than decisions to help when help was needed and decisions not to help when help was not necessarily needed, respectively.

3. Discussion

The results from the ERP analyses were as expected and suggest that there are neural correlates of reasoning about prosocial-helping decisions. The interaction between helping

actions and the situation showed a trend where higher P3 amplitudes were recorded in the hypothesized right parietal region in response to decisions not to help when help was obviously needed and in response to decisions to help when help was not necessarily needed. Because this study examined the P3 component, a time period during which the ERP

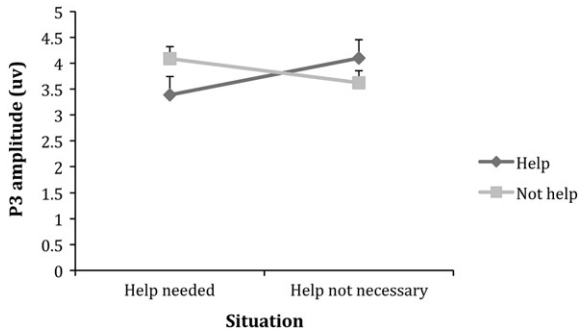


Fig. 2 – Illustration of the significant interaction between situation and helping actions on P3 amplitude. Data for decisions to help and decisions not to help are represented by separate plots.

represents the processing of an unexpected or salient event (Fabiani et al., 2000; Segalowitz and Davies, 2004), these results suggest that people do expect others to help when help is obviously needed. Interestingly, the results also suggest that people do not expect others to help when help is not necessarily needed.

Shorter peak latencies were recorded in the frontomedial and left parietal regions for decisions not to help regardless of whether help was necessary. This result was not found just for the situation in which help was obviously needed or in the right-hemispheric brain region as expected. However, it is possible that processing the decision to help or not to help regardless of situational context does not involve an evaluative component. In line with the general expectation that others help (Penner et al., 2005), the shorter peak latency for decisions not to help may have indicated their saliency but

evaluation processes may have only been engaged by differences in the situation: when help was obviously needed versus when help was not necessary. Thus, peak latency differences were not found in right-hemispheric brain regions where evaluative processes have been thought to occur (Cacioppo et al., 1996; Cunningham et al., 2005).

Importantly, brain-based activities associated with reasoning about prosocial-helping were found to be related to participants’ prosocial personality. This relation was established between two measures that were collected separately: scalp EEG recorded during a reasoning task and a self-report questionnaire completed after the EEG procedure. The results of this study showed that longer P3 peak latencies were recorded in the right parietal region from people with higher scores on the prosocialness questionnaire. This result suggests that more prosocial individuals were slower to evaluate decisions to help as an unexpected event in situations where help was obviously needed. This is consistent with the idea that more prosocially oriented individuals, compared with less prosocially oriented individuals, value helping behavior and expect others to help if help is needed (Penner et al., 2005).

The gender differences found in this study were consistent with literature that describes male and female differences in prosocial reasoning and personality (Skoe et al., 2002). Females in this study recorded higher overall P3 amplitude and scored higher on the Prosocialness Scale for Adults. These scalp-based and survey results suggest that females may be more sensitive to situations involving helping decisions and that this sensitivity may be reflected in their prosocial personality. These results further suggest that gender differences in reasoning about prosocial-helping may have neural correlates.

The cortical source analysis estimated differential brain-based activation in response to different prosocial-helping

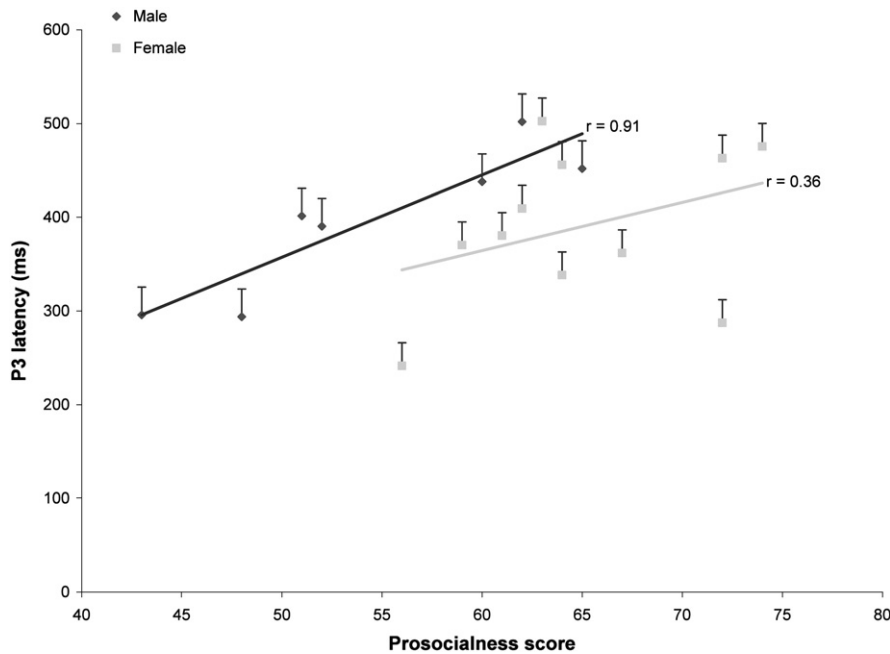


Fig. 3 – Scatter plots of the correlations between right parietal P3 latencies in response to story characters’ decisions to help when help was needed and participants’ scores on the prosocial personality scale. Male and female participants’ data are represented by separate plots.

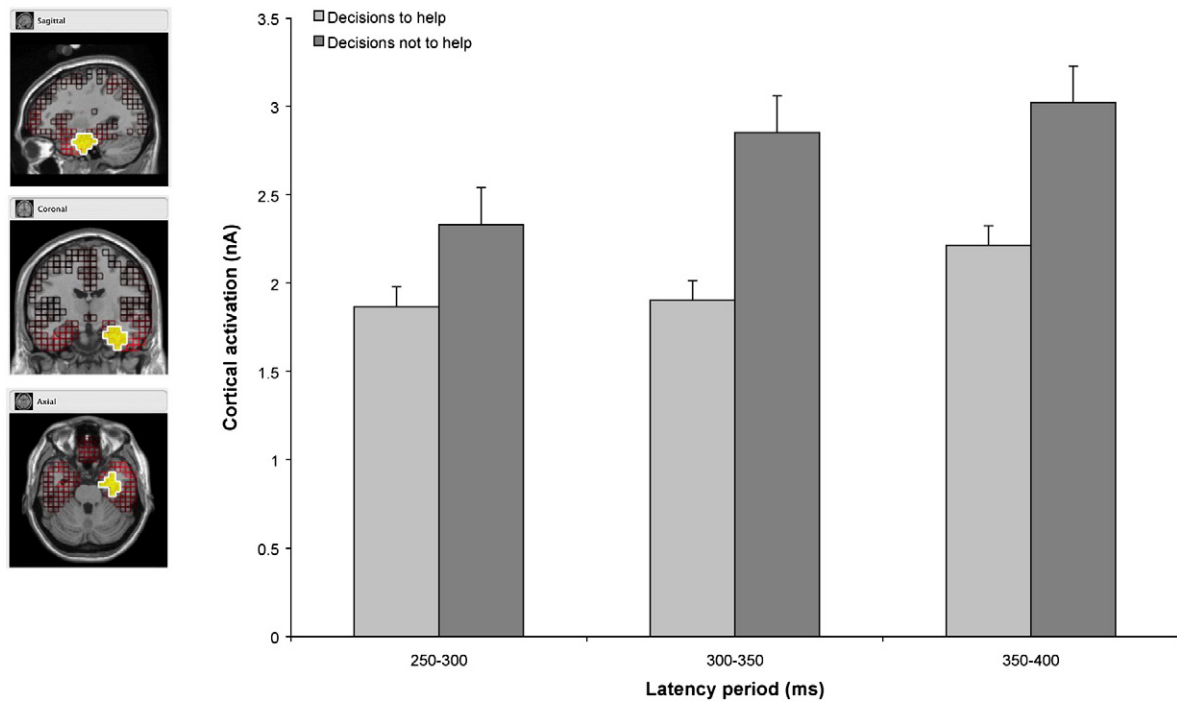


Fig. 4 – Right limbic ROI created with the GeoSource (EGI, Eugene, OR) interface. Graph shows cortical activation in the right limbic ROI in response to story characters' decisions to help and decisions not to help, regardless of whether help was needed for the time periods of 250–300, 300–350, and 350–400 ms after the stimulus presentation. Participants' cortical activation for decisions not to help was significantly different from their cortical activation for decisions to help for this region during these time latencies.

decisions. Despite the limitations of current source analysis methods (please refer to the [Experimental procedures](#) section), the analysis did indicate that reasoning about prosocial-helping can be measured using neurophysiological methods. The estimations were conducted to reflect source-based activation evoked by this study's task but were guided by previous literature on the neural generators of the P3, the neural correlates of moral reasoning, and this study's scalp EEG projections. Previous research about the potential neural generators for the P3 component has estimated its source to be in the medial temporal or hippocampal regions ([Halgren et al., 1980](#)), and the temporal-parietal junction ([Polich, 2003](#)). Source models derived from the results of this study revealed that activity related to decisions not to help was estimated in the right limbic region. Studies attempting to establish the relation between neuroimaging findings and moral cognition have hypothesized that this region is involved in the assessment of reward or punishment value, especially if the stimulus has a negative association ([Adolphs, 1999](#); [Greene and Haidt, 2002](#)), and in affective responses to others' pain from a self- and an other-perspective ([Lamm et al., 2007](#)). An estimation of activation in the limbic region in response to one's decision not to help another person is consistent with this hypothesis, as the evaluation of a decision not to help often involves an affective response and an assessment of negative valence. The source models also estimated different cortical activity between males and females in response to decisions to help and not to help in the left superior temporal pole. This region has previously been thought to be involved in

reasoning about different perspectives ([Greene and Haidt, 2002](#)), affective portions of prior experience ([Dolan et al., 2000](#)), and simple moral judgments ([Moll et al., 2002](#)). Although the left regions of the brain have not typically been indicated in the processing of evaluative stimuli, it is possible that the functions of this region may be related to factors previously found to be linked with gender differences in the evaluation of prosocial behavior ([Skoe et al., 2002](#)). However, these findings are preliminary and require more specific examination with the use of methods, such as fMRI, that have a high spatial resolution.

In addition to the use of alternate methods, future research can also investigate the neural correlates of reasoning about prosocial-helping using alternate study designs. For instance, this study's task was designed to reflect the reality that moral judgment and the expectedness of an event are intimately related and that judgments are made based on whether a person has acted according to expectation. To help disentangle the relation and investigate the possibility that differential neural activity is specific to moral judgment or to processing an unexpected event, future studies can use a similar design as this study but include a condition in which individuals are not asked to make moral judgments.

In conclusion, the findings from this study indicate that there are neural correlates for reasoning about prosocial-helping decisions and that there is a relation between these neural correlates and individuals' prosocial personality. As one of the first attempts to examine the neural correlates of reasoning about prosocial-helping, this study provides a

foundation for future investigation of the neural bases of prosocial reasoning and behavior.

4. Experimental procedures

4.1. Participants

Eighteen right-handed adult participants (7 male, mean age = 25.39 years, SD = 4.64) provided informed consent to participate in the study. Handedness was assessed using a self-report Handedness Inventory (adapted from Oldfield, 1971). Participants were compensated for participating in the study.

4.2. Materials and stimuli

ERPs were elicited during a task where participants were asked to read and reason about 120 short stories about different helping decisions. There were 30 stories from each of four conditions. The *prosocial-helping* condition described situations where help was obviously needed and the character decided to help (e.g., “Jimmie is walking on the sidewalk and sees someone who has fallen and has blood dripping down his arm. Jimmie decides to help”). The *prosocial-not helping* condition described situations where help was obviously needed and the character decided not to help (e.g., “Lisa is running around the track when she sees someone else on the track fall unconscious. Lisa decides not to help”). The *neutral-helping* condition described situations where help was not necessarily needed and the character decided to help (e.g., “Ethan is out for a walk and sees someone trying to take off his rollerblades. Ethan decides to help”). The *neutral-not helping* condition described situations where help was not necessarily needed and the character decided not to help (e.g., “Connie is running around the track when she sees someone on the track stop to tie her running shoe. Connie decides not to help”).

The stories were designed to be similar in length and matched in content across the types of situations and helping actions. Each story was presented in short segments in the center of a computer screen using E-Prime software (Psychological Software Tools, Pittsburgh, PA). Participants were given as much time as they needed to read the story content (e.g., “Jimmie is walking on the sidewalk and sees someone who has fallen and has blood dripping down his arm. Jimmie decides”). Once participants pressed the appropriate key, a crosshair flashed in the center of the screen to fixate participants’ gaze in preparation for the critical stimulus presentation. Immediately following the crosshair, the stimulus, which was the completion of the story (e.g., “to help.”), appeared for 1000 ms. This stimulus presentation signalled the start and end of the EEG segment of interest. Once the stimulus disappeared, participants were instructed to make a judgment about whether the first character’s decision was “good” or “bad”. After making the judgment, participants were asked to evaluate “how good” or “how bad” the first character’s behavior was on a scale of one to four with one being “a little bit” and four being “extremely”. Participants made the judgments and evaluations by pressing the keys on the response pad that corresponded to their selection. EEG was not recorded when participants were making their judgments and evaluations. Participants were given four practice stories before they started the first block of 60 stories.

After a break, they proceeded through the second block of 60 stories. Fifteen of each type of stories were randomized within each block.

After the ERP session, the participants completed the Prosocialness Scale for Adults (PSA; Caprara et al., 2005) to measure their level of prosocialness. The PSA is a 16-item self-report questionnaire that asks respondents to indicate whether each statement about prosocial behavior was true of themselves on a 5-point Likert scale (e.g., “I easily lend money and other things”). Individuals scoring higher on the PSA were characterized as having more prosocial personality traits (Caprara et al., 2005).

4.3. EEG data acquisition

EEG was recorded using a 128-channel Geodesic Sensor Net (Tucker, 1993) and sampled at 500 Hz using EGI software (EGI, Eugene, OR). Impedances for EEG channels were below 50 k Ω at the start of data acquisition. All channels were referenced to Cz during recording and later re-referenced against an average reference (Tucker et al., 1994). Data were run through a bandpass filter (FIR) with a low-pass frequency of 30 Hz and a high-pass frequency of 1 Hz to reduce effects of skin potential noise and to help smooth slow wave drifts. Stimulus-locked data were segmented into epochs from 100 ms before to 1000 ms after the stimulus and baseline corrected for the 100 ms preceding the stimulus. Epochs were excluded if they contained eye-blink or eye movement artifacts, large drifts, or amplifier interference exceeding $\pm 100 \mu\text{V}$ at any electrode site.

Although it was hypothesized that P3 peak amplitude and latency differences evoked by the task stimuli would be found in right-hemispheric brain regions, the neural correlates of reasoning about prosocial-helping have not previously been investigated. Thus, to fully explore this reasoning process, electrode montages of interest used to derive the ERP data were identified by exploring regions of electrode groupings with maximal activation using a grand average of all of the participants’ waveforms. Spatiotemporal information about areas of peak activation from the dense-array topographical animations of the grand-averaged waveform (head surface potential maps) was used to select a frontomedial electrode montage (Geodesic sensor net sites 6, 7, 106, Cz), a right parietal montage (Geodesic sensor net sites 87, 79, 86, 78), and a left parietal montage (Geodesic sensor net sites 37, 54, 53, 61) that were subsequently used to derive the data. The amplitude of each ERP was derived from each participant’s average waveform across the trials. The ERP component of interest, P3b, was scored as the most positive peak occurring in the time window of 250 and 600 ms after the stimulus presentation with at least three points of smaller amplitude around it and was always scored after the N2 component (i.e., the negative inflection that occurs at approximately 200 ms after the event). Peak latency was measured in relation to this local P3 peak (Luck, 2005). Statistical data were extracted for both the amplitude and the latency of the P3 component.

4.4. Cortical source estimation

Source modelling was conducted using a program that computes voxel-by-voxel activation on the basis of scalp voltage

patterns. Low-resolution brain electromagnetic tomography algorithm (LORETA; Pascual-Marqui et al., 1994), a constraint applied to the minimum-norm method, which minimizes the discrepancy between values of adjacent voxels to achieve the most realistic model (TSVD regularization, 10^{-3}), was used to calculate the inverse solution within the GeoSource (EGI, Eugene, OR) interface. A major limitation of current source analysis methods is that they only provide an estimation of the neural generators for ERP components (Polich, 2007). Also, source-space activation within the GeoSource interface is superimposed onto an average magnetic resonance image (MRI) rather than specific individuals' MRIs. Acknowledging these limitations, this study used this source analysis method to explore potential regions involved in generating the observed scalp EEG patterns and provide a basis for future investigation of the neural correlates of prosocial reasoning using methods with higher spatial resolution (e.g., fMRI).

Regions of interest (ROIs) were generated through a whole-brain analysis for subsets of voxels or dipoles with peak activation during the time period of interest. Because of the novelty of the topic being examined, brain regions found to be of interest in previous research investigating moral reasoning were not directly used but guided the whole-brain analysis for the ROIs. Subsets of dipoles were identified by applying spherical models to specific dipoles that were manually observed to display peak activation. The resultant ROIs used in the analyses were the right limbic ROI (25 dipoles), which approximated activation in the hippocampus and amygdala regions, and the left temporal ROI (25 dipoles), which approximated activation in the region of the superior temporal pole. Amplitudes for all dipoles within an ROI were baseline corrected to 100 ms before stimulus onset. The time period of interest of 250 ms to 500 ms after the stimulus presentation was selected based on an evaluation of grand-averaged source-based rather than scalp-based activation. However, the latency range for the analyses of the potential generators for the P3 was divided into 50 ms bins (i.e., 250 to 300, 300 to 350, 350 to 400, 400 to 450, and 450 to 500 ms), and data were extracted for each range for each ROI.

Acknowledgments

This study was supported by grants from the Social Sciences and Humanities Research Council of Canada and the National Institutes of Health (R01 HD 048962) to the last author, an Ontario Ministry of Research and Innovation post-doctoral fellowship to the first author, and a Social Sciences and Humanities Research Council of Canada post-doctoral fellowship to the second author.

REFERENCES

- Adolphs, R., 1999. Social cognition and the human brain. *Trends Cogn. Sci.* 3, 469–479.
- Bersoff, D.M., 1999. Explaining unethical behaviour among people motivated to act prosocially. *J. Moral Educ.* 28, 413–428.
- Cacioppo, J.T., Crites, S.L., Gardner, W.L., 1996. Attitudes to the right: evaluative processing is associated with lateralized late positive event-related brain potentials. *Pers. Soc. Psychol. Bull.* 22, 1205–1219.
- Caprara, G.V., Steca, P., Zelli, A., Capanna, C., 2005. A new scale for measuring adults' prosocialness. *Eur. J. Psychol. Assess.* 21, 77–89.
- Carlo, G., Hausmann, A., Christiansen, S., Randall, B.A., 2003. Sociocognitive and behavioural correlates of a measure of prosocial tendencies for adolescents. *J. Early Adolesc.* 23, 107–134.
- Cunningham, W.A., Espinet, S.D., DeYoung, C.G., Zelazo, P.D., 2005. Attitudes to the right- and left: frontal ERP asymmetries associated with stimulus valence and processing goals. *Neuroimage* 28, 827–834.
- Cuthbert, B.N., Schupp, H.T., Bradley, M.M., Birbaumer, N., Lang, P.J., 2000. Brain potentials in affective picture processing: covariation with autonomic arousal and affective report. *Biol. Psychol.* 52, 95–111.
- Darley, J.M., Latané, B., 1968. Bystander intervention in emergencies: diffusion of responsibility. *J. Pers. Soc. Psychol.* 8, 377–383.
- Darley, J.M., Baston, C.D., 1973. "From Jerusalem to Jericho": a study of situational and dispositional variables in helping behaviour. *Pers. Soc. Psychol.* 27, 100–108.
- De Cremer, D., Snyder, M., Dewitte, S., 2001. "The less I trust, the less I contribute (or not)?" The effects of trust, accountability and self-monitoring in social dilemmas. *Eur. J. Soc. Psychol.* 31, 93–107.
- Dolan, R.J., Lane, R., Chua, P., Fletcher, P., 2000. Dissociable temporal lobe activations during emotional episodic memory retrieval. *Neuroimage* 11, 203–209.
- Eisenberg, N., Cumberland, A., Guthrie, I.K., Murphy, B.C., Shepard, S.A., 2005. Age changes in prosocial responding and moral reasoning in adolescence and early adulthood. *J. Res. Adolesc.* 15, 235–260.
- Eisenberg, N., Zhou, Q., Koller, S., 2001. Brazilian adolescents' prosocial moral judgment and behaviour: relations to sympathy, perspective taking, gender-role orientation, and demographic characteristics. *Pers. Soc. Dev.* 72, 518–534.
- Epley, N., Dunning, D., 2000. Feeling "holier than thou": are self-serving assessments produced by errors in self- or social prediction? *J. Pers. Soc. Psychol.* 79, 861–875.
- Fabiani, M., Gratton, G., Coles, M.G.H., 2000. Event-related brain potentials. Methods, theory and applications. In: Cacioppo, J.T., Tassinari, L.G., Berntson, G.D. (Eds.), *Handbook of psychophysiology*, 2nd ed. Cambridge University Press, Cambridge, UK, pp. 53–83.
- Fiddick, L., Spampinato, M.V., Grafman, J., 2005. Social contracts and precautions activate different neurological systems: an fMRI investigation of deontic reasoning. *Neuroimage* 28, 778–786.
- Finger, E.C., Marsh, A.A., Kamel, N., Mitchell, D.G.V., Blair, J.R., 2006. Caught in the act: the impact of audience on the neural response to morally and socially inappropriate behaviour. *Neuroimage* 33, 414–421.
- Fritzsche, B.A., Finkelstein, M.A., Penner, L.A., 2000. To help or not to help: capturing individuals' decision policies. *Soc. Behav. Pers.* 28, 561–578.
- Greene, J., Haidt, J., 2002. How (and where) does moral judgment work? *Trends Cogn. Sci.* 6, 517–523.
- Greene, J., Sommerville, R.B., Nystrom, L.E., Darley, J.M., Cohen, J.D., 2001. An fMRI investigation of emotional engagement in moral judgment. *Science* 293, 2105–2108.
- Halgren, E., Squires, N., Wilson, C., Rohbraugh, J., Bab, T., Crandall, P., 1980. Endogenous potentials in the human hippocampal formation and amygdala by infrequent events. *Science* 210, 803–805.
- Johnston, V.S., Wang, X., 1991. The relationship between menstrual phase and the P3 component of ERPs. *Psychophysiology* 28, 400–409.
- Lamm, C., Batson, C.D., Decety, J., 2007. The neural substrate of human empathy: effects of perspective taking and cognitive appraisal. *J. Cogn. Neurosci.* 19, 42–58.

- Levine, M., Prosser, A., Evans, D., Reicher, S., 2005. Identity and emergency intervention: How social group membership and inclusiveness of group boundaries shape helping behaviour. *Pers. Soc. Psychol. Bull.* 31, 443–453.
- Luck, S.J., 2005. An introduction to the event-related potential technique. The MIT Press, Massachusetts.
- Moll, J., de Oliveira-Souza, R., Bramati, I.E., Grafman, J., 2002. Functional networks in emotional moral and nonmoral social judgments. *Neuroimage* 16, 696–703.
- Neff, K.D., Turiel, E., Anshel, D., 2002. Reasoning about interpersonal responsibility when making judgments about scenarios involving close personal relationships. *Psychol. Rep.* 90, 723–742.
- Oldfield, R.C., 1971. The assessment and analyses of handedness: the Edinburgh inventory. *Neuropsychologia* 9, 97–113.
- Pascual-Marqui, R.D., Michel, C.M., Lehmann, D., 1994. Low resolution electromagnetic tomography: a new method of localizing electrical activity in the brain. *Int. J. Psychophysiol.* 18, 49–65.
- Penner, L.A., Dovidio, J.F., Piliavin, J.A., Schroeder, D.A., 2005. Prosocial behaviour: multilevel perspectives. *Annu. Rev. Psychol.* 56, 1–28.
- Polich, J., 2003. Overview of P3a and P3b. In: Polich, J. (Ed.), *Detection of Change: Event-Related Potential and fMRI Findings*. Kluwer, Boston, MA, pp. 83–98.
- Polich, J., 2007. Updating P300: an integrative theory of P3a and P3b. *Clin. Neurophysiol.* 118, 2128–2148.
- Schupp, H.T., Cuthbert, B.N., Bradley, M.M., Cacioppo, J.T., Ito, T., Lang, P.J., 2000. Affective picture processing: the late positive potential is modulated by motivational relevance. *Psychophysiology* 37, 257–261.
- Segalowitz, S.J., Davies, P.L., 2004. Charting the maturation of the frontal lobe: an electrophysiological strategy. *Brain Cogn.* 55, 116–133.
- Skoe, E.E.A., Cumberland, A., Eisenberg, N., Hansen, K., Perry, J., 2002. The influences of sex and gender-role identity on moral cognition and prosocial personality traits. *Sex Roles* 46, 295–309.
- Tucker, D.M., 1993. Spatial sampling of head electrical fields: the geodesic sensor net. *Electroencephalogr. Clin. Neurophysiol.* 87, 154–163.
- Tucker, D.M., Liotti, M., Potts, G.F., Russell, F.S., Posner, M.I., 1994. Spatiotemporal analysis of brain electrical fields. *Brain Mapp.* 1, 134–152.
- World Values Survey, 2006. European and World Values Surveys Four-Wave Integrated Data File, 1981–2004, v.20060423 Retrieved June 27, 2008, from <http://www.jdsurvey.net/bdasepjd/questioncrosstab.jsp>2006.
- Young, L., Cushman, F., Hauser, M., Saxe, R., 2007. The neural basis of the interaction between theory of mind and moral judgment. *PNAS* 104, 8235–8240.