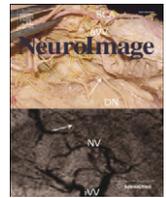




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How choice modifies preference: Neural correlates of choice justification

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ABSTRACT

When making a difficult choice, people often justify the choice by increasing their liking for the chosen object and decreasing their liking for the rejected object. To uncover the neural signatures of choice justification, we used functional magnetic resonance imaging to monitor neural activity when subjects rated their preference for chosen and rejected musical CDs before and after they made their choices. We observed that the trial-by-trial attitude change (i.e., increase of preference for chosen items and decrease of preference for rejected items) was predicted by post-choice activity in the ventral medial prefrontal cortex (MPFC), right temporal-parietal junction, anterior insula, and bilateral cerebellum. Furthermore, individual difference in choice justification (i.e., increased preference for chosen items minus decreased preference for rejected items) was predicted by post-choice neural activity in the dorsal MPFC, left lateral prefrontal cortex, and right precentral cortex positively. In addition, interdependent self-construal was correlated with decreased activity in the ventral MPFC in the post-choice than pre-choice sessions. These findings suggest that both negative arousal/regulation and self-reflection are associated with choice justification. This provides evidence for the self-threat theory of choice justification.

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Introduction

Cognitive dissonance has been investigated using a wide variety of methodologies (see [Harmon-Jones and Harmon-Jones, 2007](#) for a review). One of the most commonly used experimental paradigms involves a choice between two equally attractive objects ([Brehm, 1956](#)). Numerous behavioral studies have shown that, after making a difficult choice, people justify this choice by increasing their liking for the chosen item and decreasing their liking for the rejected item. The choice justification is believed to occur because people are motivated to reduce their cognitive conflict or dissonance ([Brehm, 1956](#); [Festinger, 1957](#)). Researchers have hypothesized that this choice-induced conflict, and the resulting dissonance reduction, may be most likely to occur when the conflict poses a threat to a person's private sense of the self as rational and competent ([Steele, 1988](#)), the sense of the self as publicly recognized as rational and decent ([Kitayama et al., 2004](#); [Tedeschi and Reiss, 1981](#)), or both.

Recent functional magnetic resonance imaging (fMRI) studies have provided some insight into the neural correlates of dissonance. In one study, [van Veen et al. \(2009\)](#) found that neural activity in the dorsal anterior cingulate cortex (dorsal ACC) and in the anterior insula

increased to statements that conflicted with subjective feelings. This suggests that detection of cognitive conflict (dorsal ACC) and aversive somatic arousal (anterior insula) constitute important elements of cognitive dissonance, as implied by [Festinger \(1957\)](#) in his original formulation. Indeed, as would be predicted by the dissonance theory, the dissonance as indexed by the activity in these brain regions during the choice predicted subsequent attitude change in the form of justifying the dissonance-producing behavior ([van Veen et al., 2009](#)).

In another study, [Jarcho et al. \(in press\)](#) found that choice justification is reliably predicted by increased activations in the right inferior frontal gyrus and medial frontoparietal regions during the choice. The finding suggests that choice justification is mediated by regulation of negative arousal through inhibition of both competing information (right inferior frontal gyrus) and conscious attention (frontoparietal regions) to the chosen and rejected items. This study, however, scanned the brain only during the choice. Therefore, it is not clear whether and how representations of the chosen and rejected items might change as a consequence of choice.

A more recent study ([Sharot et al., 2009](#)) addressed this issue by testing choices among hypothetical vacation destinations. It was found that the attitude change involved in dissonance was mirrored by caudate activations in relation to the chosen and rejected items after the choice. However, this finding might not be applicable to difficult decisions involving objects one may actually be able to actually possess. Given this, much has yet to be learned about the neural mechanisms underlying *post-decisional* choice justification or dissonance reduction.

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To fill the gap of empirical knowledge on neural mechanisms underlying cognitive dissonance, we used a modified free-choice paradigm and scanned healthy young Chinese adults as they rated a set of CDs both before and after making a series of choices between these CDs. During the choice, the CDs were paired in such a way that the two CDs in each pair were equally attractive, as previous work shows that dissonance arises only when choices are difficult (Brehm, 1956; Sharot et al., 2009; Jarcho et al., in press). Moreover, in order to increase choice justification during the post-choice sessions, subjects were reminded which choice they had made earlier. We had two primary aims.

First, we aimed to investigate the brain regions recruited when subjects justified their choices. Previous research has found that choice justification is eliminated when one's sense of the self is affirmed after making a difficult choice (Hoshino-Browne et al., 2005; Steele, 1988). This supports the proposal that individuals justify their choice in order to eliminate a threat to the self. On the basis of this literature, we predicted that self-related brain areas such as the ventral MPFC (Kelley et al., 2002) and the dorsal/ventral lateral prefrontal cortex (Liberman, 2010) would be engaged in *post-decisional* choice justification. Furthermore, because the public sense of the self involves taking the perspectives of others (Imada and Kitayama, 2010; Kitayama et al., 2004), we anticipated that brain areas implicated in mind reading such as temporal-parietal junction (TPJ, e.g., Saxe and Kanwisher, 2003) and dorsal MPFC (e.g., Gallagher et al., 2000) might also be related to choice justification. In addition, since individuals justify their choices by inhibiting choice-inconsistent information while augmenting choice-consistent information (Jarcho et al., in press), we predicted that the brain areas implicated in regulation, such as the dorsal MPFC (Venkatraman et al., 2010), the dorsal LPFC (Ochsner and Gross, 2008), and the inferior frontal gyrus (Jarcho et al., in press), would also be involved.

Second, we aimed to examine whether, similar to the Sharot et al. (2009) study, choice justification might be tracked by neural activity that is related to subjectively experienced preferences. We expected that neural activities reflecting subjects' preferences, such as caudate (Sharot et al., 2009), ventral MPFC (McClure et al., 2004), and/or PCC (Kawabata and Zeki, 2008), would be altered by choice justification. In addition, given cultural differences in cognitive dissonance (Hoshino-Browne et al., 2005; Imada and Kitayama, 2010) and considerable variation within cultures in the extent to which they endorse their cultural norms, we assessed the relationship between change in the neural signatures related to subjects' preference and individual differences in independent self-construals (i.e., the view the self as an autonomous entity separate from others) and interdependent self-construals (i.e., the view of the self as interconnected with others as well as the social contexts; Markus and Kitayama, 1991).

Materials and methods

Subjects

Sixteen undergraduate and graduate students from Peking University, China (5 males, 11 females; 19–26 years of age, mean 22.3 ± 1.91 , values are given as mean \pm SD throughout), participated in this study as paid volunteers. All subjects were right-handed, had normal or corrected-to-normal vision, and had no neurological or psychiatric history. Informed consent was obtained prior to scanning. This study was approved by a local ethics committee.

Stimuli

Stimuli consisted of 60 popular music CDs, including 48 Chinese CDs and 12 European/American CDs. The artists of the CDs were known to college students. The cover of each CD was scanned and saved as a .jpg file.

Pre-scanning procedure

Subjects were asked to rank 60 CDs according to their degree of liking by categorizing the CDs into 10 boxes with 6 CDs in each box. The ten boxes were marked with numbers from 1 to 10 (1 = slightly like the CD, 10 = extremely like the CD).

fMRI Scanning sessions and "free-choice" session

After the pre-scanning CD categorization task, subjects were scanned to get anatomical structures. This was followed by eight functional scanning sessions and intervened by a "free-choice" session.

Pre-choice session

The pre-choice session consisted of four event-related functional scanning sessions. On each trial, subjects were presented with a picture of a CD cover. They were then asked to either indicate "How much do you like the CD?" (preference judgment task) or "How new is the CD?" (recency judgment task) on a 4-point scale (1 = slightly like/slightly new; 2 = somewhat like/somewhat new; 3 = like/new; 4 = extremely like/extremely new). Subjects responded to each stimulus by pressing one of the four buttons as accurately and quickly as possible using the index and middle fingers of their left and right hands. Thirty preference judgments and 15 recency judgments were conducted in a random order in each scanning session.

Each trial started with the presentation of an instruction for 1000 ms, which defined the task (i.e., preference or recency judgments). Then the cover of a CD was presented for 3000 ms followed by an inter-stimulus interval that varied randomly among 1500, 2000, 2500 ms. Sixty CDs were used for the preference judgment task and, of those, 30 CDs were randomly selected for the recency judgment task. In order to collect enough data, these tasks consisted of two functional scanning sessions and were repeated once in an additional two scanning sessions.

Free choice

After the pre-choice session, subjects engaged in 30 free-choice trials. On each trial, two CD covers were presented on either side of the screen (i.e., right or left). Each CD was shown only once. Subjects were instructed to indicate which CD they wanted more by pressing one of the two buttons using the left or the right index finger. Prior to this, subjects were informed that one CD would be randomly selected from the CDs they chose and given to them as a token of appreciation for their participation at the end of the study. CDs pairs were determined by each subject's ranking of the CDs during the pre-scanning categorization task. That is, each pair was randomly selected from one of the 10 boxes so that each pair was equal in liking. Choices made during the free-choice session were used to classify the 60 CDs into the chosen and rejected items in the post-choice sessions.

Post-choice session

The post-choice session also consisted of four functional scanning sessions. All aspects of the post-choice session were identical to those in the pre-choice session except that each CD was shown with a color frame (i.e., red = chosen; green = rejected; gray = used in the recency judgment task) to indicate the status of the CD.

Post-scanning procedure

After the scanning procedure, each subject was asked to rate his/her independent/interdependent self-construal (Singelis, 1994) on a 7-point Likert-type scale (1 = strongly disagree to 7 = strongly agree).

203 *fMRI Data acquisition*

204 Scanning was performed at Peking University First Hospital on a
 205 GE 3-T scanner with a standard head coil. Thirty-two transverse slices
 206 of functional images covering the whole brain were acquired using a
 207 gradient-echo echo-planar pulse sequence ($64 \times 64 \times 32$ matrix with a
 208 spatial resolution of $3.75 \times 3.75 \times 4$ mm, repetition time = 2000 ms,
 209 echo time = 30 ms, FOV = 24×24 cm, flip angle = 90°). Anatomical
 210 images were obtained using a 3D FSPGR T1 sequence ($256 \times 256 \times 128$
 211 matrix with a spatial resolution of $0.938 \times 0.938 \times 1.4$ mm,
 212 TR = 7.4 ms, TI = 450 ms, TE = 3.0 ms, flip angle = 20°). Subjects'
 213 heads were immobilized during the scanning sessions using pieces
 214 of foam. Stimuli were presented via a mirror mounted on the head
 215 coil.

216 *Data analysis*

217 The mean rating scores of the preference judgments were calculated
 218 during the pre-choice and post-choice sessions were calculated for
 219 chosen and rejected CDs. The results were then submitted to a 2 (Choice:
 220 chosen/rejected) \times 2 (Session: pre-choice/post-choice) repeated mea-
 221 sures analysis of variances (ANOVA).

222 SPM2 (Wellcome Department of Cognitive Neurology, London,
 223 UK) was used for the imaging data analysis. The time-series for the
 224 voxels within each slice were realigned temporally to the acquisition
 225 of the middle slice. The functional images were realigned to the first
 226 scan to correct for the head movement between scans, and the
 227 anatomical image was co-registered with the mean functional image
 228 produced during the process of realignment. All images were
 229 normalized to a $2 \times 2 \times 2$ mm Montreal Neurological Institute (MNI)
 230 template using bilinear interpolation. Functional images were
 231 spatially smoothed using a Gaussian filter with a full-width at half
 232 maximum (FWHM) parameter set to 8 mm.

233 We first conducted whole-brain exploratory analysis. The image
 234 data were modeled using a canonical hemodynamic response
 235 function (HRF) and a general linear model (GLM). The time
 236 derivatives and the head motion parameters were included to account
 237 for extra variance of onset and residual movements (the three rigid-
 238 body translations and rotations determined from the realignment
 239 stage). All data were globally normalized with proportional scaling of
 240 the image means. High-pass filtering was used with a cutoff of 128 s.
 241 Effects at each voxel were estimated, and regionally specific effects
 242 were compared using linear contrasts.

243 There were six types of trials in our experiment. There were four
 244 types of preference judgment trials, each classified according to the
 245 subjects' choices during the "free-choice" session: (1) preference
 246 judgments for chosen CDs during pre-choice session, (2) preference
 247 judgments for rejected CDs during pre-choice session, (3) preference
 248 judgments for chosen CDs during post-choice session, and (4)
 249 preference judgments for rejected CDs during post-choice session.
 250 There were also two types of recency judgment trials: (1) recency
 251 judgment during pre-choice session and (2) recency judgment during
 252 post-choice session. We contrasted and reversely contrasted blood
 253 oxygenation level-dependent (BOLD) signal of the preference judgment
 254 trials for the chosen CDs with those for the rejected CDs, and BOLD
 255 signal of preference judgment trials of chosen/rejected CDs with recency
 256 judgment trials, during both pre-choice and post-choice sessions. Areas
 257 of significant activation were identified using threshold of $p < 0.001$
 258 (uncorrected) and a spatial extent threshold of $k = 100$.

259 Conjunction analysis implemented in SPM2 (ANOVA with inclusive
 260 masking) was used to determine areas of activation common to
 261 preference judgment of chosen CDs during pre-choice and post-choice
 262 sessions, areas of activation common to preference judgment of rejected
 263 CDs during pre-choice and post-choice sessions, areas of activation
 264 common to preference judgment of chosen and rejected CDs in pre-
 265 choice session, and areas of activation common to preference judgment

of chosen and rejected CDs in the post-choice session. All inclusive
 266 masking analyses used an uncorrected p value of 0.05 for their choice.

267 To examine brain areas linked with attitude change during choice
 268 justification, we first conducted parametric modulation analysis using
 269 an independent GLM model for post-choice session that used change
 270 in the preference rating score for each trial as the regressor. Then we
 271 constructed a simple regression analysis. Parametric maps contrasting
 272 preference judgment of chosen CDs vs. that of rejected CDs during
 273 post-choice session were taken as the dependent variables for each
 274 subject, and the corresponding attitude change scores (the absolute
 275 amount of preference increase for chosen items plus the absolute
 276 amount of preference decrease for rejected items) served as
 277 covariates. The resulting maps were identified using a threshold of
 278 $p < 0.001$ (uncorrected) and a spatial extent threshold of $k = 100$.

279 To assess the relationship between change of neural activities
 280 (post-choice session minus pre-choice session) in the brain areas that
 281 are likely to reflect subjects' preferences (i.e., ventral mPFC, PCC, and
 282 caudate) and individual differences in attitude change and self-
 283 construal, we also conducted another parametric modulation analysis
 284 for pre-choice and post-choice session respectively using participants'
 285 rating score on each preference judgment trial as the regressor.
 286 Conjunction analysis (ANOVA with inclusive masking) was used to
 287 identify the areas of activation generally related to subject's
 288 preference. A relatively stringent threshold, cluster level $p < 0.05$
 289 (corrected), was used because this analysis included 120 trials.
 290 We then calculated correlations between change of activities in the brain
 291 areas reflecting subjects' preferences and their attitude change. A
 292 similar analysis was conducted on the brain areas that were shown to
 293 be linked to subjects' preference in previous studies, the vmPFC
 294 ($x = 8/y = 56/z = 0$), which is associated with behavioral preference
 295 (McClure et al., 2004), and the caudate ($x = 10/y = 22/z = 0$), which is
 296 linked to hedonic rating scores (Sharot et al., 2009). Similar to the
 297 previous studies, region of interests (ROIs) were defined as spheres
 298 with 5-mm radius. Parameter estimates of signal intensity in the ROIs
 299 were calculated using MarsBaR 0.38 (<http://marsbar.sourceforge.net>).
 300

301 **Results**302 *Behavioral results*

303 ANOVAs on the preference rating scores showed a significant main
 304 effect of choice ($F(15,1) = 97.93$; $p < 0.001$) with subjects showing
 305 greater preference for the chosen CDs than for the rejected CDs
 306 (Fig. 1). There was a significant interaction of choice (chosen vs.
 307 rejected) and session (pre-choice vs. post-choice) ($F(15,1) = 74.04$,

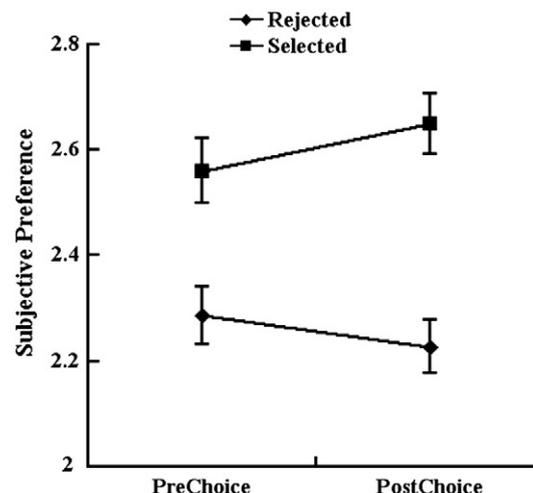


Fig. 1. Mean subjective preference ratings for chosen and rejected CDs during pre-choice and post-choice sessions. Error bars indicate standard error of the mean.

308 $p < 0.001$), suggesting that the preference for chosen over rejected CDs
 309 was larger during the post-choice than pre-choice sessions. Post hoc
 310 analysis confirmed that the rating scores for chosen CDs were higher
 311 in the post-choice than pre-choice sessions ($t(15) = 2.93, p < 0.05$),
 312 whereas rating scores for rejected CDs did not differ significantly
 313 between the post-choice than pre-choice sessions ($t(15) = 2.03,$
 314 $p = 0.06$).

315 fMRI Results

316 To identify neural activities associated with post-choice attitude
 317 change, we calculated the change in preference rating by subtracting
 318 the rating score of each CD in the pre-choice sessions from the rating
 319 score of the same CD in the post-choice sessions. We then conducted
 320 parametric modulation analysis during post-choice session using the
 321 change in preference rating as a regressor. We found that attitude
 322 change was associated with activations in the ventral MPFC ($x = -12/$
 323 $y = 54/z = 0, Z = 3.53$; cluster size = 165 voxel), right temporal-
 324 parietal junction (TPJ) ($x = 48/y = -60/z = 12, Z = 3.02$; cluster
 325 size = 205 voxel), anterior insula ($x = 42/y = -2/z = 6, Z = 3.05$;
 326 cluster size = 66 voxel), and bilateral cerebellum ($x = 28/y = -64/$
 327 $z = -30, Z = 3.42$; cluster size = 131 voxel; $x = -38/y = -66/z =$
 328 $-30, Z = 3.12$; cluster size = 121 voxel) (Fig. 2a).

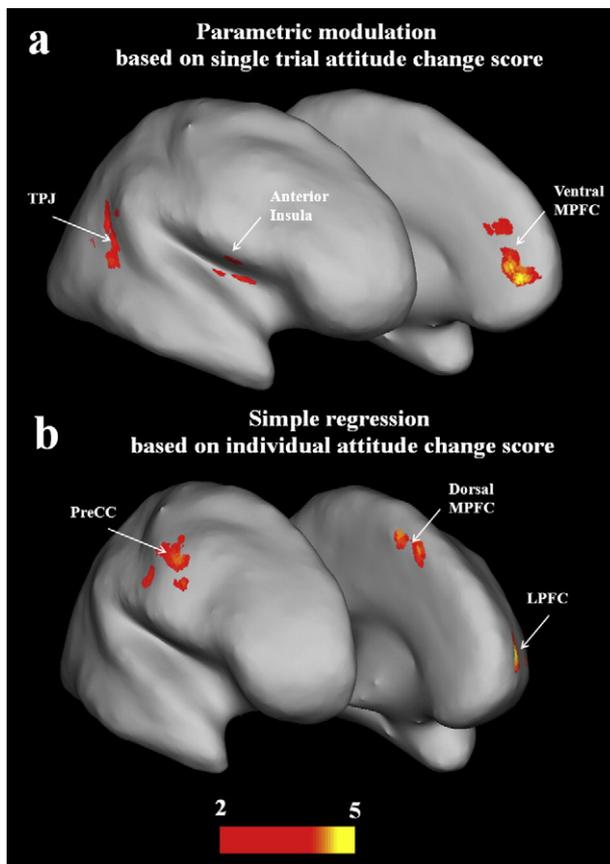
329 We also conducted a regression analysis using the individual
 330 attitude change score (increase of preference for the chosen items
 331 minus decrease of preference for the rejected items) as the regressor.
 332 We found that activities in left LPFC ($x = -24/y = 56/z = 8, Z = 3.73$;
 333 cluster size = 133 voxel), dorsal MPFC ($x = -4/y = 14/z = 54,$
 334 $Z = 3.23$; cluster size = 111 voxel), and right precentral cortex

($x = 54/y = -8/z = 44, Z = 3.09$; cluster size = 212 voxel) positively
 335 correlated with subjects' attitude change scores (Fig. 2b).

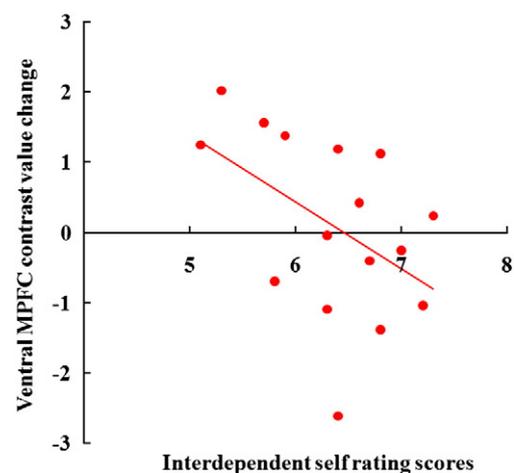
336 Similar to the previous research (Sharot et al., 2009), we assessed
 337 whether neural activities can predict individual differences in
 338 preference. To do this, we identified preference related neural activity
 339 by conducting parametric modulation analysis for pre-choice and
 340 post-choice sessions, respectively, using participants' rating score of
 341 each preference judgment trial as the covariate. We found significant
 342 positive correlations between BOLD signal and subjects' preference in
 343 the PCC ($x = -2/y = -56/z = 22, Z = 3.95$; cluster size = 1240 voxel)
 344 and right cerebellum ($x = -46/y = -26/z = 48, Z = 5.50$; cluster
 345 size = 1137 voxel) in pre-choice sessions. The same analysis
 346 performed on the post-choice sessions showed significant positive
 347 correlations between BOLD signal and subjects' preference in the
 348 precuneus/PCC ($x = 24/y = -54/z = -34, Z = 4.97$; cluster size =
 349 2568 voxel) and ventral MPFC ($x = 2/y = 64/z = -2, Z = 4.07$; cluster
 350 size = 919 voxel). The conjunction analysis of the data in pre-choice
 351 and post-choice sessions identified the PCC ($x = 4/y = -62/z = 12,$
 352 $Z = 4.48$; cluster size = 1039 voxel) as the common brain areas related
 353 to subject's preference.
 354

355 We also examined whether changes in PCC activity between post-
 356 choice and pre-choice sessions could predict subjects' attitude change.
 357 We also carried out comparable analyses to see if changes in neural
 358 activities might be related to self-construals. These analyses, however,
 359 failed to show any significant correlations between changes in brain
 360 activities and attitude change. We then conducted similar correlation
 361 analysis on two additional ROIs that have been associated with
 362 behavioral preference (ventral MPFC, $x = 8/y = 56/z = 0,$ McClure
 363 et al., 2004) and hedonic rating scores (caudate, $x = 10/y = 22/z = 0,$
 364 Sharot et al., 2009) in previous studies. Interestingly, we found that
 365 changes in the ventral MPFC activity between post-choice and pre-
 366 choice sessions were negatively correlated with interdependent self-
 367 construal ($r = -0.569, p = 0.027$ for 15 subjects without an outlier
 368 subject; $r = -0.480, p = 0.060$ for all 16 subjects, Fig. 3).

369 To assess which brain regions were involved in subjects'
 370 preference for the chosen and rejected CDs, we contrasted the neural
 371 activity linked to preference judgment for chosen CDs versus rejected
 372 CDs. These revealed activations in the PCC/precuneus and middle
 373 cingulate cortex (Table 1: Pre-choice). The reverse contrast showed
 374 activations in the right postcentral/paracentral cortex, left paracentral
 375 cortex/precuneus, left superior temporal cortex, and right insula.
 376 Similar results were found for the same contrasts during post-choice
 377 session (Table 1: Post-choice). The conjunction analysis for the pre-
 378 choice and post-choice sessions identified that the PCC/precuneus



379 **Fig. 2.** (a) Parametric analysis revealed neural activities related to subjects' attitude
 380 change. (b) Simple regression analysis revealed neural activities positively correlated
 381 with individual attitude change score. Ventral MPFC = ventral medial prefrontal cortex;
 382 TPJ = temporal-parietal junction; dorsal LPFC = dorsal lateral prefrontal cortex; dorsal
 383 MPFC = dorsal medial prefrontal cortex; PreCC = precentral cortex.



384 **Fig. 3.** Correlation between ventral MPFC activation level (contrast values) change and
 385 rating scores on interdependent self-construal. Each subject's mean rating score and
 386 parameter estimates value is indicated by a single square, the line represents the linear
 387 best fit.

t1.1 **Table 1**
t1.2 Brain activities differentiating preference judgment of chosen CDs and that of rejected CDs during pre-choice and post-choice sessions.

t1.3	Brain region	X	Y	Z	Z value	Voxel no.
t1.4	Pre-choice					
t1.5	Preference_{Chosen} > Preference_{Rejected}					
t1.6	Posterior cingulate cortex/precuneus	0	-64	28	3.89	455
t1.7	Middle cingulate cortex	2	-62	18	3.48	
t1.8	Preference_{Rejected} > Preference_{Chosen}					
t1.9	Postcentral/paracentral cortex (R)	30	-40	60	5.04	7356
t1.10		20	-44	60	4.59	
t1.11	Paracentral cortex/precuneus (L)	-8	-44	60	3.45	327
t1.12		-10	-44	48	3.39	
t1.13	Superior temporal cortex (L)	-46	-32	4	3.20	290
t1.14	Insula (R)	32	-28	10	3.00	183
t1.15	Post-choice					
t1.16	Preference_{Chosen} > Preference_{Rejected}					
t1.17	Cuneus/precuneus	-2	-70	30	3.50	538
t1.18		6	-60	48	3.23	
t1.19	Preference_{Rejected} > Preference_{Chosen}					
t1.20	Insula (R)	40	-20	8	3.77	1158
t1.21	Postcentral cortex (R)	44	-28	56	3.46	380
t1.22	Conjunction					
t1.23	Preference_{Chosen} > Preference_{Rejected}					
t1.24	Posterior cingulate/precuneus	0	-68	32	3.95	429
t1.25		6	-54	28	3.34	
t1.26	Preference_{Rejected} > Preference_{Chosen}					
t1.27	Insula (R)	40	2	4	3.86	725
	Postcentral cortex (R)	44	-28	56	3.76	1115

t1.27 R: right hemisphere; L: left hemisphere. Voxels survived an uncorrected p value of 0.005, cluster size > 100, $p < 0.001$ uncorrected.

379 activity was linked to preference judgment for the chosen CDs,
380 whereas the right insula and postcentral cortex were associated with
381 preference judgment for the rejected CDs (Fig. 4a; Table 1: Conjunction)
382 (Fig. 4a; Table 1: Conjunction). The neural activity linked to preference judgments was assessed

by contrasting preference and recency judgment tasks. These revealed
activations in the precuneus as well as the right PCC in the pre-choice
session and in the ventral MPFC in the post-choice session (Fig. 4b;
Table 1: Conjunction).

Discussion

Neural mechanisms of choice justification

Our behavioral measurements showed, consistent with the
previous studies (Brehm, 1956; Kitayama et al., 2004), that after
making choices between two similarly likable CDs, subjects increased
their liking for chosen CDs and tended to decrease their liking for
rejected CDs. The increase of liking for chosen CDs was highly
significant, but the decrease of liking for rejected CDs was rather weak
possibly due to a simple floor effect on rejected CDs. Given the data
reported by Shultz et al. (1999), who found that choice justification is
realized by boosting the preference of chosen items when the relevant
items are relatively unattractive, the present finding might mean that
the CDs we used were not highly attractive for the subjects we tested.

Our fMRI results uncovered neural activities associated with the
trial-by-trial attitude change in the ventral MPFC, right TPJ, anterior
insula, and bilateral cerebellum. The ventral MPFC was activated in
studies involving self-reference processing (Kelley et al., 2002; Han
et al., 2008; Zhu et al., 2007), whereas the right TPJ is commonly
recruited when perspective taking is required during mental
attribution (Frith and Frith, 2006; Decety and Lamm, 2007; Carrington
and Bailey, 2009). Thus our fMRI results suggest that self-reflection
resulting from taking others' perspectives (i.e., an appraisal of the
public self) was possibly involved during choice justification in our
Chinese subjects. This evidence converges with recent behavioral data
that participants from Asian cultural groups tend to show a choice
justification effect when the self is experienced as "being seen" by
others (Imada and Kitayama, 2010; Kitayama et al., 2004). In line with
the previous fMRI studies (van Veen et al., 2009; Jarcho et al., in
press), we also found anterior insula activation in association with
choice justification, suggesting that negative somatic arousal might be
generated when individuals justify their choices.

In addition, we found that activations in the dorsal MPFC, left LPFC,
and right precentral cortex positively correlated with each subject's
overall attitude change score. These findings are consistent with the

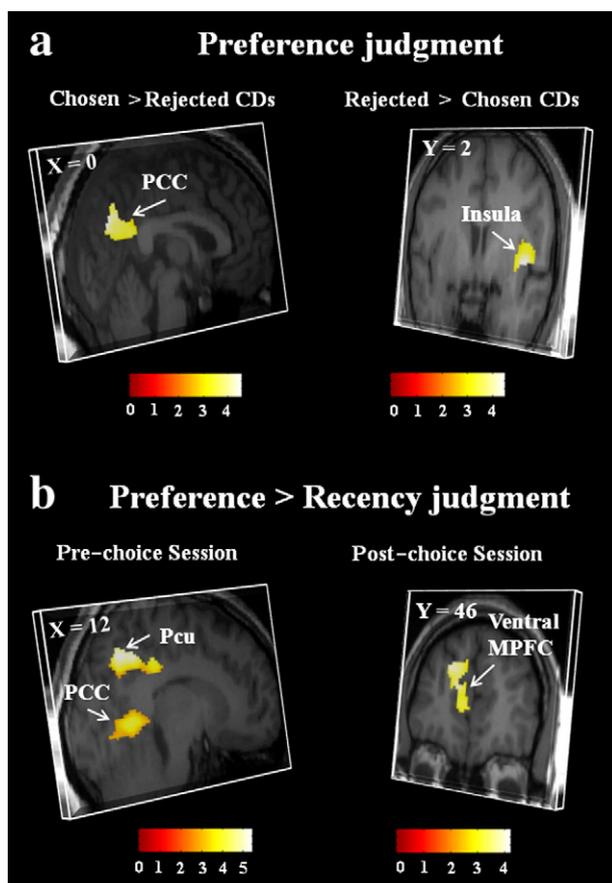


Fig. 4. (a) Brain activities differentiating preference judgment of chosen CDs and preference judgment of rejected CDs. (b) Brain activities linked to preference judgment during pre-choice and post-choice sessions. PCC = posterior cingulate cortex; Pcu = Precuneus; MPFC = medial prefrontal cortex.

hypothesis that choice justification may require regulation processes that are mediated by the dorsal MPFC and left LPFC (Venkatraman et al., 2010; Ochsner and Gross, 2008). However, the activations in the dorsal MPFC, left LPFC, and right precentral cortex did not overlap with regions that correlated with the trial-by-trial attitude change score. It is possible that there is a relatively stable individual difference in the degree to which the self-regulatory processes are engaged across all trials throughout the entire experimental session. The overall degree of choice justification may be expected to be greater for those who engage self-regulatory processes to justify their choices than those who do not. At the same time, however, across the 30 choices, people may engage their self-appraisals (vMPFC) mediated by perspective taking (TPJ) to varying extent. They may do so more on some trials than on some other trials. This may be expected to result in a trial-by-trial variation in choice justification. The two processes (i.e., self-regulation that varies across individuals and self-referential processing that varies within each individual) are distinct and, yet, we suspect within the specific experimental setting of the present study that they result in the same behavioral outcome of choice justification.

During the post-choice rating session of the present study, subjects were given an explicit marker of whether they had chosen or rejected each CD. This procedure might have resulted in top-down modulation of preference related brain response (de Araujo et al., 2005; Plassmann et al., 2008; Kirk et al., 2009). However, the brain areas that were associated with attitude changes in the present study included left LPFC (−24, 56, 8), dorsal MPFC (−4, 14, 54), and right precentral cortex (54, −8, 44). These brain regions are different from those involved in the top-down modulation of preference responses. For example, Kirk et al. (2009) found that neural activity in the right medial orbitofrontal cortex (12, 48, −20) and the ventral medial prefrontal cortex (−10, 60, 2) correlated with aesthetic ratings. Accordingly, it is unlikely that the present results were influenced by the top-down modulation of preference responses (Table 2).

Neural markers of preferences

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Parametric modulation analysis showed that PCC activity was positively correlated with subjects' preference. Consistent with this, the previous studies have shown that activation in the PCC is positively correlated with the perceive desirability of objects (Kawabata and Zeki, 2008) or the subjective value of delayed monetary rewards (Kable and Glimcher, 2007). Because the PCC is also implicated in self-referential processing and autobiographic memory (Rameson et al., 2010; Sajonz et al., 2010), this brain region might play a significant role in indexing preferences that are grounded in the personal self.

It is important to note, however, that the PCC activation did not relate to the choice justification effect in our study. This might indicate that there are multiple neural bases for expressed preferences. The choice justification effect we observed might be based on preferences that are tied to appraisals of the public self (vMPFC and TPJ). Both the public self (vMPFC and TPJ) and the personal self (PCC) could inform expressed preferences.

Neural activations that predicted choices

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Because PCC activation is related to personal preferences and, moreover, personally preferred CDs are more likely to be chosen than personally less preferred CDs, it should not come as any surprise that activation in the PCC/precuneus was linked to preference judgment of chosen CDs. Moreover, previous studies have linked anterior insula to negative somatic arousal. It would therefore seem reasonable that activations in the right insula were associated with preference judgment of rejected CDs during post-choice session. Importantly, however, these brain activations were observed during the pre-choice scanning session, meaning that in our studies, the PCC activity predicted selection of CDs and the anterior insula activity predicted rejection of CDs during the subsequent choice session.

Table 2
Brain activities linked to preference judgment during pre-choice and post-choice sessions.

Brain region	X	Y	Z	Z value	Voxel no.
Pre-choice					
Preference_{Chosen} > Recency					
Middle cingulate cortex/precuneus	4	−66	12	4.42	3244
	0	4	36	4.12	
Posterior cingulate (R)	6	−38	22	4.03	160
Preference_{Rejected} > Recency					
Precuneus/paracentral cortex	10	−52	48	4.19	5214
	−12	−40	58	3.87	
Lingual cortex/posterior cingulate (R)	12	−70	0	4.23	3048
	8	−40	8	4.18	
Temporal/fusiform cortex (R)	38	−48	−4	4.27	434
	46	−34	−20	3.35	
Superior temporal cortex/insula (L)	−42	4	−8	4.16	245
Insula/precentral cortex (R)	44	−2	4	3.25	187
Conjunction					
Precuneus	12	−60	48	4.49	2335
Posterior cingulate (R)	10	−60	4	3.70	1587
Post-choice					
Preference_{Chosen} > Recency					
Medial prefrontal/anterior cingulate cortex	6	54	0	3.96	5944
	−6	48	2	3.83	
	−4	36	12	3.23	
Precuneus/posterior cingulate (R)	2	−66	34	3.73	406
	10	−64	14	2.92	
Middle cingulate cortex	0	−36	12	4.42	163
Preference_{Rejected} > Recency					
Medial prefrontal cortex	−14	60	4	4.24	831
	8	58	6	3.91	
	20	58	6	3.82	
Superior temporal cortex (R)	52	−58	14	3.16	189
Precuneus (R)	6	−66	28	3.47	137
Conjunction					
Medial prefrontal cortex	−14	58	2	3.71	488

R: right hemisphere; L: left hemisphere. Voxels survived an uncorrected p value of 0.005, cluster size > 100, $p < 0.001$ uncorrected.

One previous study (Sharot et al., 2009) found a similar effect, but the brain area that was implicated was very different. In this study, activity in the caudate nucleus predicted subsequent choices. Whereas our study tested incentive compatible choices of pop music CDs, Sharot et al. tested choices among various hypothetical vacation sites. Moreover, whereas our study tested Chinese subjects, Sharot et al. tested British subjects. These factors might prove to be important in explaining the different pattern of results.

Conclusion

While the phenomenon of cognitive dissonance was discovered five decades ago and different theories have been proposed to interpret this phenomenon (see Harmon-Jones and Harmon-Jones, 2007 for a review), the underlying neural mechanisms remain undefined. Our fMRI study suggests that self-reflection (the ventral MPFC) that is mediated by perspective taking (TPJ) is crucially involved in choice justification. This finding goes along with the existing behavioral data that suggest the significance of a threat to the public self in mediating choice justification in Asian, interdependent cultural contexts. As the current work tested only Chinese subjects and found a correlation between the variation of the ventral MPFC activity and subjective ratings of interdependent self-construals, future work should expand the current work to Western, more independent cultural contexts.

Uncited references

- Heine and Lehman, 1997
 Kitayama and Imada, 2010
 Lebreton et al., 2009
 Zeki and Romaya, 2008

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