

Research

The neural basis of cultural differences in delay discounting

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People generally prefer to receive rewarding outcomes sooner rather than later. Such preferences result from delay discounting, or the process by which outcomes are devalued for the expected delay until their receipt. We investigated cultural differences in delay discounting by contrasting behaviour and brain activity in separate cohorts of Western (American) and Eastern (Korean) subjects. Consistent with previous reports, we find a dramatic difference in discounting behaviour, with Americans displaying much greater present bias and elevated discount rates. Recent neuroimaging findings suggest that differences in discounting may arise from differential involvement of either brain reward areas or regions in the prefrontal and parietal cortices associated with cognitive control. We find that the ventral striatum is more greatly recruited in Americans relative to Koreans when discounting future rewards, but there is no difference in prefrontal or parietal activity. This suggests that a cultural difference in emotional responsivity underlies the observed behavioural effect. We discuss the implications of this research for strategic interrelations between Easterners and Westerners.

Keywords: delay discounting; cultural neuroscience; ventral striatum; dorsolateral prefrontal cortex; posterior parietal cortex

1. INTRODUCTION

In an ever-increasingly global economy, cultural differences in financial attitudes are bound to be a potent source of conflict. We investigated differences in one fundamental component of valuation: preferences related to time. Aggregate cultural differences in intertemporal valuation are likely to produce conflicting preferences and opposing opinions on optimal courses of action across a broad span of situations. Our aim was to understand the source of differences in temporal valuation using functional neuroimaging to guide inference about governing cognitive processes. We anticipate that greater understanding about cultural differences in basic valuation processes can only help to overcome any resultant conflicts.

Preferences related to time affect nearly every aspect of our lives. Everyday decisions commonly involve selecting between a more proximate outcome and another that will be realized only after an extended delay. So, for example, whether to spend or save for retirement and whether to eat sweet food or preserve long-term health both require making intertemporal trade-offs between reward and time. At a larger scale, intertemporal preferences of various sorts are reflected in government actions as well.

Temporal valuation processes are commonly studied in the laboratory using a very reduced form of

intertemporal choice. Decisions made between receiving \$10 today or \$12 next week are a tremendous simplification of what we are confronted with in everyday life. However, these choices can be manipulated parametrically, thereby allowing intertemporal preferences to be quantified. Temporal discounting functions derived in this manner have external validity in that they correlate with many important life outcomes, such as differences in propensity for obesity [1] and addiction [2].

From a neuroscience perspective, multiple processes may be expected to underlie differences in temporal discounting. Intertemporal choices are determined from an interaction of emotion-related basic reward mechanisms and more cognitive judgements derived from long-term goals [3]. Neurally, these processes are linked to brain reward areas (including the ventral striatum, VStr, and ventromedial prefrontal cortex, VMPFC) and regions associated with executive functions (dorsolateral prefrontal cortex, DLPFC, and posterior parietal cortex, PPC), respectively [4–6]. Individual differences in either reward- or executive control-related brain responses both predict rates of delay discounting [7,8].

The goal of this study was to provide a plausible explanation for cultural differences in delay discounting. There have been some investigations into differences in intertemporal preferences across cultures [9–12]. To our knowledge, the focus to date has been exclusively on differences between Western and Eastern attitudes. The conclusions from this work are highly consistent: Eastern culture implies a greater tendency to select later options.

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One contribution of 12 to a Theme Issue ‘The biology of cultural conflict’.

Recently, both anatomical and functional differences have been reported in the brains of Eastern and Western subjects [13–15]. Using functional neuroimaging, we expected that cultural differences in temporal discounting would be linked to either activity in brain reward areas, activity in regions associated with cognitive control, or both. One can hypothesize that Easterners are less sensitive to immediate reward than Westerners, because they have long-term perspectives that emphasize the future. In the brain, this difference should be reflected by the levels of activation in reward areas (the mesolimbic dopamine system, including VStr and VMPFC). In this case, Westerners' reward areas should show higher activation in response to immediate rewards compared with Easterners. Alternatively, it may be the case that Easterners do not behave as impulsively as Westerners even when faced with equally tempting immediate outcomes. This would predict that cognitive areas should be more active in Easterners, reflecting their greater tendency to regulate their emotional response [5,6]. Of course, both mechanisms may simultaneously contribute to behavioural differences.

To date, combining neuroscientific and cross-cultural methodologies has been uncommon in psychology, since these two fields tend to represent relative extremes of scope and level of analysis. Culture research examines the macroscale, using culture—an interpersonal variable—as its level of analysis. By contrast, neuroscience studies the microscale, measuring brain activity, an intrapersonal biological response. However, there has been increasing interest in combining these two perspectives to identify fundamental mechanisms underlying cultural differences and to explore interactions among environment, behavioural and biological differences [16–18].

Given our understanding of the neuroscientific basis of intertemporal choice, we expect this study will further our understanding of the fundamental differences in intertemporal preferences across cultures. Assuming that interacting with one's environment is important as one develops decision-making strategies, cultural differences could strongly influence one's attitudes towards time and hence one's intertemporal preferences. Any such differences should be reflected in patterns of neural responses evident when making intertemporal choices.

In the study reported below, we found that there is a significant difference in intertemporal preferences between Western (American) and Eastern (Korean) participants in behavioural measures of delay discounting. Using functional magnetic resonance imaging (fMRI), we tested between the possible neural bases of this difference. We found that there were no differences in brain responses in areas associated with executive processes. However, there were significant differences in VStr activity across the participant cohorts, thus suggesting that differences in intertemporal preferences derive from emotional responsivity to the presence of immediate rewards.

2. MATERIAL AND METHODS

(a) Subjects

We collected complete datasets from a total of 14 Western (American) and 19 Eastern (Korean) subjects.



Figure 1. (a) American and (b) Korean subjects indicated their preferences for a series of intertemporal choices while undergoing fMRI scanning. Responses were self-paced, followed by a 2 s display indicating choice outcome.

The mean age of the participants used in the analysis was 22 years (s.d. = 2.65, five females) for Western subjects and 21.2 years (s.d. = 1.72, 10 females) for Eastern subjects. All participants were recruited from top universities in their respective countries. We therefore presume that they are comparable in terms of socioeconomic status. No participant reported a history of psychiatric disorder or current use of psychoactive medication.

There was a significant difference in the composition of our two participant cohorts in terms of gender. To remove this as a possible confound in our analyses, we tested both whether the observed results were evident on the basis of gender alone and controlled for gender in all analyses. For all tests conducted, gender did not account for differences in either behaviour or brain activity.

(b) Task

The task required subjects to make a series of choices between smaller, sooner rewards (r_1 available at delay t_1), and later, larger rewards (r_2 available at delay t_2 , where $r_1 < r_2$ and $t_1 < t_2$). The sequence and timing of the different experimental events are shown in figure 1. After the choice was displayed, participants indicated their preference by pressing one of two buttons corresponding to the location of preferred options (i.e. left button for smaller, sooner reward). Decisions were effectively self-paced with a maximum allowed reaction time of 15 s (all responses were submitted well before this deadline). After subjects submitted their choice, a feedback screen was shown for 2 s, indicating that the response was recorded successfully. Each choice trial was followed by a 12 s inter-trial interval to allow blood oxygenation level-dependent (BOLD) responses to return to baseline between trials. The task was implemented with E-PRIME (Psychology Software Tools Inc., Pittsburgh, PA, USA).

Before presenting the choices of interest, subjects were given two control questions to familiarize them with the nature of the task. The first question asked them to choose between two outcomes of the same magnitude ($r_1 = r_2$) and different delays. Assuming that

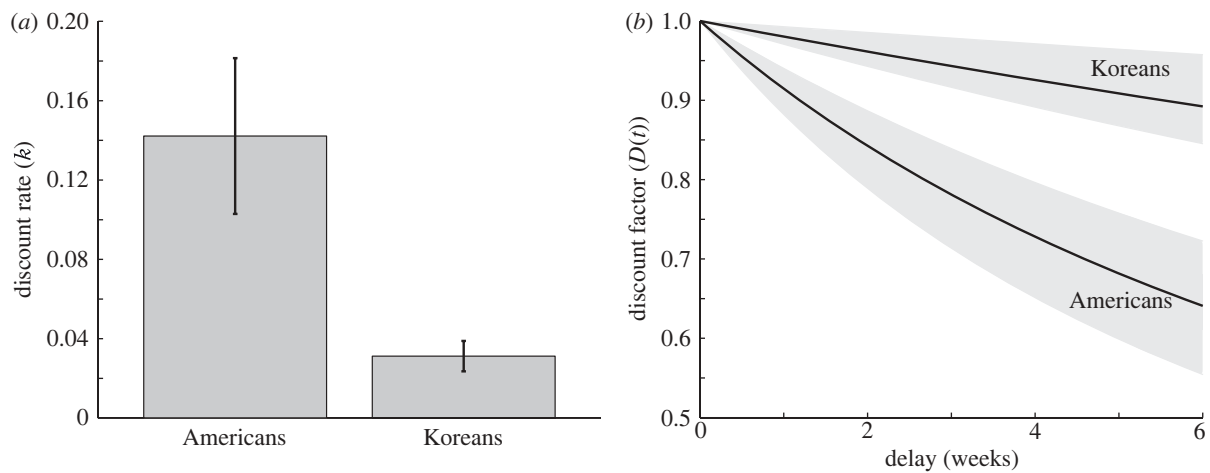


Figure 2. Best-fitting discount functions were acquired from each subject's choices. We used a hyperbolic function to summarize preferences, with a single free parameter of discount rate (k). (a) Americans had significantly higher discount rates than did Korean participants. Error bars indicate s.e. (b) The result replicated when discount rates were calculated based on the aggregate data across subject groups. Grey bands indicate 95% CIs.

people discount for delay, subjects should (and did) always choose the sooner reward for this question. For the second question, the smaller, sooner reward was less than 1 per cent of the magnitude of the delayed option (e.g. \$0.16 today versus \$34.04 in one month and two weeks). All subjects preferred the delayed option in this trial.

In the main tasks, we varied r_1 and r_2 to span differences from 1 to 50 per cent in reward values (actual differences, $(r_2 - r_1)/r_1$, were 1, 3, 5, 10, 15, 25, 35, 50%). Rewards were expressed in US dollars for American subjects, and in Korea Won for Korean subjects. To control the magnitude of rewards across groups, we generated values in dollars and converted into Won. The smaller dollar value (r_1) was drawn from a normal distribution with mean \$20 and the larger value was calculated to give a randomly selected percentage difference. The conversion rate between dollars and Won at the time of the experiment was approximately 1 : 1150. Both r_1 and r_2 were scaled by this amount to control for the magnitude of rewards across cohorts. Discount rates are known to depend on reward magnitude [19–21]. Since we controlled for magnitude in this manner, the magnitude *per se* should not confound our experiment.

We selected t_1 from the set of (today, two weeks, four weeks) and the difference between two delays ($t_2 - t_1$) was either two weeks or one month. By varying time in this manner, we were able to indentify brain regions that are sensitive to delay. Delays were expressed in English for both groups. All Korean subjects had extensive education in English and none reported any difficulty in understanding the time delays. All choices were hypothetical. Previous research indicates that there are no significant differences, either behaviourally or neurally, between hypothetical and real reward outcomes [22]. The order of choices was randomized within and across participants.

(c) Functional magnetic resonance imaging data acquisition

Brain-imaging data of Western subjects were collected on a 3 T Siemens Allegra scanner located at Princeton

University. Eastern data were collected on an ISOL 3 T Forte scanner located at KAIST Brain Science Research Centre, South Korea. High-resolution T1-weighted images were first acquired ($1 \times 1 \times 1 \text{ mm}^3$ resolution). Whole-brain BOLD weighted echo-planar images (TR = 2 s, TE = 30 ms, flip angle = 90° , 37 total slices with 2 mm slice gap, 64×64 matrix) were then acquired approximately 30° off the anterior commissure–posterior commissure lines to maximize signal in the ventral prefrontal cortex and VStr. To correct for differences in signal strength between scanners, we analyse BOLD data as per cent signal change.

(d) Behavioural data analysis

We fit behavioural data assuming a hyperbolic discount function that has been found to provide an excellent description of discounting behaviour in a cross-cultural context previously [9]. The discounted value function is given by

$$V(r, t) = \frac{r}{1 + kt}, \quad (2.1)$$

where r is the reward amount available at delay t and V is the subjective value of the offer. Subjective value (V) depends on time through a discount rate k , such that higher k indicates greater discounting and a stronger preference for immediate outcomes. We estimated the discount rate (k) for each subject individually by assuming a logistic decision function and maximizing the log-likelihood of the observed choices. Matlab was used to find best-fitting model parameters using a simplex search algorithm with 100 random initial parameter values.

We compared discount rates across the groups in two ways. First, we performed a t -test comparing the distribution of best-fitting k values in each group (figure 2a). Second, we calculated an aggregate discount rate for each group by combining choices over all participants within the group and finding the best-fitting k to this aggregate data. We estimated 95% CIs for these group fits using a bootstrap procedure in which data were sampled with replacement

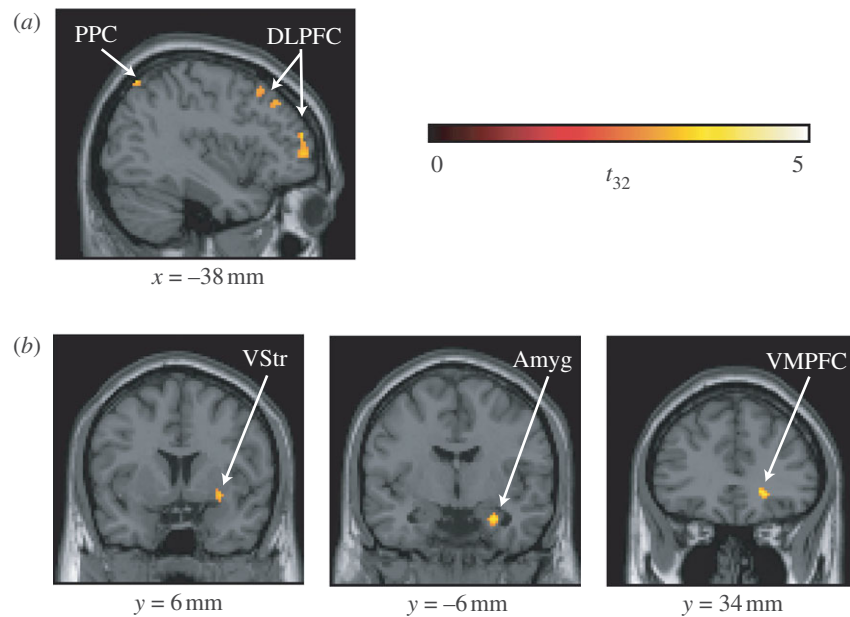


Figure 3. (a) Regions of the DLPFC and PPC were equally activated for all choices, consistent with a role in mediating executive processes associated with delay discounting. (b) Brain regions associated with reward processing, including the VStr, amygdala and VMPFC, were significantly more activated when choices included an immediate reward. The regions shown here also correlated significantly with individually determined discount rates (k).

randomly from the groups (to give 100 random collections of n choice sets, where n was equal to the number of participants in each group). Figure 2*b* shows best-fitting group discount functions with these 95% confidence bounds.

(e) Functional magnetic resonance imaging data analysis

fMRI data were analysed using Statistical Parametric Mapping 5 (SPM5, Wellcome Department of Cognitive Neurology, London, UK). Prior to statistical analysis, we first performed slice-timing correction. Data were then aligned to correct for head movement during the experiment. Images were smoothed with an 8 mm full-width at half maximum Gaussian kernel. Volumes were normalized to the Montreal Neurological Institute (MNI) template, and were resampled at $4 \times 4 \times 4 \text{ mm}^3$ resolution.

All statistical analyses were performed using a random effects analysis with a general linear model (GLM) designed to estimate neural responses to events of interest. In all analyses, potentially confounding variables such as trial-by-trial head movement and choice outcome (i.e. motor responses) were included in the GLM as regressors of no interest. We consider results from the GLM analysis significant if they are composed of 20 or more contiguous voxels each significant at $p < 0.005$.

3. RESULTS

Behaviourally, we found large differences in discounting across the American and Korean subject groups. First, a t -test between best-fitting discount rates (k , equation (2.1)) showed a significant effect of culture ($t = 3.1$, $p < 0.005$; figure 2*a*), such that Western subjects discounted more than Eastern subjects. Additionally, fitting aggregate discount rates

across groups shows that discounting by group was non-overlapping at the 95% level (figure 2*b*).

For fMRI data analysis, we began by identifying brain areas that showed high or low sensitivity to delays as in McClure *et al.* [4,23]. This analysis localizes brain areas associated with emotional reactivity [7,24] and cognitive control [5,8], respectively. To perform this analysis, we combined both subject groups and conducted a voxel-wise, event related GLM analysis. We included regressors that modelled BOLD responses to (i) choices involving an immediate reward (today) versus all other choices, and (ii) all choices independent of the time of reward outcomes. We use the term ‘immediacy effect’ to refer to the difference in activity identified in the first contrast (response to choices involving an immediate reward minus choices involving only delayed rewards). The results of these analyses largely replicated previous studies [4,12,23]. Brain areas that were preferentially activated by the prospect of an immediate reward included a number of areas associated with reward processing and emotional reactivity, including the VStr, amygdala and VMPFC (see below). Those areas that were equally activated in all intertemporal choices included regions associated with cognitive control, including regions throughout the PPC and DLPFC (including frontopolar cortex [8]; figure 3*a*).

Our primary aim was to identify brain areas that predict cultural differences in delay discounting. In order to refine our subsequent analyses, we therefore next determined whether any of the identified brain regions predicted individual differences in discount rate (k). We subjected the contrast images from the previous GLM analyses to a correlation test. Of the identified regions, only the VStr, amygdala and VMPFC survived this additional test. The results of the correlation analysis are shown in figure 3*b*. For each of these brain regions, there was a positive correlation

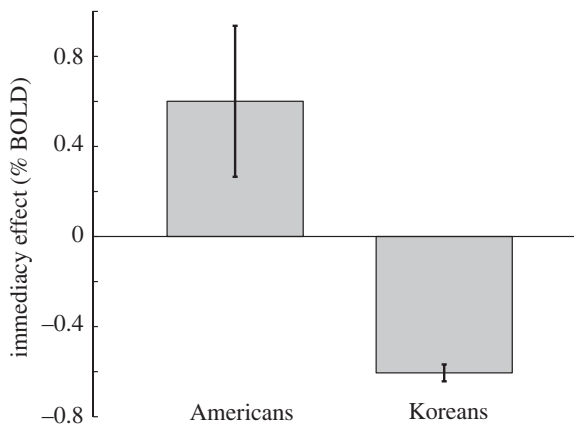


Figure 4. Of all the brain areas identified to be associated with aspects of delay discounting, only the VStr showed a significant group difference between Americans and Koreans. For Americans, the VStr showed greater activity when choices involved an immediate reward compared to choices involving only delayed rewards. This pattern of responses was reversed for the Korean subjects, with greater activity for choices involving only delayed rewards. Error bars indicate s.e.

between the BOLD immediacy effect and discount rate such that greater activity differences predicted greater delay discounting.

Given that there were culture-dependent differences in discount rates, we took the VStr, amygdala and VMPFC as candidate regions for brain areas that predict this cultural difference in behaviour. As a final analysis, we therefore tested whether activity in these brain reward areas also differed by culture. Of course, as these areas were selected based on a positive correlation with k , we fully expected that they should also show a difference across cultural groups.

We returned to the results of our first analysis and compared beta values from the GLM analysis across the two groups averaged over each of these brain regions of interest (ROIs taken from the results of the correlation analysis). For completeness, we included the DLPFC and PPC in these final tests as well. Only the VStr ($p = 0.001$; note that this is significant after Bonferroni correction for the number of independent tests; figure 4) showed a significant difference across subject groups in this final analysis. Of the other regions tested, only the amygdala approached significance (amygdala: $p = 0.10$; VMPFC: $p = 0.40$; PPC: $p = 0.77$; DLPFC: $p = 0.84$ and $p = 0.94$ for more posterior and more anterior cluster, respectively). Looking at the mean responses in the VStr across subject groups shows a surprising sign difference across cultural groups. Americans show the expected positive immediacy effect indicating a greater response when choices involve an immediate option. However, for Korean subjects, VStr activity is *less* when an immediate option is available. Our experiment design controlled for reward magnitudes (r_1 and r_2) over choices involving an immediate option and only delayed choices. Therefore, this result indicates that VStr activity depends positively on delay in Korean subjects, even though behaviourally Korean participants still evidence a positive discount rate.

We also performed a separate ROI analysis using brain voxels reported in previous studies. In particular, we analysed responses in the VStr (x, y, z MNI coordinates: [6, 8, -4]) and DLPFC ([44, 44, 16]) from McClure *et al.* [4]. Mean beta values were calculated within a sphere of radius 4 mm surrounding these locations and compared across cultural groups. We found no differences in these regions ($p = 0.48$ for VStr, $p = 0.69$ for DLPFC). The peak voxel in the VStr that we identified in the analysis above was lateral to the regions we identified in the study by McClure *et al.* [4]. We believe that the variation in the region of the VStr identified in these separate studies is inconsequential and results from imprecision in brain normalization.

4. DISCUSSION

In the midst of the recent financial crisis in the USA over raising the national debt ceiling, the Chinese government news agency Xinhua lambasted American financial policy. They called for the USA to show 'some sense of global responsibility' by curbing government spending for the sake of long-term financial stability. It is certainly a stretch to relate these events to our findings here on cultural differences in delay discounting. However, it stands to reason that consistent cultural differences in financial attitudes related to risk and time have the potential to scale up to conflicts that manifest in this manner.

A few previous studies have found differences in delay discounting between Westerners and Easterners. One behavioural study examined behavioural differences in a task very similar to ours [9]. They compared discount rates across American, Chinese and Japanese participants. Although they did not find different discounting rate between Chinese and Americans, Japanese discounted less sharply than the two other groups. One limitation of this study was that all students were currently enrolled as graduate students at an American university. It is reasonable to suspect that immersion in Western culture could have reduced the cultural differences between groups. Indeed, our observed discount rates showed a much bigger difference than those reported by Du *et al.* [9]. Of course, given the small sample sizes of both studies, it is impossible to arrive at a conclusion about the relative impact of cultural priming versus cultural background on the basis of these data. However, other studies have shown a substantial impact of cultural priming. Chen *et al.* [10] found that bi-cultural Singaporeans are more willing to pay for fast delivery service when primed with iconic pictures from America, compared with when Asian culture is primed. Also, participants primed with Western images express their impatience by mentioning the importance of immediate consumption of the purchased product. It would therefore be interesting to re-examine differences in discounting between Chinese and Americans in their native contexts, and to directly manipulate cultural context to determine the potential for eliminating culture-dependent time preferences.

The primary contribution of this study is the finding that cultural differences in intertemporal preferences

between Koreans and Americans are predicted by differences in neural responses in the VStr. Of course, behavioural differences must necessarily have corresponding effects somewhere in the brain (whether or not fMRI is satisfactory for identifying the source). The novelty of our findings is that we are able to localize differences in intertemporal preferences to the VStr, whereas previous research indicates other possible candidate neural systems that can produce the effect. The VStr has been associated with basic reward and motivational processes in previous work [4,24], so we can conclude that emotional responsivity is the cognitive process that underlies our observed cultural difference in discounting. By contrast, we found that activity in the DLPFC and PPC does not vary across our cultural groups. It therefore is unlikely that differences in executive functions such as self-control contribute to differences in behaviour [5,6].

The nature of the difference in VStr activity that predicted intertemporal preferences is surprising to us. We, and other investigators, have previously found a positive immediacy effect in Western subjects. We did not anticipate that this same contrast would be reversed in sign for Eastern subjects. It would be interesting to determine in future studies whether there are behavioural consequences to this discovery.

Given the nature of our findings, it is interesting to speculate about the relative possible roles of nature versus nurture in producing the profound differences in behaviour we observed. As indicated by the discussion above, from our perspective, temporal discounting appears to be largely related to attitudes and not to a basic biological consequence resulting from genetic makeup. Chen *et al.*'s [10] study of bi-cultural Singaporeans indicate that discount rates can vary substantially within people. Similarly, we have found that Korean Americans have much higher discount rates than do Koreans, despite identical genetic heritage [12]. Of course, this does not rule out the possibility that genetic factors play a role in sculpting intertemporal preferences. There are basic gross anatomical differences between Americans and Asians that should at least produce different potentials for behaviour [13]. Furthermore, there is a long history in psychology of thinking of discount rates as trait-like measures [25–27].

There is a rich history in psychology investigating cultural differences in attitudes about time. Cross-cultural psychology has focused on the difference between individualism and collectivism inherent in Eastern and Western societies [28]. Collectivist attitudes imply that behaviour reflects the needs of the collective to which one belongs, such as one's family or co-workers. Since collectivist cultures emphasize group preferences and group rules, people are likely to suppress personal preferences and maintain norms that devalue impulsive emotions. By contrast, people in individualist societies conceive of themselves as independent agents and are motivated by their own preferences to pursue personal goals [29]. We expect that adherence to collectivist versus individualist ideals may also be reflected in brain activity. Interestingly, these differences in social orientation have been shown to be associated with differences in striatal activity in Japanese versus American subjects [14].

Our findings contribute to a consistent finding that financial preferences involving time are dramatically different between Eastern and Western populations. We conclude based on neuroimaging data that this finding is rooted in emotional responses to immediately available outcomes. Whether this refined mechanistic understanding will be effective in shaping judgements about financial responsibility remains to be seen.

This work was supported in part by NIA grant R01 031310. We thank Wouter van den Bos for comments on the manuscript and Jisun Kim and Matt Samberg for help with data collection.

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