Cultural neuroeconomics of intertemporal choice

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Abstract

According to theories of cultural neuroscience, Westerners and Easterners may have distinct styles of cognition (e.g., different allocation of attention). Previous research has shown that Westerners and Easterners tend to utilize analytical and holistic cognitive styles, respectively. On the other hand, little is known regarding the cultural differences in neuroeconomic behavior. For instance, economic decisions may be affected by cultural differences in neurocomputational processing underlying attention; however, this area of neuroeconomics has been largely understudied. In the present paper, we attempt to bridge this gap by considering the links between the theory of cultural neuroscience and neuroeconomic theory of the role of attention in intertemporal choice. We predict that (i) Westerners are more impulsive and inconsistent in intertemporal choice in comparison to Easterners, and (ii) Westerners more steeply discount delayed monetary losses than Easterners. We examine these predictions by utilizing a novel temporal discounting model based on Tsallis' statistics (i.e. a *q*-exponential model). Our preliminary analysis of temporal discounting of gains and losses by Americans and Japanese confirmed the predictions from the cultural neuroeconomic theory. Future study directions, employing computational modeling via neural networks, are outlined and discussed.

Keywords: culture, neuroeconomics, attention, intertemporal choice, discounting

Intertemporal choice model based on Tsallis' statistics and psychophysics of time

Recently, behavioral neuroeconomic and econophysical studies established discount models in order to better describe neural and behavioral correlates of impulsivity and inconsistency in intertemporal choice. In order to analyze human and animal intertemporal choice behavior in a manner that would provide a dissociation between impulsivity and inconsistency, recent econophysical studies (Takahashi, Oono, Radford, 2007) proposed and examined the following q-exponential discount function for subjective value $V(D)$ of delayed reward:

$$V(D)=A/\exp_q(k_q D)=A/[1+(1-q)k_q D]^{1/(1-q)} \qquad \text{(Equation 1)}$$

where $\exp_q(x):=[1+(1-q)x]^{1/(1-q)}$ is a "q-exponential" function, D is a delay until receipt of a reward, A is the value of a reward at D=0, and k_q is a parameter of impulsivity at delay D=0 (q-exponential discount rate). We can easily see that this generalized q-exponential function approaches the usual exponential function in the limit of $q\rightarrow 1$. The q-exponential function has extensively been utilized in econophysics, where the application of Tsallis' non-extensive thermostatistics may possibly explain income distributions following power functions (Michael and Johnson 2003). It needs to be noted here that when q=0, the equation (1) becomes the same as the "hyperbolic" discount function (i.e., $V(D)=A/(1+k_q D)$), while in the limit of $q\rightarrow 1$, it reduces to the "exponential" discount function (i.e., $V(D)=A\exp(-k_q D)$). In exponential discounting (when $q\rightarrow 1$ in equation (1)), intertemporal choice is consistent, because the discount rate := $-(dV/dD)/V=k_q$ is time-independent when $q\rightarrow 1$. The q-exponential discount function is capable of continuously quantifying human subjects' inconsistency in intertemporal choice (Takahashi, Oono, Radford, 2007). Namely, human agents with smaller q values are more inconsistent in intertemporal choice. If q is less than 0, the intertemporal choice behavior is more inconsistent than hyperbolic discounting. Thus, $1-q$ can be utilized as an inconsistency parameter. Moreover, it is possible to examine neuropsychological modulation of k_q (impulsivity in temporal discounting) and q (dynamic consistency) in the q-exponential discount model. It is now important to note that in any continuous time-discounting functions, a discount rate (preference for sooner rewards over later ones) is defined as $-(dV(D)/dD)/V(D)$, independently of functional forms of discount models, with larger discount rates indicating more impulsive intertemporal choice.

In the q-exponential discount model, the discount rate ("impulsivity") is defined as:

$$(q\text{-exponential discount rate})=k_q/(1+k_q(1-q)D). \qquad \text{(Equation 2)}$$

We can see that when q=1, the discount rate is independent of delay D, corresponding to the exponential discount model (consistent intertemporal choice); while for q<1, the discount rate is a decreasing function of delay D, resulting in preference reversal over time. This can be seen by a direct calculation of the time-derivative of the q-exponential discount rate:

(d /dD)(q-exponential discount rate)= $-k_q^2(1-q)/(k_q(1-q)D+1)^2$ (Equation 3)

which is negative for $q<1$, indicating "decreasing impatience" for q smaller than 1. Also, impulsivity at delay $D=0$ is equal to k_q irrespective of q. Therefore, k_q and q can parameterize impulsivity and consistency, respectively, in a distinct manner.

Regarding the neuropsychological processing underlying the q-exponential discounting (i.e., inconsistent intertemporal choice), Takahashi (2005) proposed that exponential discounting with logarithmic time-perception, $\tau(D)=\alpha \log(1+\beta D)$, may explain dynamic inconsistency in intertemporal choice. If a subject tries to discount a delayed reward exponentially with the logarithmic time-perception (i.e., Weber-Fechner law in psychophysics), then $F(\tau)=\exp(-k\tau)=1/(1+\beta D)^{k\alpha}$, which has the q-exponential functional form. Intuitively, subjects try to discount exponentially (rationally and consistently), but actual intertemporal choice behavior may be hyperbolic and dynamically inconsistent, due to a distortion in time-perception. This may also explain subadditive discounting, because $\tau(D)$ is concave in delay D (i.e., the subjective delay length is larger when the delay is divided into shorter time-intervals than when the delay is perceived as a single time-interval)(Takahashi, 2006). Therefore, it can be expected that the non-linear psychophysical effects of temporal cognition on intertemporal choice may be reflected in the q parameter in the q-exponential discount function. However, to our knowledge, no study has yet examined how psychological factors, such as attention to a time-interval between sooner and later rewards, modulate intertemporal choice behavior by utilizing the q-exponential function, although a recent study reported attention effects on time modulated dynamic consistency in temporal discounting (Ebert & Prelec, 2007; Zauberman et al., 2008). In this study, we address how cultural differences in attention allocation (i.e., “analytic” versus “holistic” allocation) modulate intertemporal choice behavior between American and Japanese subjects.

Cultural neuroscience of attention and thought

In the recent years, cultural psychologists have begun to show that there are systematic cultural variations in human (neuro)psychological processes (Markus & Kitayama, 1991). These researchers assume that neuropsychological processes are by nature socially driven. According to their theories, the neuropsychological processes are shaped through their interaction with cultural, social and environmental factors. Based on this assumption, it has often been examined how particular cognitive processes (e.g., attention allocation) could be manifested in particular cultural contexts and how different cultural environments in turn lead to the development of different patterns of ability. These studies reported that East Asians’ patterns of attention were in general ‘context dependent’, whereas Westerner’s patterns of attention were “context independent”. According to these studies, Westerners are more likely to focus on some salient objects or contents (“analytic” attention), whereas East Asians are more likely to attend to the global context ("holistic" attention) of an object, and its broad spectrum of perceptual and conceptual fields, in addition to its local characteristics (e.g. Masuda & Nisbett, 2001; Kitayama, Duffy, Kawamura, Larsen, 2003; Chua , Boland, & Nisbett, 2005).

Attention and perception in neural valuation of delayed rewards

In neuroeconomic studies of the valuation of delayed rewards, it has been reported that (i) immediate rewards activates midbrain regions (McClure et al., 2004, 2007), (ii) subjective value of the delayed reward is encoded as the midbrain dopaminergic activities (Kable & Glimcher 2007). Regarding the role of temporal cognition in intertemporal choice, Whittmann and colleagues reported that the psychological time is represented in the striatum (Whittmann et al, 2007); while no neuroimaging study to date examined the neural correlates of attention allocation during intertemporal choice.

Recent behavioral economics studies (Ebert and Prelec, 2007; Zauberman et al., 2008) have demonstrated that modulation of attention to time perspectives (time-sensitivity) changes the human intertemporal choice behavior by shifting the functional form of the psychophysical time-perception from a logarithmic to a linear function. This is consistent with the psychophysical account of hyperbolic discounting (Takahashi, 2005; Takahashi 2006). Together, these studies suggest that control of attention allocation to time explains both hyperbolic and subadditive discounting. Specifically, (i) if a subject pays more attention to the delayed reward but less attention to the time-length of delay ("time-insensitivity"), her/his temporal discounting may be inconsistent due to non-linearly distorted time-perception (i.e., hyperbolic discounting), and (ii) if a subject focuses her/his attention on each temporal "segment" along the future time (i.e., "analytic" temporal cognition) rather than overviews the future time perspective as a whole (i.e., "holistic" temporal cognition), her/his temporal discounting may be exaggerated (i.e., subadditive discounting). In both cases, it can be predicted that narrower allocation of attention should be associated with more impulsive and inconsistent temporal discounting behavior.

Cultural differences in temporal discounting behavior

In order to examine the cultural differences in temporal discounting, we compared intertemporal choices for monetary gains and losses by American and Japanese subjects, by utilizing the q-exponential discount model based on Tsallis' statistics. For discounting behavioral data by Americans, we analyzed Estle et al's raw data obtained from students (N=27) at Washington University (Estle et al., 2006). Japanese subjects were students at the University of Tokyo and Hokkaido University (N=21). In order to avoid the magnitude effect on temporal discounting (i.e., small rewards are more rapidly discounted than large ones), we compared time-discounting behavior for $100 and ¥10,000 (about US$100) gains and losses between Americans and Japanese. Our experimental procedure was exactly the same as in our previous study (Takahashi, Ikeda, Hasegawa, 2007). In order to parameterize impulsivity and inconsistency in intertemporal choices, we employed k_q and q parameters in the q-exponential discount model (equation (1)).We fitted the q-exponential function to the behavioral data by utilizing a non-linear least square algorithm implemented in *R* statistical computing software (The R Project for Statistical Computing). Note that larger k_q and smaller q correspond to more impulsive and inconsistent temporal discounting. The results are summarized in *Table* 1. For both gains and losses, Americans discounted the delayed outcomes more steeply (larger k_q) and inconsistently (smaller $q<1$). The present observations are consistent with predictions from cultural neuroeconomic theory combining findings in behavioral neuroeconomics, cultural neuroscience, and social psychology.

Discussions and future directions

This study is the first to (i) propose cultural neuroeconomic theory of intertemporal choice based on cultural neuroscience theory of attention and neuroeconomics and (ii) demonstrate that Westerners discounted delayed outcomes more rapidly and inconsistently than Easterners. Our present findings are in line with (i) the reported role of attention allocation in neurocomputational processes involved in intertemporal choice and with (ii) the effects of attention allocation strategies (i.e., “analytic” versus “holistic”) on temporal discounting. Although a previous study examined cross-cultural differences in discounting behavior by American, Chinese, and Japanese students in the United States, the study did not analyze time-consistency and impulsivity separately (Wanjiang et al., 2002).

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	Gain		Loss	
	American	Japanese	American	Japanese
k_q (impulsivity)	0.021	0.0053	0.073	0.0
q(consistency)	0.520	0.78	0.82	0.99

Table 1 Impulsivity and inconsistency in temporal discounting for gain and loss
Americans (N=27, Estle et al., 2006) discounted delayed outcomes more steeply and inconsistently than Japanese (N=21).