

Victims' Time Discounting 2.5 Years after the Wenchuan Earthquake: An ERP Study

Jin-Zhen Li¹✉, Dan-Yang Gui¹✉, Chun-Liang Feng¹, Wen-Zhong Wang², Bo-Qi Du¹, Tian Gan¹, Yue-Jia Luo^{1*}

1 State Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University, Beijing, China, **2** Institute of Psychology, Chinese Academy of Sciences, Beijing, China

Abstract

Background: Time discounting refers to the fact that the subjective value of a reward decreases as the delay until its occurrence increases. The present study investigated how time discounting has been affected in survivors of the magnitude-8.0 Wenchuan earthquake that occurred in China in 2008.

Methodology: Nineteen earthquake survivors and 22 controls, all school teachers, participated in the study. Event-related brain potentials (ERPs) for time discounting tasks involving gains and losses were acquired in both the victims and controls.

Findings: The behavioral data replicated our previous findings that delayed gains were discounted more steeply after a disaster. ERP results revealed that the P200 and P300 amplitudes were increased in earthquake survivors. There was a significant group (earthquake vs. non- earthquake) \times task (gain vs. loss) interaction for the N300 amplitude, with a marginally significantly reduced N300 for gain tasks in the experimental group, which may suggest a deficiency in inhibitory control for gains among victims.

Conclusions: The results suggest that post-disaster decisions might involve more emotional (System 1) and less rational thinking (System 2) in terms of a dual-process model of decision making. The implications for post-disaster intervention and management are also discussed.

Citation: Li J-Z, Gui D-Y, Feng C-L, Wang W-Z, Du B-Q, et al. (2012) Victims' Time Discounting 2.5 Years after the Wenchuan Earthquake: An ERP Study. PLoS ONE 7(7): e40316. doi:10.1371/journal.pone.0040316

Editor: Aldo Rustichini, University of Minnesota, United States of America

Received: December 24, 2011; **Accepted:** June 6, 2012; **Published:** July 5, 2012

Copyright: © 2012 Li et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Funding: This research was supported by the National Natural Science of China (91132704, 30930031), Ministry of Sci & Tech (973 Program, 2011CB711000), National Key Technologies R & D Program (2009BAI77B01), China Postdoctoral Science Foundation (No.20100480224) and Global Research Initiative Program, National Institutes of Health (NIH), USA (1R01TW007897). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing Interests: The authors have declared that no competing interests exist.

* E-mail: luoyj@bnu.edu.cn

✉ These authors contributed equally to this work.

Introduction

Disasters have a large impact on cognition and decision-making processes [1–7], which has led to an ongoing debate regarding whether people become more rational or irrational after a disaster [2–5,8]. For example, after the 9/11 terrorist attacks Americans avoided flying due to a perceived dreaded risk and instead chose to drive, which resulted in more car accidents than usual [3]. As flying is generally considered safer than driving [9], Gigerenzer [3] argued that the avoidance of flying indicated a more irrational tendency after disasters. By contrast, Sacco et al. [2] reported that the events of 9/11 caused outcomes of the decision making process to move closer to those expected from rational choices. Most of the existing studies regarding the effects of disasters on decision making, however, have focused predominantly on risky decision making (i.e., choices involving probabilities) [2,4,7]. Few studies have investigated the influence of disasters on decision-making rationality from the perspective of intertemporal choices, despite the fact that intertemporal choices play just as important a role as risky choices in the field of decision making.

Intertemporal choices – decisions involving tradeoffs among outcomes occurring at different points in time [10] – have a major bearing on many everyday life problems, such as decisions about savings, investments, health, education, and even policy debates about long-term challenges (e.g., global warming) [11–13]. The typical example of intertemporal choices involves a choice between a smaller, more immediate reward and a larger, more delayed reward [14]. A substantial amount of research shows that people have some form of time preference, with a tendency to prefer immediate rewards rather than delayed ones and, conversely, to prefer losses occurring later over now [10,13,15]. Such preferences could be viewed from the perspective of discounting, which assumes that the subjective value of a reward decreases as the delay until its occurrence increases [16–18]. Time discounting was found a robust phenomenon that can be observed even in rats and pigeons [19,20]. Most previous studies have focused on intertemporal choices of gains, with only a few studies on losses. Although discounting of delayed gains and losses could be described by similar discounting functions [14,21], empirical

evidence has suggested that losses and gains are discounted asymmetrically [17,22–24].

To our knowledge, up till now, only quite a few studies have investigated the effect of disasters on intertemporal choices. By studying the same participants before and after the 2008 Wenchuan earthquake, our previous study [25] demonstrated how a major disaster could influence the discounting of delayed gains and losses. The results indicated that, when facing the choice between a sooner and smaller (SS) gain/loss and a later and larger (LL) one, more people after the earthquake compared with before tended to prefer the SS gain and LL loss, but the effect in the loss domain failed to reach statistical significance. However, it is known that field studies are subject to additional confounds due to the inability to control some important factors. There are two such issues in the original work of Li et al. [25]. First, because the earthquake could not be foreseen there was no comparable control group. Hence the differences found in intertemporal choices between the pre-test (which was administered six months before the earthquake) and the post-test (which was administered one week after the event) by Li et al. [25] might be not due to the earthquake per se, but simply to changes over time, even though some previous work has suggested a test-retest reliability for time discounting over a 3-month interval [26]. The second issue with Li et al.'s [25] study is that the number of scenarios used was quite limited, which calls into question the reliability of the findings. Given these limitations, our previous findings [25] need to be further tested.

Time discounting is considered as a bias deviate from rational choices [27–29]. Thus, our previous finding [25] that delayed gains were discounted more steeply after a disaster may suggest a less rational tendency in post-disaster decision making if the effect could be verified.

Furthermore, researchers have recently proposed that there are two distinct systems underlying the decision-making process [30–34]. System 1 (the intuitive system) is also referred to as 'affective heuristics', which is relatively emotional, associative, automatic, contextualized and implicit [34–36]; while System 2 (the rational system) is deliberate, rule-based, controlled, and explicit [30,35,36]. Judgment and decision making may be based on either or both of these two systems [35]. Choices employed System 2 are essentially rational, whereas decision biases commonly occur in System 1. Neuroscientists have put forth further proposals regarding the brain systems that may support the dual-process model [37]. For example, using functional magnetic resonance imaging (fMRI), McClure et al. [38] hypothesized and tested that the differences between choices made with immediate versus delayed rewards are due to the operation of the two systems in the brain: an emotional, intuitional system (System 1) versus a deliberate, rational system (System 2). Their results show a nice differential activation of emotional and rational regions for immediate versus delayed reward choices. Specifically, parts of the limbic system associated with the midbrain dopamine system, including the paralimbic cortex, are preferentially activated by decisions involving immediate rewards. By contrast, regions of the lateral prefrontal cortex and posterior parietal cortex are engaged uniformly by delayed gains. Following the call of Breiter *et al.* [39] to study the two systems by "using new techniques in neuroscience to provide time-ordered data localized to particular brain areas", in the current study, we attempt to use event-related brain potential (ERP) methods to investigate how a catastrophic disaster could influence the operation of the two brain systems during the intertemporal decision-making process.

On May 12, 2008, an earthquake measuring 8.0 on the Richter scale shook Wenchuan, China's Sichuan Province, leaving 69,227

people dead, more than 374,000 injured, and approximately 5 million people homeless (as of 25 September, 2008). Based on the finding that victims are still influenced by a major earthquake for two or more years after the event [40–43], in the present study, we compared the ERP data recorded during time discounting tasks performed by the disaster-exposed group with those performed by the unexposed population approximately 2.5 years after the Wenchuan Earthquake. There were two main purposes of this study: the first was to test whether the original effect found by Li et al. [25] was due to the disaster rather than time, and the second and primary purpose of this study was to investigate the neural basis of the effect of disasters on intertemporal choices using ERPs, with the hopes of finding neural evidence to contribute to the post-disaster rationality debate.

Methods

Ethics

The study was approved by the ethics committee of Beijing Normal University and informed consent was obtained from all participants. A written agreement was signed during the recruitment procedure and all participants verbally reconfirmed their consent to participate before the experiment. Specifically, with the assistance of a local teacher, two members of the study team went door-to-door in the selected school to recruit participants. Each teacher was presented with a one-page recruitment sheet that illustrated the ERP study, informing them of the goals, procedures, study criteria, potential risks (including discomfort), research sites and payment, etc. In addition to the verbal description, there was also a picture of a girl wearing an ERP cap on the recruitment sheet to illustrate the ERP method more clearly. After being fully informed about the study, teachers who met the study criteria and agreed to volunteer were asked to write down their names and contact numbers on the recruitment sheet. In addition to the prior signed agreement on the recruitment sheet, all participants verbally reconfirmed their consent to participate before the experiment began.

Participants

The selected experimental site was the Bayi Middle School, which is located in the town of Yinghua in the rural city of Shifang, Sichuan Province. This school was selected because it was a rebuilt school that accommodated teachers and students from four schools that were severely damaged by the Wenchuan earthquake. There were more than 200 students and approximately 18 teachers died in the tremendous earthquake, with even more injured. A comparable rural middle school located in a town out of the earthquake area was selected as the control school.

The participants in the experimental group were 19 teachers from Bayi Middle School who experienced the major earthquake but were not injured. The participants in the control group were 22 teachers recruited from the control school who did not experience the earthquake.

The two towns are comparable in their natural/social economic environment; both towns are located at the foot of a hill, and the living/consumer price levels are approximately the same for the two towns. Although there is, to our knowledge, no current data on the Consumer Price Index for the two towns, the descriptions of prices for goods and services when the experiment took place in 2010 may be helpful to illustrate the living/consumer price levels. For example, in both towns the price for a haircut was about ¥20 and for a carwash was about ¥10. The prices of meat, vegetables and fruits were also similar. Financial officials in the two selected schools reported that almost all the teachers earn a monthly salary

Table 1. Study Sample Demographics.

Area		Earthquake Devastated(N = 19)	Non-devastated(N = 22)
Occupation		Middle School teacher	Middle School teacher
Monthly salary range		¥ 3,000– ¥ 4,000	¥ 3,000– ¥ 4,000
Gender	Male	13 (68.5%)	14 (64.4%)
	Female	6 (31.5%)	8 (36.6%)
Age	Mean	35.16	34.09
	SD	6.26	8.46

doi:10.1371/journal.pone.0040316.t001

of ¥3,000 to ¥4,000. There were no significant differences in demographic features between the experimental and control groups (see Table 1).

All participants were healthy and right handed with normal or corrected-to-normal visual acuity. They were paid for their participation after the experiment. The study was performed from September to October 2010, approximately 2.5 years (29 months) after the earthquake.

Procedures

The participants performed the experimental tasks in quiet hotel rooms adjacent to the schools.

The experimental tasks were similar to those employed by former studies [38,44]. Participants were instructed to choose between two monetary gain/loss (SS *vs.* LL) alternatives at different times (today *vs.* a month later or 1.5 months later) (See Figure 1). For each set of the intertemporal alternatives, the early dollar amount was randomly drawn from a Gaussian distribution with a mean of ¥100 and standard deviation of ¥50. The percentage difference between the larger and the smaller alternatives was selected from the set {5%, 10%, 15%, 25%, 35%, 50%}. In total there were 16 practice trials and 256 test trials, with an equal number of gain and loss trials. The intertemporal choices of gains and losses were identical except the signs (“+” or “−”) before the monetary amount, indicating that money would be gained or lost at the corresponding time. The choices were presented in a pseudo-random order.

The two alternatives for each choice were presented on either side of the screen. Participants were instructed to press the “F” or “J” key on the computer keyboard to indicate their choice.

EEG recording

The electroencephalogram (EEG) was recorded from 64 scalp sites using electrodes mounted on an elastic cap (Brain Product,

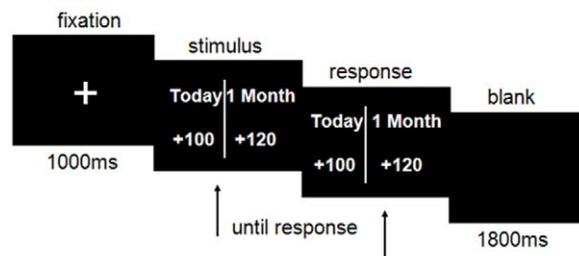


Figure 1. Sequence of events in a single trial of gain task. The loss trials were identical to the gain trials except that there was a “−” sign before the monetary amounts.

doi:10.1371/journal.pone.0040316.g001

GmbH, Germany), with an online reference to the left mastoid. The horizontal electroencephalogram (HEOG) was recorded with two electrodes placed laterally to the right and left eyes. The vertical electroencephalograms (VEOG) were recorded with electrodes placed above and below the right eye. All inter-electrode impedances were maintained below 10 k Ω . The EEG and EOG were amplified using a 0.01–100 Hz band-pass and continuously sampled at 500 Hz in each channel for off-line analysis. All EEG signals were re-referenced off-line to the average of the left and right mastoids. The EEG data were low-pass filtered below 30 Hz (24 dB/oct) and were corrected for eye movements and/or blinks with the Gratton and Coles’ method as implemented in the Brain Vision analysis software (Brain Product, GmbH, Germany). Trials containing EEG sweeps with amplitudes exceeding $\pm 100 \mu\text{V}$ were excluded.

For each stimulus, epochs of 1000 ms duration including a 100 ms pre-stimulus period were extracted from the continuous EEG record. Because the P200 and P300 components are components commonly found in decision-making processes, we analyzed the P200, P300 and N300 components.

Results

Behavioral results

In each trial, participants indicated their preferences for SS or LL by pressing the corresponding key. The percentage of SS gain/loss choices in the earthquake-devastated and non-devastated areas are illustrated in Figure 2.

A chi-square test revealed that the SS options involving gains were chosen more in the earthquake-devastated compared with non-devastated areas ($p < 0.05$), suggesting that delayed gains were discounted more by earthquake victims than by the control group. Additionally, fewer trials involving an SS loss were chosen in the earthquake-devastated (72.8%) than in non-devastated (75.4%) area, but this did not reach statistical significance ($p > 0.05$).

There was no significant difference in reaction time between groups for both gain and loss tasks ($p > 0.05$).

ERP Results

Repeated measures analyses of variance (ANOVAs) for each ERP component were conducted with group (earthquake *vs.* non-earthquake) as a between-participants factor, and with task (gain *vs.* loss) as a within-participants factor. Another within-participants factor was the electrode, which included Fz, F3, F4, FCz, FC3 and FC4 for the P200 component; Pz, P3, P4, POz, PO3, PO4, CPz, CP3 and CP4 for the P300 component; and Fz, FCz, Cz for the N300 component. These electrode sites were chosen based on the literature [45,46] and after visual inspection of the ERP grand average waveforms. In all the analyses, the Greenhouse-Geisser correction for non-sphericity was applied where appropriate.

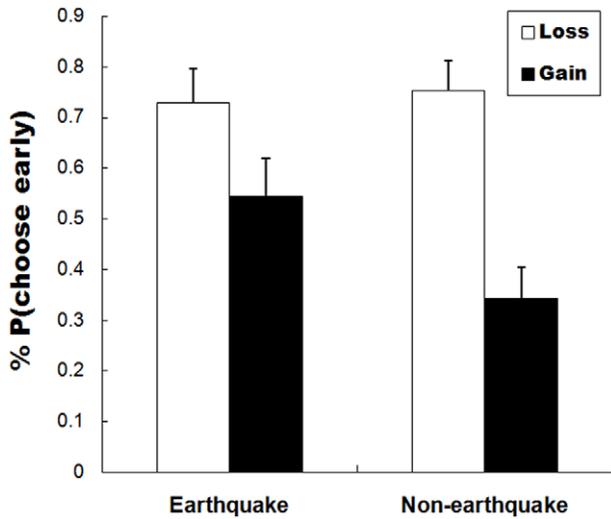


Figure 2. Percentage choices of sooner and smaller (SS) gains/losses in earthquake-devastated and non-devastated areas.
doi:10.1371/journal.pone.0040316.g002

Figure 3 shows the grand average ERPs at the sites of the maximum amplitude (Fz for the P200 and N300, Pz for the P300) as well as scalp potential maps for the earthquake and non-earthquake groups for time discounting tasks involving gains (G-TD) and losses (L-TD) and losses (L-TD).

P200. The P200 amplitudes were measured as the average amplitudes of the waveform in a window from 180–220 ms. ANOVAs indicated that the P200 amplitudes differed significantly between the earthquake and non-earthquake groups ($F(1, 39) = 4.471, p < .05$). The P200 amplitudes for the earthquake-devastated group were larger than those for the non-devastated group. No other effects were significant.

P300. The P300 amplitudes were measured as the average amplitudes of the waveform in a window from 250–350 ms following stimulus presentation. P300 amplitudes showed signifi-

cant main effect of group ($F(1, 39) = 4.288, p < .05$). The P300 amplitudes for the earthquake-devastated group were larger than those for the non-devastated group. No other effects were significant.

N300. The N300 amplitude was calculated as the average amplitudes of the waveform in a window from 280–320 ms following stimulus presentation. For the N300 amplitude, a significant interaction was found between group and task ($F(1, 39) = 6.562, p < .05$). Further simple effects analyses revealed that, for gain tasks, the N300 amplitude was marginally significant smaller in the earthquake-devastated group compared with the control group ($p = 0.059$). With regard to the N300 amplitude for loss tasks, there was no significant difference found between groups ($p = 0.555$). In addition, the N300 amplitude for gains and losses showed a marginally significant difference ($p < .1$) in both the earthquake and non-earthquake groups.

Repeated ANOVAs for the P200, P300 and N300 were also conducted with group (earthquake vs. non-earthquake) as a between-participant factor, and with choice (sooner vs. later) and electrode as within-participant factors. The Greenhouse-Geisser correction for non-sphericity was applied when necessary. Only participants with at least 20 trials in either condition (sooner and later) were taken into account. Finally, there were 20 participants (7 in the experimental group and 13 in the control group) included in the analysis. Only the results for gains are presented in detail because there were insufficient data (too few participants) for losses to allow for a meaningful ERP analysis.

ANOVAs revealed that neither the effect of group (P200: $F(1, 18) = 0.03, p > .05$; P300, $F(1, 18) = 0.530, p > .05$; N300: $F(1, 18) = 0.008, p > .05$) nor the effect of choice (P200: $F(1, 18) = 0.17, p > .05$; P300, $F(1, 18) = 1.432, p > .05$; N300: $F(1, 18) = 2.4, p > .05$) were significant. It is worth noting that the group effect was significant in the group (earthquake vs. non-quake) \times domain (gain vs. loss) \times electrode ANOVA. Therefore, the insignificance of choice effect might be due to one of these two main factors: (1) insufficient number of participants and (2) imbalance number of epochs between the sooner and the later choices, which is likely to influence the amplitude of the averaged ERP.

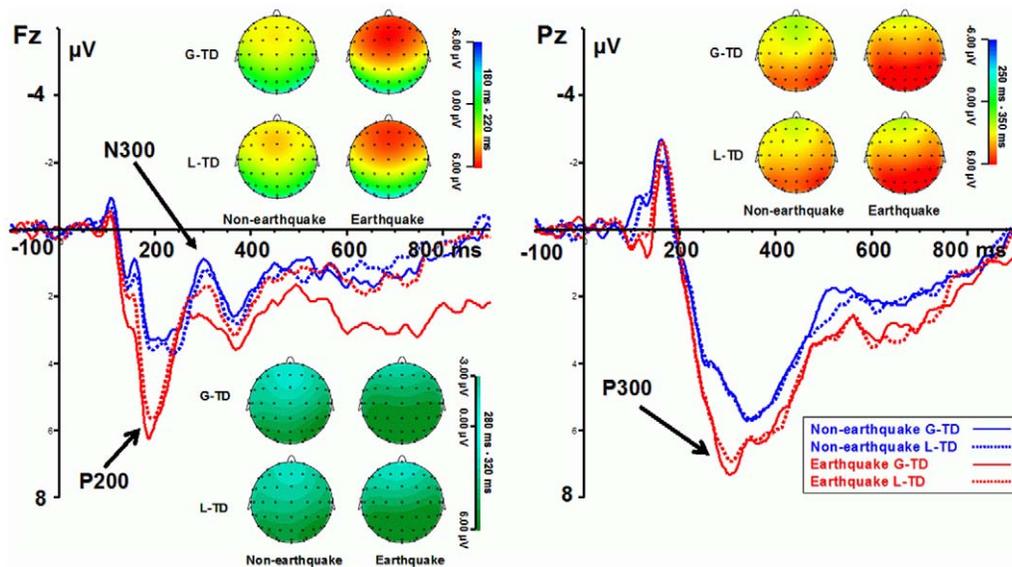


Figure 3. Grand average ERPs and scalp potential maps (at the time range of P200, N300 and P300 components) on time discounting tasks involving gains (G-TD) and losses (L-TD) for the earthquake and non-earthquake groups.
doi:10.1371/journal.pone.0040316.g003

Source Analysis

Source analysis was performed for components that differed between the groups using standardized low-resolution brain electromagnetic tomography (sLORETA) [47], which is a tomographic technique that gives a solution to the so-called inverse problem (i.e., the computation of images of electric neuronal activity based on extracranial measurements). sLORETA yields images of standardized current density with zero localization errors, allowing a more precise source localization than the older LORETA method [48]. It has been previously shown that sLORETA can achieve a reliable localization of possible underlying sources [49,50].

As shown in Figure 4, significant sources relating to the difference in the time range of the P200 component between the experimental and control groups are located in the insula (BA 13) and inferior frontal gyrus (IFG; BA 44, BA 45). For the N300 and P300 components the difference is mainly located in the cingulate gyrus (BA 31) and precuneus (BA 7, BA 23). In all of these regions the earthquake group showed increased activity compared with controls.

Discussion

In the previous study [25] conducted shortly after the Wenchuan Earthquake, we found that delayed gains were discounted more steeply after compared with before the earth-

quake, while the effect in the loss domain did not reach statistical significance. One of the biggest drawbacks of our prior work [25] is the lack of a comparable control group, which raised the question that the reported effect might be not due to the disaster. By having teachers from earthquake-devastated and non-devastated areas as participants, this study re-examined the influence of the Wenchuan Earthquake on victims' time discounting. The behavioral results from the current study are consistent with those of our prior work [25], suggesting that the effect was caused by the disaster and remained robust even two more years passed by. In addition, it has been repeatedly found that people's discounting of delayed gains is influenced more by the earthquake than delayed losses, which can be interpreted, as explained by Li et al. [25], as due to the asymmetry in discounting processes of future gains and losses [22,23,44,51].

The ERP data were of particular importance in specifying the influence of the earthquake on intertemporal decision making. The time discounting task elicited larger P200 and P300 amplitudes in earthquake survivors than in the control group. Furthermore, there was an interaction for the N300 amplitude between group (earthquake *vs.* control) and task (gain *vs.* loss).

P200

It is assumed that the P200 is related to early stimulus encoding, reflecting stimulus detection, semantic processing and the early

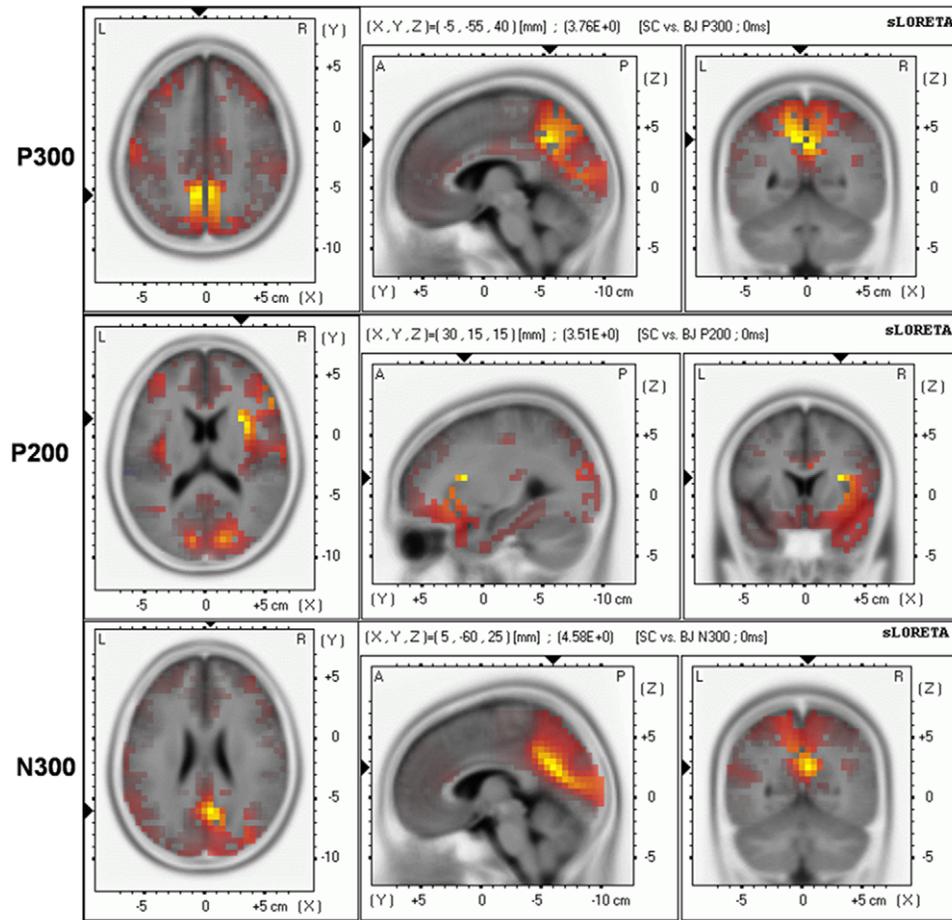


Figure 4. Graphical representation of the sLORETA results comparing the ERPs between the earthquake and control groups at the time range of P300, P200 and N300. Orange indicates significant hyperactivity for earthquake survivors compared with controls. doi:10.1371/journal.pone.0040316.g004

stages of decision making. Recently, Polezzi et al. [52] reported that unpredictable outcomes elicited larger P200 amplitudes than did predictable outcomes. The increased P200 amplitudes among earthquake victims may reflect that, after a disaster, future events seem more unpredictable.

P300

The P300 is widely reported as a component linked to risky decision making [53–55]. The P300 amplitude is found to vary with event probability and outcome magnitude [53,56]. Larger amounts and lower probabilities elicit a larger P300 [53,56]. P300 amplitude was also found to reflect risk-taking behavior, with larger amplitudes in the context in which participants showed a higher risk-tendency [56]. Generally, the P300 seems to reflect characteristics of the evaluation process for making a decision, with larger P300 amplitudes being associated with more risky alternatives or behaviors.

One explanation for intertemporal discounting is that throughout evolutionary history future rewards have been uncertain [57]; time delays are associated with implicit risks [58]. With longer delays there could be a greater risk that the expected or promised reward will not actually be received [57,59]. Thus, delayed positive consequences are avoided because they are less certain (time introduces a risk component) [59]. From this perspective, the enhanced P300 found among the survivors could reflect that time delays were viewed as even more risky after the earthquake. According to Tversky and Kahneman's [60] availability and representativeness heuristics, a catastrophic disaster may make the uncertainty of receiving a later gain more salient because an intervening event might block the possibility of making it real.

N300

Time discounting is often used as a measure of compulsivity or self-control [61,62]. A higher discounting rate indicates a higher focus on immediate compared with delayed events, i.e., more impulsive and less controlled. Within the field of cognitive neuroscience, impulsivity is often equated with the term 'disinhibition', referring to the idea that top-down control mechanisms ordinarily suppress automatic or reward-driven responses that are not appropriate to the current demands [63]. A large amount of literature has emerged on the role of the anterior N2 component, a negative wave peaking between 200 and 350 ms after stimulus onset, in inhibitory control process [45,64,65]. For example, various studies using go/no-go tasks have found that larger N2s are elicited by "no-go" trials than "go" trials [45,64,65], suggesting that the N2 component is consistently linked to inhibitory control. Therefore, it is appropriate to identify the N300 found in the present study – peaking within 200 and 350 ms with an anterior scalp distribution – as an N2 component, reflecting the process of inhibiting the impulsivity towards the immediate rewards rather than delayed larger ones. The statistical analysis revealed that the N300 amplitude for gain tasks tended to decrease in the experimental group, suggesting that there might be a deficiency in inhibitory control for gains among earthquake survivors. This group difference was not true for loss tasks. This pattern of results may provide a further neural explanation for the repeated behavioral findings that discounting of delayed gains was more influenced by the earthquake than delayed losses.

The sLORETA analysis of the ERP components that differed between the groups (the P200, P300 and N300) revealed significant hyperactivity for the earthquake group in the insula (BA 13), cingulate gyrus (BA 31), precuneus (BA 7, BA 23) and inferior frontal gyrus (BA 44, BA 45). This pattern of findings indicates more activation of emotion-related areas including the

insula and cingulate gyrus [66,67] in the earthquake group, suggesting that earthquake survivors employed a more emotional, intuitive system to make their decisions. According to McClure et al.'s [38] findings that the activation of emotional brain areas predicted choices for immediate rewards, the hyperactivity of emotion-related regions among victims were congruent with our behavioral findings that immediate gains are chosen more by earthquake survivors than controls. Notably, it has been proposed that the activation of the precuneus is involved in source memory (in which the "source" circumstances of a memory are recalled), especially during the regeneration of previous episodic contextual associations [68–70]. In line with Tversky and Kahneman's [71] 'availability heuristic' of intuitive decision making, that individuals estimate the likelihood of an event "by the ease with which instances or associations come to mind", the hyperactivity of the precuneus among earthquake survivors suggests that victims referred to their past earthquake experience when making decisions involving delayed gains and losses. In a recent fMRI study [72] it was found that the IFG has an inhibitory and risk-averse role in decision making, with increasing IFG activity to higher risk aversion. Furthermore, according to Christopoulos et al. [72], the IFG "does not influence the objective evaluation of risk but rather the subjective perception of the riskiness of the option". The increased activations of the IFG in the earthquake group suggest that other options with the same time delay were perceived to be more risky and, therefore, resulted in higher risk aversion (i.e., more selection of the immediate gains). It is worth mentioning that, the sLORETA analysis provides only an estimate of the source(s) for the various ERP components, since sLORETA inherently would not produce a pinpoint solution for a point source [47], and its present implementation offers only a spatial resolution of 5 mm. Therefore, the source analysis results presented here are suggestive, not definitive, evidence of specific brain areas being affected by the earthquake. Further research using neuroimaging methods, such as fMRI, is needed to specify the brain regions associated with post-disaster decision making.

Our results provided convergent evidence that post-disaster decisions may be less rational, involving more emotional thinking (System 1) and less rational thinking (System 2) in terms of a dual-process model of decision making. First, the behavioral findings that the immediate gains were chosen more by the earthquake survivors than by the control group implies a more irrational tendency among victims, because discounting future gains is viewed as an irrational decision bias which "ought to be resisted" [29]. Second, the ERP results suggest less inhibitory control (i.e., less rational decision making) for immediate gains after the earthquake than in normal circumstances, which electrophysiologically implies a less rational/cognitive tendency after the disaster as well. Third, the sLORETA analysis indicates more activation of emotion-related regions among earthquake survivors. From an evolutionary standpoint [35,73,74], in the environment of human ancestors, most decisions relied on the operation of System 1, with System 2 only needed to deal with some unusual cases. In modern society, however, the more sophisticated environment may require more and more System 2 thinking. The results from the current study imply that, after a disaster, people seemed to make irrational regressions towards the thinking style of our ancestors, with a heavier reliance on System 1 when making a decision.

One limitation of the present study is the relatively small number of participants included in the ERP analysis distinguishing between immediate and delayed choices, which may lead to the argument that the statistical approach was not sufficiently robust

to produce clearly significant results. Further research is needed to clarify this issue.

The findings of the present study highlight the lasting influence of the Wenchuan earthquake and its neural mechanism. The results indicate that immediate gains were more preferred by the earthquake survivors than by people who did not experience the earthquake. It might be inferred from the results that a major natural disaster could cause people to have less inhibitory control and to evaluate future gains as more risky, leading to more shortsighted decisions involving intertemporal tradeoffs. The current data behaviorally and electrophysiologically suggest that post-disaster decisions may be less rational. As mentioned above, time discounting plays an important role in many everyday life problems, such as decisions about investments and savings, dieting, education, marriage, alcohol and drug use/abuse, etc. The current findings can then also be related to theoretical and policy

implications for a better understanding of post-disaster behavior and for effective intervention and management in the aftermath of a disaster.

Acknowledgments

The authors are grateful to Youze Xiao, Ying Li, Yuying Li, and Ning Yan for assistance in data collection, and Ruolei Gu, Suyong Yang, Lili Wang for their helpful comments.

Author Contributions

Conceived and designed the experiments: YJL JZL. Performed the experiments: JZL DYG CLF BQD. Analyzed the data: DYG TG. Contributed reagents/materials/analysis tools: YJL WZW. Wrote the paper: JZL.

References

- Tamura H, Yamamoto K, Tomiyama S, Hatono I (2000) Modeling and analysis of decision making problem for mitigating natural disaster risks. *Eur J Oper Res* 122: 461–468.
- Sacco K, Galletto V, Blanzieri E (2003) How has the 9/11 terrorist attack influenced decision making? *Appl Cognitive Psych* 17: 1113–1127.
- Gigerenzer G (2004) Dread risk, September 11, and fatal traffic accidents. *Psychol Sci* 15: 286–287.
- Li JZ, Li S, Wang WZ, Rao LL, Liu H (2011) Are people always more risk averse after disasters? Surveys after a heavy snow-hit and a major earthquake in China in 2008. *Appl Cognitive Psych* 25: 104–111.
- Li S, Li JZ, Chen YW, Bai XW, Ren XP, et al. (2010) Can Overconfidence be Debaised by Low-Probability/High-Consequence Events? *Risk Anal* 30: 699–707.
- Dearstynne B (2007) The FDNY on 9/11: Information and decision making in crisis. *Government Information Quarterly*, 24: 29–46.
- Havenaar J, de Wilde E, van den Bout J, Drottz-Sjöberg B, van den Brink W (2003) Perception of risk and subjective health among victims of the Chernobyl disaster. *Soc Sci Med* 56: 569–572.
- Ganderton P, Brookshire D, McKee M, Stewart S, Thurston H (2000) Buying insurance for disaster-type risks: Experimental evidence. *J Risk Uncertainty* 20: 271–289.
- Myers DG (2001) Do we fear the right things? *Observer*. 14: 3.
- Frederick S, Loewenstein G, O'Donoghue T (2002) Time discounting and time preference: a critical review. *J Econ Lit* 40: 351–401.
- Logue AW (1988) Research on self-control: An integrating framework. *Behav Brain Sci* 11: 665–679.
- Schoenfelder TE, Hantula DA (2003) A job with a future? Delay discounting, magnitude effects, and domain independence of utility for career decisions. *J Vocat Behav* 62: 43–55.
- Berns GS, Laibson D, Loewenstein G (2007) Intertemporal choice – toward an integrative framework. *Trends Cogn Sci* 11: 482–488.
- Green L, Myerson J (2004) A discounting framework for choice with delayed and probabilistic rewards. *Psychol Bull* 130: 769–792.
- Benzion U, Rapoport A, Yagil J (1989) Discount rates inferred from decisions: An experimental study. *Manage Sci* 35: 270–284.
- Green L, Myerson J (1993) Alternative frameworks for the analysis of self control. *Behavior and Philosophy* 21: 37–47.
- Read D (2004) Intertemporal choice. In: Koehler, D, Harvey, N (Eds.), *Blackwell Handbook of Judgment and Decision Making*. Blackwell, Oxford, 424–443.
- Estle SJ, Green L, Myerson J, Holt DD (2007) Discounting of monetary and directly consumable rewards. *Psychol Sci* 18: 58–63.
- Rachlin H, Green L (1972) Commitment, choice and self-control. *J Exp Anal Behav* 17: 15–22.
- Green L, Myerson J, Holt DD, Slevin JR, Estle SJ (2004) Discounting of delayed food rewards in pigeons and rats: Is there a magnitude effect? *J Exp Anal Behav* 81: 39–50.
- Murphy JG, Vuchinich RE, Simpson CA (2001) Delayed reward and cost discounting. *Psychol Rec* 51: 571–588.
- Loewenstein G (1987) Anticipation and the valuation of delayed consumption. *The Economic Journal* 97: 666–684.
- Thaler R (1981) Some empirical evidence on dynamic inconsistency. *Econ Lett* 8: 201–207.
- MacKeigan LD, Larson LN, Draugalis JR, Bootman JL, Burns LR, (1993) Time preference for health gains versus health losses. *Pharmacoeconomics* 3: 374–386.
- Li JZ, Li S, Liu H (2011) How has the Wenchuan earthquake influenced people's intertemporal choices? *J Appl Soc Psychol* 41: 2739–2752.
- Ohmura Y, Takahashi T, Kitamura N, Wehr P (2006) Three-month stability of delay and probability discounting measures. *Exp Clin Psychopharm* 14: 318–328.
- Boettiger CA, Mitchell JM, Tavares VC, Robertson M, Joslyn G, et al. (2007) Immediate reward bias in humans: fronto-parietal networks and a role for the catechol-O-methyltransferase 158(Val/Val) genotype. *J Neurosci* 27: 14383–14391.
- Hardman D (2009) Judgment and choice over time. In: *Judgment and decision making: psychological perspectives*. Malden, MA: Wiley-Blackwell. 106–116.
- Pavel C (2011) Rational choice in field archaeology. *Journal of Comparative Research in Anthropology and Sociology* 2: 117–136.
- Evans BT (2008) Dual-processing accounts of reasoning, judgement and social cognition. *Annu Rev Psychol* 59: 255–278.
- Sloman SA (1996) The empirical case for two systems of reasoning. *Psychol Bull* 119: 3–22.
- Kahneman D, Frederick S (2002) Representativeness revisited: Attribute substitution in intuitive judgment. In: Gilovich T, Griffin D, Kahneman D, editors. *Heuristics and Biases: The Psychology of Intuitive Judgment*. Cambridge: Cambridge University Press. 49–81.
- Stanovich KE, West RF (2000) Individual differences in reasoning: Implications for the rationality debate. *Behav Brain Sci* 23: 645–726.
- Ferreira MB, Garcia-Marques L, Sherman SJ, Sherman JW (2006) Automatic and controlled components of judgment and decision making. *J Pers Soc Psychol* 91: 797–813.
- Payne JW, Bettman JR (2004) Walking with the scarecrow: the information-processing approach to decision research. In: Koehler DJ, Harvey H, editors. *Blackwell Handbook of Judgment and Decision Making*. Malden: Blackwell Publishing Ltd. 110–132.
- Slovic P, Finucane M, Peters E, MacGregor DG (2002) The affective heuristic. In: Gilovich T, Griffin D, Kahneman D, editors. *Heuristics and biases: The psychology of intuitive judgement*. Cambridge: Cambridge University Press. 397–420.
- Frank MJ, Cohen MX, Sanfey AG (2009) Multiple systems in decision making: a neurocomputational perspective. *Curr Dir Psychol Sci* 8: 73–77.
- McClure SM, Laibson DI, Loewenstein G, Cohen JD (2004) Separate neural systems value immediate and delayed monetary rewards. *Science* 306: 503–507.
- Breiter HC, Aharon I, Kahneman D, Dale A, Shizgal P (2001) Functional imaging of neural responses to expectancy and experience of monetary gains and losses. *Neuron* 30: 619–639.
- Ganzel BL, Kim P, Glover GH, Temple E (2008) Resilience after 9/11: Multimodal neuroimaging evidence for stress-related change in the healthy adult brain. *NeuroImage* 40: 788–795.
- Bland S, Valoroso L, Stranges S, Strazzullo P, Farinero E, et al. (2005) Long-term follow-up of psychological distress following earthquake experiences among working Italian males: A cross-sectional analysis. *J Nerv Ment Dis* 193: 420–423.
- Bal A (2008) Post-traumatic stress disorder in Turkish child and adolescent survivors three years after the Marmara earthquake. *J Child Adolesc Ment Health* 13: 134–139.
- Karakaya I, Agaoglu B, Coskun A, Sismanlar SG, Yildiz O (2004) The symptoms of PTSD, depression and anxiety in adolescent students three and a half years after the Marmara earthquake. *Turk Psikiyatri Derg* 15: 257–263.
- Xu IJ, Liang ZY, Wang K, Li S, Jiang TZ (2009) Neural mechanism of intertemporal choice: From discounting future gains to future losses. *Brain Res* 261: 65–74.
- Bruin KJ, Wijers AA (2002) Inhibition, response mode, and stimulus probability: A comparative event-related potential study. *Clin Neurophysiol* 113: 1172–1182.
- 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. *Cognitive, Affective & Behavioral Neuroscience* 3: 17–26.

47. Pascual-Marqui RD (2002) Standardized low resolution brain electromagnetic tomography (sLORETA): technical details. *Methods & Findings in Experimental & Clinical Pharmacology* 24D: 5–12.
48. Pascual-Marqui RD, Lehmann D, Koenig T, Kochi K, Merlo MCG, et al. (1999) Low resolution brain electromagnetic tomography (LORETA) functional imaging in acute, neuroleptic-naive, first-break, productive schizophrenics. *Psychiatry Res* 90: 169–179.
49. Greenblatt RE, Ossadchi A, Pflieger ME (2005) Local linear estimators for the bioelectromagnetic inverse problem. *IEEE T Signal Proces* 53: 3403–3412.
50. Sekihara K, Sahani M, Nagarajan SS (2005) Localization bias and spatial resolution of adaptive and non-adaptive spatial filters for MEG source reconstruction. *Neuroimage* 25: 1056–1067.
51. Shelley MK (1994) Gain/loss asymmetry in risky intertemporal choice. *Organ Behav Hum Dec* 59: 124–159.
52. Polezzi D, Daum I, Rubaltelli E, Lotto L, Civai C, et al. (2008) Mentalizing in economic decision-making. *Behav Brain Res* 190: 218–223.
53. Yeung N, Sanfey AG (2004) Independent coding of reward magnitude and valence in the human brain. *J Neurosci* 24: 6258–6264.
54. Ma Q, Wang X, Shu L, Dai S (2008) P300 and categorization in brand extension. *Neuroscience Letter* 431: 57–61.
55. Polezzi D, Sartori G, Rumiati R, Vidotto G, Daum I (2010) Brain correlates of risky decision-making. *Neuroimage* 49: 1886–1894.
56. Rigoni D, Polezzi D, Rumiati R, Guarino R, Sartori G (2010) When people matter more than money: An ERPs study. *Brain Res Bull* 81: 445–452.
57. Fehr E (2002) The economics of impatience. *Nature* 415: 269–272.
58. Mischel W, Grusec J (1967) Waiting for rewards and punishments: Effects of time and probability on choice. *J Pers Soc Psychol* 5: 24–31.
59. Stevenson MK (1986) A discounting model for decisions with delayed positive and negative outcomes. *J. Experiment. Psych* 115: 131–154.
60. Tversky A, Kahneman D (1974) Judgment under Uncertainty: Heuristics and Biases. *Science* 185: 1124–1131.
61. Crean JP, de Wit H, Richards JB (2000) Reward discounting as a measure of impulsive behavior in a psychiatric outpatient population. *Exp Clin Psychopharmacol* 8: 155–162.
62. Glimcher PW, Kable JW, Louie K (2007) Neuroeconomic Studies of Impulsivity: Now or Just as Soon as Possible? *Am Econ Rev* 97: 142–147.
63. Aron AR (2007) The neural basis of inhibition in cognitive control. *Neuroscientist* 13: 214–228.
64. Pfefferbaum A, Ford JM, Weller BJ, Kopell BS (1985) ERPs to response production and inhibition. *Electroenceph Clin Neurophysiol* 60: 423–434.
65. Folstein JR, Van Petten C (2008) Influence of cognitive control and mismatch on the N2 component of the ERP: A review. *Psychophysiology* 45: 152–170.
66. Bechara A (2002) The neurology of social cognition. *Brain* 125: 1673–1675.
67. Apkarian AV, Sosa Y, Krauss BR, Thomas PS, Fredrickson BE, et al. (2004) Chronic pain patients are impaired on an emotional decision-making task. *Pain* 108: 129–136.
68. Frank MJ, Cohen MX, Sanfey AG (2009) Multiple systems in decision making: A neuro-computational perspective. *Curr Dir Psychol Sci* 18: 73–77.
69. Grasby PM, Frith CD, Friston KJ, Bench C, Frackowiak RS, et al. (1993) Functional mapping of brain areas implicated in auditory-verbal memory function. *Brain* 116: 1–20.
70. Shallice T, Fletcher P, Frith CD, Grasby P, Frackowiak RS, et al. (1994) Brain regions associated with acquisition and retrieval of verbal episodic memory. *Nature* 368: 633–635.
71. Lundstrom BN, Ingvar M, Petersson KM (2005) The role of precuneus and left inferior frontal cortex during source memory episodic retrieval. *Neuroimage* 27: 824–834.
72. Tversky A, Kahneman D (1973) Availability: A heuristic for judging frequency and probability. *Cog. Psychol* 5: 207–232.
73. Christopoulos GI, Tobler PN, Bossaerts P, Dolan RJ, Schultz W (2009) Neural correlates of value, risk, and risk aversion contributing to decision making under risk. *J Neurosci* 29: 12574–12583.
74. Reber AS (1992) An evolutionary context for the cognitive unconscious. *Philos Psychol* 5: 33–51.
75. Evans BT (1996) Deciding before you think: Relevance and reasoning in the selection task. *Brit J Psychol* 87: 223–240.