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Neuroanatomical substrates accounting for the effect of present hedonistic time perspective on risk preference: the mediating role of ~~the~~ right posterior parietal cortex

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Abstract

~~A~~The preference for taking risk troubles people across multiple domains including health, economics, and social well-being. Prior research has demonstrated that risk preference can be influenced by time perspective (TP). However, little is known about the neural substrates underlying the effect of TP on risk preference. Here, we used a voxel-based morphometry (VBM) method across two samples to address this question. In Sample 1, the behavioral results showed a positive correlation between present hedonistic TP (PHTP) and gambling rate (the index of risk preference), indicating the higher PHTP, the greater the preference for risk. Subsequently, the whole-brain VBM results found that gambling rate was negatively correlated with the gray matter (GM) volume of a cluster in the right posterior parietal cortex (rPPC). The PHTP score was also negatively related to the GM volume of another cluster in the rPPC. We then examined an overlapping region in the rPPC using a conjunction analysis method. The GM volume of this overlapping brain region was related to both PHTP score and gambling rate. Finally, the mediation analysis found that the GM volume of overlapping region in rPPC played a role in explaining the effect of PHTP on risk preference. This result was also reproduced and validated in another independent sample. Taken together, our findings manifest that the structural variation of rPPC can account for the influence that PHTP has upon the risk preference.

Keywords

Time perspective
Risk preference
Right posterior parietal cortex
Voxel-based morphometry

Ting Xu and Zhiyi Chen contributed equally to this work.

Introduction

Although some people consistently undertake risky activities, others avoid risk across a wide variety of situations. The stable risk proneness of former individuals in phenomenon mentioned-above actually depicts risk preference. As a vital hallmark of risky behaviors, risk preference describes individuals' favoritism for alternatives with a potential probability of winning (Weber and Milliman 1997). This attitude of preferring risk generally relies on the consideration one puts on the immediate consequences or future implications of current behaviors (Fromme et al. 1997). Therefore, individuals' beliefs to different temporal frames (i.e., time perspective [TP]) can have associations with risk preference. Supporting this view, ample studies have confirmed that some TPs can affect the preference for risky behaviors, such as gambling, risky driving, drug use and unsafe sex (Hodgins and Engel 2002; Keough et al. 1999; MacKillop et al. 2006; Rothspan and Read 1996; Zimbardo et al. 1997). However, less is concern about the neural substrates underlying the effect of TP on risk preference.

TP, as defined by Zimbardo and Boyd (1999), is the non-conscious process reflecting how the flow of experiences are attributed to different temporal frames (Zimbardo and Boyd 1999). Such automatic process can over time become stable individual differences that can be quantified across three temporal frames (past, present, and future) comprised of five dimensions, including Past-Negative, Past-Positive, Present-Fatalistic, Present-Hedonistic, and Future TPs (Zimbardo and Boyd 2008). Prior research has underscored that TP can remain an independent predictor of risk preference, and have further made inferences about why this happens. For instance, it has been reported that those scoring high on future TP exhibit less preference towards risky behaviors, such as risking health to engage in smoking and excessive alcohol use (Adams and Nettle 2009; Beenstock et al. 2010; Sekścińska et al. 2018). The reason for this is that cohorts with assessed high future TP follow high self-control, thus they have a low desire for seeking risk (MacKillop et al. 2006; Zimbardo and Boyd 2008). On the other hand, for individuals with high present TPs, they show risk preference across domains including financial decisions, health care and ethics (Jochemczyk et al. 2017; Sekścińska et al. 2018). However, the mechanism underlying the link between present TPs and risky behaviors is different owing to the divergent definitions of the two present time perspectives. Having a present-fatalistic TP (PFTP) reflects a belief that the future is predestined, and cannot be influenced by one's current actions (Zimbardo and Boyd 1999). This helpless attitude can in turn induce negative feelings that present fatalists try to reduce by engaging in risky activities (Chen et al. 2016; Gruber et al. 2012). The

present-hedonistic TP (PHTP), however, being characterized by a pleasure-oriented attitude towards life, exhibits little concern for future consequences (Zimbardo and Boyd 1999). These present hedonists who advocate a present-focused lifestyle, can be drawn into risky activities. Generally, individuals with high PHTP are sensitive to rewarding outcomes, especially those that can maximize pleasure (Boniwell and Zimbardo 2004; Boyd and Zimbardo 2006). However, sometimes that whether the outcome is favorable is uncertain, and this outcome can be linked with risk of suffering loss. For present hedonists, albeit they know that outcomes are risky, they nonetheless perceive the world as less threatening. During risk evaluation, present hedonists are prone to underestimate the potential risks of their current behaviors, and then bear the risks for enjoyment (Nicholson et al. 2005; Rosenbloom 2003). For example, present hedonists who underestimate the risk of loss prefer risky choices in gambling decision-making (Cosenza et al. 2017; Cosenza and Nigro 2015). Additionally, compared to individuals with other TPs, people with high PHTP are more likely to carry out risky activities such as frequent drug use, unhealthy smoking, and risky driving (Adams 2009; Wills et al. 2001; Zimbardo et al. 1997). These findings indicate that PHTP might affect risk preference through the process of risk evaluation, and may therefore have robust associations with risk preference. Supporting this notion, there is evidence that PHTP shows good predictive power for risk preference, as compared to other TPs (Jochemczyk et al. 2017). But how this occurs at the neuroanatomical level is not clear.

To date, existing research has found that risk preference is served by several brain regions embracing the frontal lobe (e.g., ventromedial prefrontal cortex [vmPFC]), insula, and posterior parietal lobe (Ernst and Paulus 2005; Venkatraman et al. 2009). Specifically, risk-seeking choices are predicted by increased activation of the vmPFC and striatum (Tobler et al. 2007), whereas the activation of anterior insula increases when people ~~making~~make risk-averse~~aversion~~ choices (Preuschoff et al. 2008). Among these studies, the posterior parietal cortex (PPC), which has been implicated in value-based decision making, is central to the preference for risk (Ballard and Knutson 2009; Kable and Glimcher 2007; McClure et al. 2004). For instance, large portions of PPC exhibit increased activation during the process of risk evaluation, therefore affecting ~~one'~~one's preference for risk (Christopoulos et al. 2009; Huettel et al. 2006). Similarly, the PPC is involved in brain circuits that participate in the processing of probability and risk, which in general determines one's willingness to take risks (Huettel and A 2005; Huk and Meister 2012; Volz et al. 2003). Furthermore, several studies have provided direct evidence that the gray matter (GM) volume of the right PPC (rPPC) predict one's risk tolerance in decision settings (Gilaie-Dotan et al. 2014; Grubb et al. 2016). Taken together, what these studies indicate is that involvement of the PPC may account for individual

differences in risk preference. This to some extent, can facilitate the exploration on the neural correlates underlying the effect of TP on risk preference.

In fact, one's preference for risk depends on the assessment towards risk levels of the current behaviors (Ernst and Paulus 2005; Smith et al. 2009). Individuals with PHTP may make inappropriate estimates in the process of evaluating levels of risk, consequently showing high preferences for risk. Specifically, the phenomenon that risk-preferring choices are made when underestimating the risk of loss often happens in those focusing on present pleasure (Abdel-khalik and Rashad 2014; Tversky and Kahneman 1992). This can also get supports from neuroimaging researches. The parietal cortex, the neuron activities of which strongly increase when people ~~evaluating~~evaluate risk levels, is a key region specialized for risk evaluation (Levy 2017; Paulus et al. 2002). For present hedonists, they will show improper underestimation of risk levels when pursuing high-value rewards (Rosenbloom 2003). Such failure in risk evaluation can be attributed to the dysfunction of parietal cortex (Qin and Han 2009). Consistent with this, it has been found that the activation of parietal cortex facilitates individuals who are highly present-oriented to make more risk-preferring choices (Wittmann et al. 2011). Therefore, as detailed above, we anticipated that the brain regions of risk evaluation (i.e., parietal cortex) might be the neural basis explaining the influence of TP (e.g., PHTP) on risk preference.

Research indicates that individual distinctions in cognitive ability can be revealed in neuroanatomical structures, and ~~this~~ these anatomical differences can be uncovered in depth by employing the VBM method (Ashburner and Friston 2000; Bellgrove et al. 2004; Valldeoriola et al. 2010). Accordingly, we quantified the GM volume using the VBM method across two independent samples to clarify the effect of TP on risk preference. In Sample 1, we investigated the influence of different TPs on risk preference in behavioral data. Based on the former results, we explored the neural basis of TP which was associated with the risk preference using multiple regression analysis. Subsequently, we identified the neural substrates of risk preference employing another multiple regression analysis. Then conjunction analysis was performed to specify whether there was an overlapping region that correlated with both TP and risk preference. A mediation analysis was also conducted to examine whether the GM volume of overlapping brain area mediated the effects of TP on risk preference. Finally, we recruited another independent sample, and replicated the mediation analysis in this second sample to examine the reliability of the results from Sample 1.

Material and methods

Participants

In Sample 1, one hundred and thirty college students from Southwest University took part in this study. Among all participants, four had to be excluded for missing responses in the experimental task, thereby leaving data from one hundred and twenty-six participants to be analyzed (63 male: age, 20.45 ± 1.82 years).

In Sample 2, forty college students were recruited as another independent dataset for examining the reliability of the results from Sample 1. Four participants were excluded for missing responses in the experimental task. Thus, data from thirty-six (17 male; age, 20.08 ± 1.90 years) participants were reported.

Each participant was in good health with no past history of psychiatric or neurological disorders. All participants provided informed written consent as a part of protocols approved by the Institutional Review Board of Southwest University. Prior to MRI anatomical scan, participants completed the behavioral measurements outside the scanner, and then were compensated with some payments because of voluntary participation.

Measures

Time perspective

Trait time perspective was assessed with the Zimbardo Time Perspective Inventory (Zimbardo and Boyd 1999). This inventory has 56 items divided into five TP categories including Past-Positive, Past-Negative, Present-Hedonistic, Present-Fatalistic, and Future TP. Each subscale item is rated on a 5-point Likert scale format, ranging from 1 (*very uncharacteristic*) to 5 (*very characteristic*). Because previous findings have demonstrated that both present and future TPs are associated with risk-taking behaviors (Alvos et al. 1993; Pluck et al. 2008), we only computed the scores for present and future TPs. The ZTPI is a relatively reliable and validated self-report scale to measure TP (Worrell and Mello 2007). In the current study, the ZTPI, PHTP, PFTP and future TP subscales had good reliability (Cronbach's alpha coefficients are 0.746, 0.726, 0.723, and 0.712, respectively).

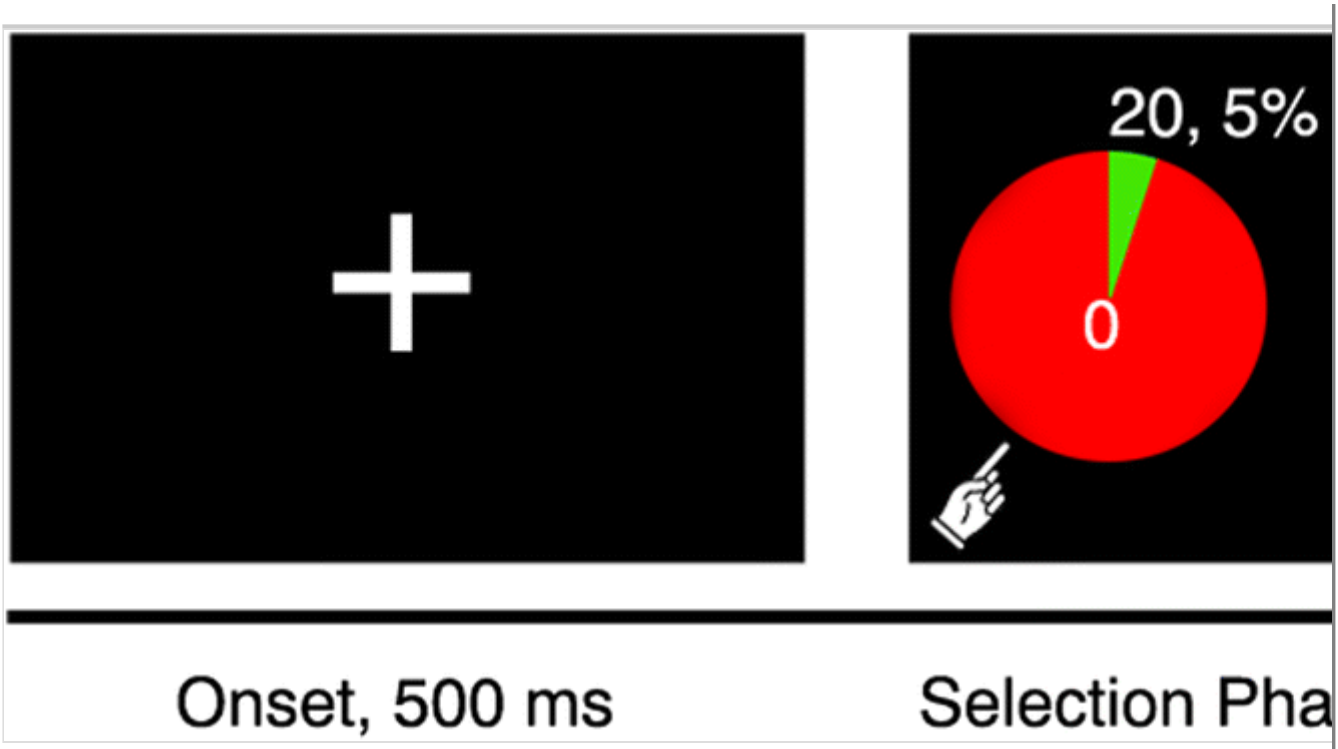
The wheel of fortune task

As a computerized two-choice decision-making task, the Wheel of Fortune task (WOF) is validated for measuring risk preference (Ernst et al. 2004). The WOF task containing probabilistic monetary outcomes, mainly consists of two-type options. One option is a risky choice displayed with 19 kinds of probability (5% to 95%, 5% intervals), and the other is a certain option presented with 9 kinds of

fixed value (¥ 1 to 9; ¥ 1 interval; averaged ¥ 5). Each two-choice combination is presented only once, thus producing a total of 171 trials. Because we concentrated on the risk preference associated with rewards, there were only gain conditions in the whole task (see Fig. 1). During each trial, all participants are presented with a two-sliced wheel and an unsliced one. The sliced wheel is divided into two slices that respectively represent the size of the potential gain (in green) and no-gain (in red), whereas the other unsliced one stands for the fixed value (in green). Participants are instructed to select one of these two options (i.e., accept or reject the gamble). If participants choose to accept the gamble, after 500 ms, the feedback (a blue dot) is presented in either green (indicating that they get the points that are presented with low-probability but high-risk) or red area (indicating that they earn nothing). If individuals choose to reject the gamble, they would acquire the fixed points for that choice. All participants are informed that their payment would be exchanged for cash according to the points they get across the whole task. The payment scheme is that every 100 points can help participants to gain 1 RMB. To ensure the ecological validity of the experiment, the participants are explicitly told that they should make choices as if they would in real life. Following this, participants are allowed to perform the task.

Fig. 1

Visual displays used in the wheel of fortune task: Task example of a risky selection. Participants view the cue for 500 ms, followed by the selection phase, and then participants have 3000 ms to give a response (Here, participants choose the risky option), after which a gain or no-gain feedback would be presented for 500 ms (Here, only the gain feedback is presented)



Of note, the probabilities and rewards magnitudes are the same for all participants. Because an individual's choice could be influenced by the difference in the expected value of the rewards, the expected value of the fixed option is designed to be equivalent to that of corresponding risky choice (Kahneman 2000). In line with the previous findings, performance on the WOF is denoted as the ratio of risky options accepted in all selections (Ernst et al. 2004; Grable 2000; Reyna and Lloyd 2006). Thus we can use the gambling rate as the index of risk preference. This index reflects a higher preference for risk, and thus that more risky choices would be made by participants.

MRI structural acquisition and pre-processing

All anatomical images were obtained with a noninvasive Siemens 3 T scanner (Siemens Magnetom Trio TIM, Erlangen, Germany). The MPRAGE pulse sequence (TR = 2530 ms; TE = 3.39 ms; flip angle = 7°; 256 × 256 matrix) was used to get high resolution T1-weighted anatomical images. Such images were acquired with a total of 128 slices at a thickness of 1.33 mm and an in-plane resolution of 1 × 1 mm^2. During the MRI anatomical scanning, all participants can have a rest, but keep their eyes open and have their heads steady.

The acquired neuroanatomical images were preprocessed using SPM12 software (http://www.fil.ion.ucl . ac.uk/spm/software/spm12/) implemented in Matlab R2014a (Math Works Inc., Natick, MA, USA). To get better image registration, the artifacts and gross anatomical abnormalities were firstly checked for each T1-weighted anatomic image in SPM 12. Then all acquired structural images were preprocessed on the basis of preprocessing steps suggested by Ashburner

(2007). Specifically, the structural images were all first manually reoriented to place the coordinates of the anterior commissure at the origin of the 3 dimensional Montreal Neurological Institute (MNI) space. Next, the reoriented structural MRI images were segmented into gray matter, white matter and cerebrospinal fluid using the SPM12 segment tool. Furthermore, the versions of gray and white matter imported by DARTEL were used to generate the flow fields and a series of template images. And then, those images before-obtained were all smoothed (8 mm Gaussian FWHM), modulated, and spatially normalized to create Jacobian scaled GM images, which were then resliced to 2 × 2 × 2 mm voxel size in MNI space.

Neuroanatomical analysis

Based on statistical results, in conformity with prior findings, only PHTP was found to robustly predict risk preference (Apostolidis et al. 2006; Lukavska 2012). Hence, in Sample 1, we focused on exploring the neural correlates underlying the PHTP and risk preference, respectively. The multiple linear regression models were then performed separately to identify the GM volumes of the brain regions that were correlated with risk preference and PHTP. Specifically, the first multiple regression analysis was performed with gambling rate as a covariate of interest, while age and gender were included as control variables. For detecting voxels of the brain regions that exhibited significant correlations with the risk preference, T contrasts were applied with significance levels set at $p < 0.001$. Notably, the brain is filled with GM volumes, white matter and cerebral spinal fluid (Kolb and Whishaw 2009). Therefore, to completely restrict the GM volume components of the whole brain, we applied an absolute threshold for masking of 0.2 in above regression model. After that, we used a non-stationary cluster correction method (corrected threshold of $p < 0.05$) on all statistical parametric maps (Hayasaka et al. 2004). This could help identify brain regions whose GM volumes were significantly correlated with risk preference. Subsequently, we employed a standard method to deal with the GM volume variances of the brain regions across participants. To be specific, for each participant, the total GM volume was calculated through the MATLAB script “get_totals” provided by Ridgway (http:// www.cs.ucl .ac.uk /staff/ g.ridgway/vbm/get_totals.m). Next, we used the same script to extract the GM volume parameters of the brain regions that survived after the whole-brain-based multiple comparison correction. The global normalization was performed via proportional scaling, which meant that the GM volume of the acquired brain region was divided by the total GM volume. The latter multiple regression analysis followed the same steps as the former one, except that the PHTP was defined as a covariate of interest.

It is noteworthy that our purpose is exploring the neural substrates responsible for the effect of TP on risk preference. Thus, we further used a conjunction analysis to identify whether there was an overlapping brain region related to both PHTP and risk preference (Nichols et al. 2005). On the basis of this analysis, we could obtain the mask of overlapping brain region in Sample 1. We then extracted the GM volume parameters of this overlapping brain region and the total GM volume via the MATLAB script "get_totals". Next, the GM volume of the overlapping brain region was converted into a proportional scale by dividing it by the total GM volume. We then examined whether the GM volume of the overlapping region was significantly correlated with both risk preference and PHTP in Sample 1. Finally, we performed a mediation analysis (including 5000 bootstrap samples) using Hayes's (2013) PROCESS macro (Hayes and Scharkow 2013). Previous research has proposed that changes in TP correspond to changes in risk preference (Cosenza et al. 2017). Accordingly, in the mediation model, the independent variable (X) was the PHTP, the dependent variable (Y) was the risk preference, and the GM volume of the overlapping brain region was the mediator (M). The aim of this analysis was to explore whether the GM volume of overlapping region mediated the impact of TP on risk preference.

AQ1

Cross-sample validation analysis

To ensure the reliability of the results from Sample 1, we replicated the mediation analysis in Sample 2. Specifically, we first defined the overlapping region obtained in Sample 1 as the region of interest, and further extracted the GM volume of this brain region in Sample 2. Then the total GM volume was obtained using the script identical to that in Sample 1. Next, using the same method, we obtained the proportional scale of the GM volume of the overlapping brain region. Finally, the mediation analysis was performed in Sample 2 following the same procedure in Sample 1. We proposed that the findings from Sample 1 could be considered reliable if we found relatively similar results in Sample 2.

Results

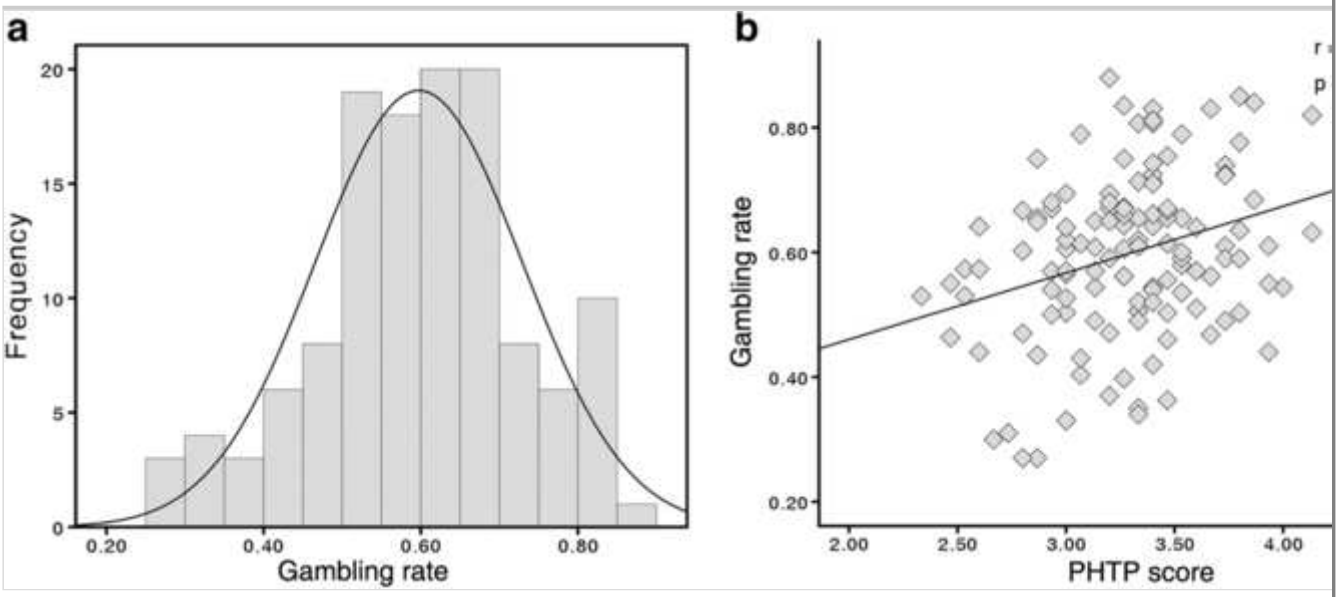
Behavioral results

Supporting the validity of analyses, there was no significant deviation from normality in the distribution of the gambling rate in our sample (Kolmogorov - Smirnov $Z = 0.522$, $p = 0.948$; see Fig. 2a). In addition, there were no gender differences in the gambling rate (t (124) = −0.130, $p = 0.897$), PHTP (t (124) =

0.690, $p = 0.491$), PFTP (t (124) = 1.121, $p = 0.265$), and FTP (t (124) = −0.093, $p = 0.926$). Age was not significantly associated with any of the study variables, including gambling rate ($r = -0.058$, $p = 0.516$), PHTP ($r = 0.043$, $p = 0.635$) and PFTP ($r = 0.118$, $p = 190$), as well as FTP ($r = 0.033$, $p = 0.710$).

Fig. 2

a The distribution of gambling rate in Sample 1 (**b**) The correlation between PHTP and gambling rate in Sample 1



After controlling the effects of the control variables (e.g., gender, age), the Spearman correlation analysis revealed that only PHTP score was positively correlated with the gambling rate ($r = 0.253$, $p < 0.01$; see Fig. 2b). We further found that PHTP significantly predicted gambling rate ($b = 0.246$, t (124) = 2.437, $p < 0.05$). This indicated that higher scores of the PHTP were indicative of increased risk-preferring choices.

Neuroanatomical basis of the effect that TP has upon the risk preference

To explore the neural substrates underlying the impact of PHTP on risk preference, we performed two separate multiple regression analysis in SPM 12. The results of first regression model showed that the GM volume of a cluster in the rPPC was negatively correlated with the gambling rate (rPPC; $r = -0.372$, $p < 0.001$; MNI coordinates; X = 30, Y = −64, Z = 38; see Fig. 3a, Table 1). The index of risk preference was also in positive relation to the GM volume of the left inferior frontal gyrus (lIFG; $r = 0.293$, $p < 0.001$; MNI coordinates; X = −60, Y = 4, Z = 22; see Fig. 3b, Table 1). However, only the cluster in the rPPC survived non-stationary correction at the cluster level (see Table 1), which

indicated the smaller GM volume of the rPPC was associated with increased preference for risk.

Fig. 3

AQ2

The correlation between the GM volumes of distinct regions and risk preference. The scatter plots presented for visualization cannot be used for statistical inference. The *y* coordinate of scattering (**a**) and (**b**) is scaled in scientific notation. **a**, the gambling rate is negatively correlated with the GM volume of the rPPC (right posterior parietal cortex; $p < 0.05$, corrected); **B**, the gambling rate is positively correlated with the GM volume of the lIFG (left inferior frontal gyrus; $p < 0.001$, uncorrected)

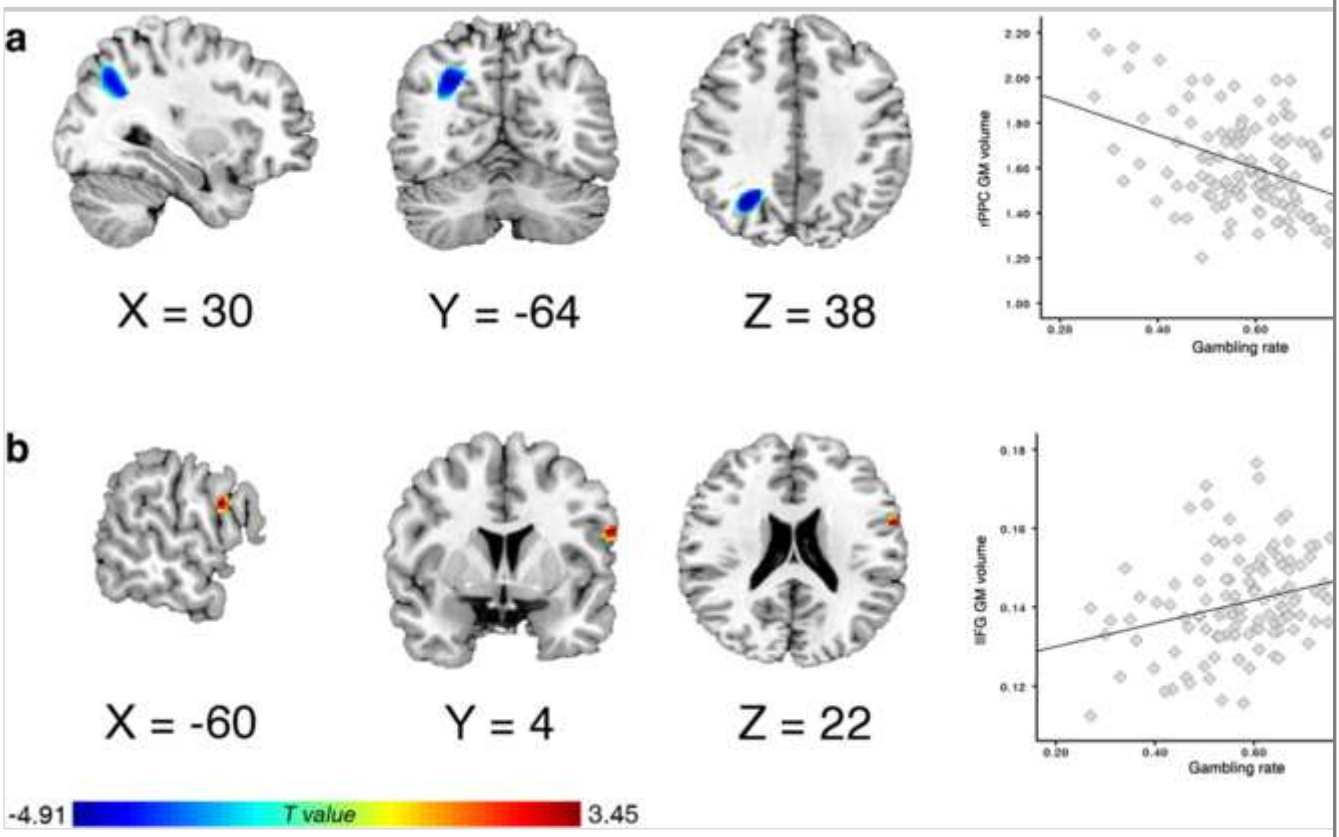


Table 1

The brain regions where the GM volumes are in relation to risk preference

AQ3

Brain region	MNI	*T*	Cluster size
Positive correlation			

All brain regions are thresholded at $p < 0.001$, uncorrected, with a minimum cluster size of 10 voxels. MNI coordinates are reported here. * Surviving non-stationary correction at the cluster level

~~*Surviving non-stationary correction at the cluster level~~

Brain region	MNI	*T*	Cluster size
Left inferior frontal gyrus	−60, 4, 22	3.453	280
Negative correlation			
Right posterior parietal cortex	30, −64, 38	−4.914*	3376
All brain regions are thresholded at $p < 0.001$, uncorrected. with a minimum cluster size of 10 voxels. MNI coordinates are reported here. * Surviving non-stationary correction at the cluster level			
~~*Surviving non-stationary correction at the cluster level~~			

Additionally, the GM volume of the left middle temporal gyrus (lMTG; $r = 0.310$, $p < 0.001$; MNI coordinates; X = −46, Y = −60, Z = 22; see Fig. 4c, Table 2) and right superior temporal gyrus (rSTG; $r = 0.252$, $p < 0.01$; MNI coordinates; X = 56, Y = −42, Z = 4; see Fig. 4b, Table 2) were positively correlated with PHTP scores. This suggested that the large GM volumes of both lMTG, and rSTG had relationships with high PHTP. Interestingly, there was a cluster in the rPPC, the GM volume of which was also negatively correlated with PHTP scores. Using a conjunction analysis, we then identified an overlapping region in the rPPC where the GM volume was correlated with both PHTP and risk preference (MNI coordinates; X = 28, Y = −64, Z = 40; see Fig. 5). The mediation results in Sample 1 further revealed the mediated effect (mediated effect; a*b/c = 0.451, 95% confidence intervals; 0.060–0.242), suggesting that 45% of the effect that PHTP had on risk preference was mediated by the GM volume alteration in the rPPC (see Fig. 6a).

Fig. 4

The correlation between the GM volumes of distinct regions and PHTP. The scatter plots presented for visualization cannot be used for statistical inference. The *y* coordinate of scattering (**a**), (**b**) and (**c**) is scaled in scientific notation. **a**, the PHTP score is negatively correlated with the GM volume of the rPPC (right posterior parietal cortex; $p < 0.001$, uncorrected); **b**, the PHTP score is positively correlated with the GM volume of the rSTG (right superior temporal gyrus; $p < 0.001$, uncorrected); **c**, the PHTP score is positively correlated with the GM volume of the lMTG (left middle temporal gyrus; $p < 0.001$, uncorrected)

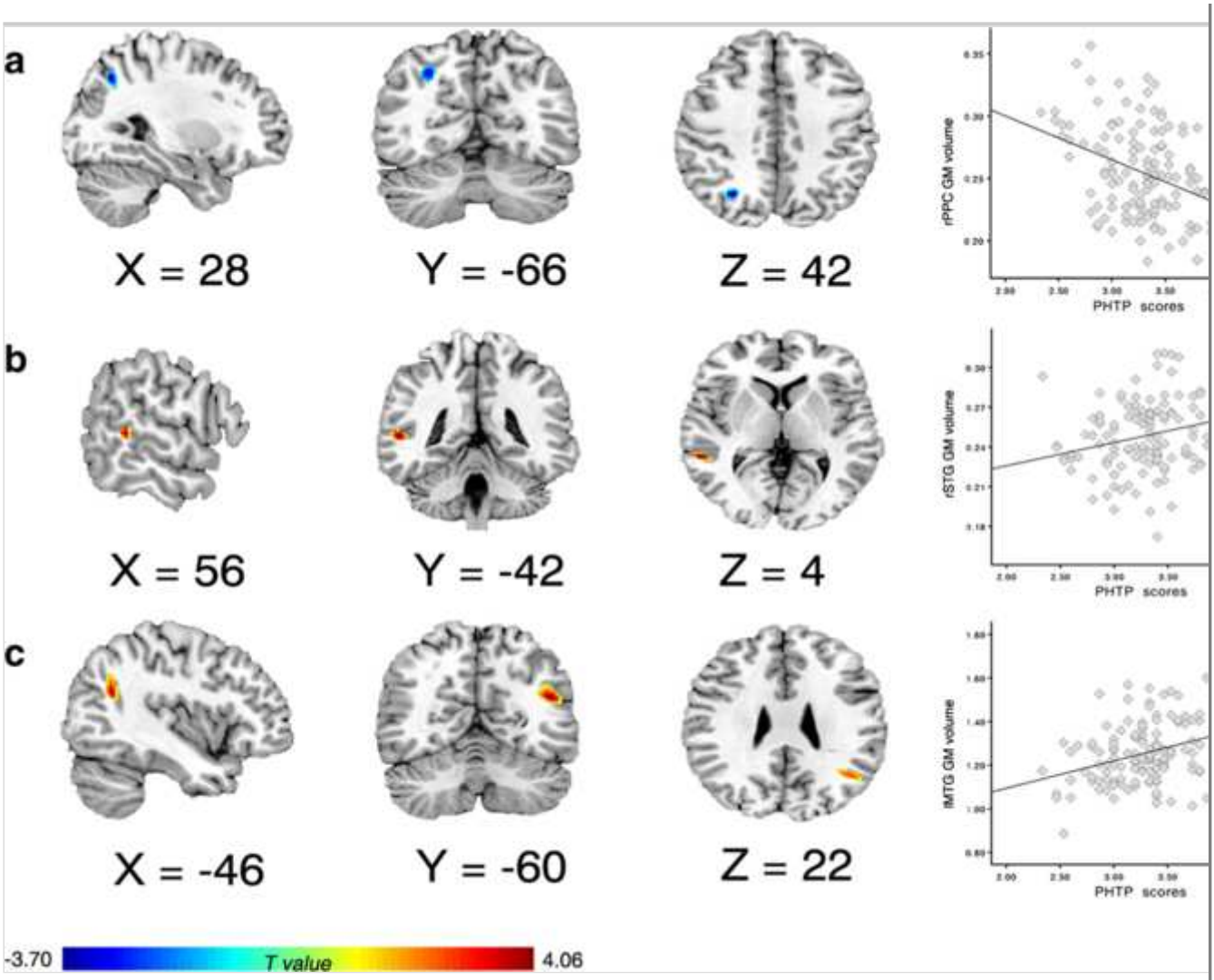


Table 2

The brain regions where the GM volumes are in relation to PHTP

Brain region	MNI	*T*	Cluster size
Positive correlation			
Left middle temporal gyrus	−46, −60, 22	4.024	2104
Right superior temporal gyrus	56, −42, 4	3.591	344
Negative correlation			
Right posterior parietal cortex	28, −66, 42	−3.593	400
All brain regions are thresholded at $p < 0.001$, uncorrected, with a minimum cluster size of 10 voxels. MNI coordinates are reported here			

Fig. 5

The overlapping brain region where the GM volume relates to both PHTP and risk preference. There is an overlapping region in rPPC (right posterior parietal cortex; cluster size >50; $p < 0.005$, uncorrected) in Sample 1. The red part represents the

region related to PHTP; blue indicates the region related to risk preference; the purple indicates the overlapping region related to both PHTP and risk preference

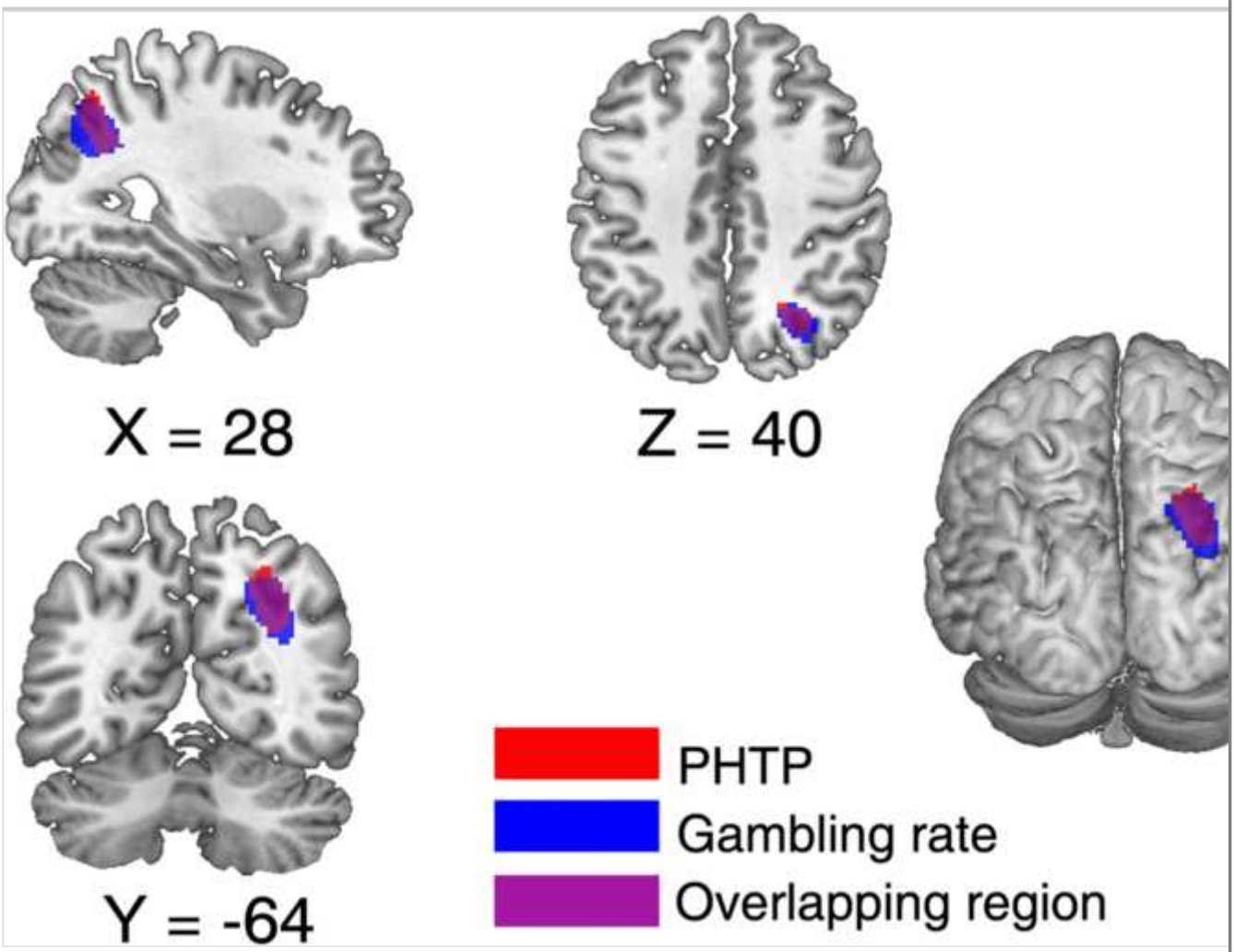
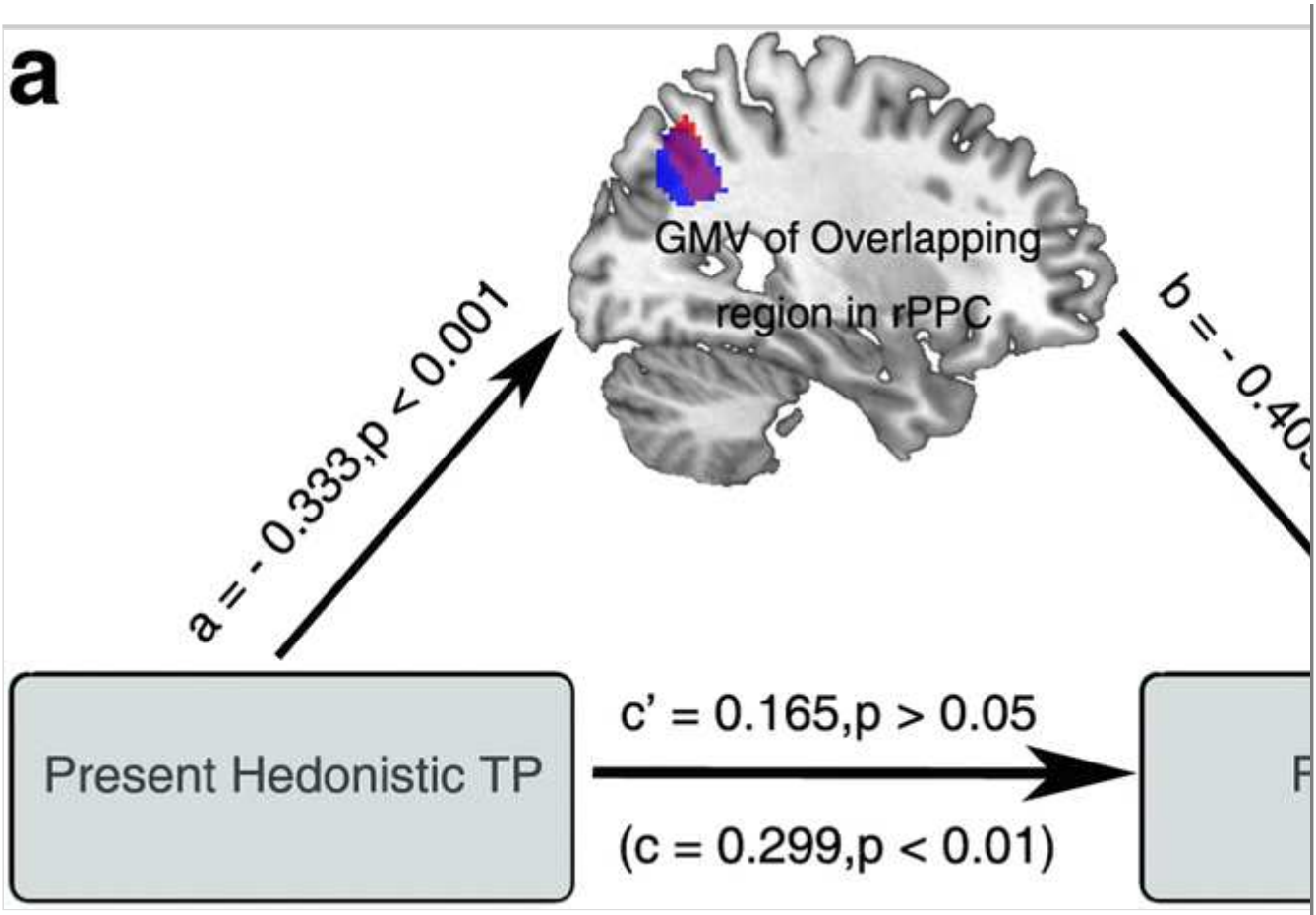


Fig. 6

Neuroanatomical basis of the effect that PHTP has upon risk preference. **a** Mediation results in Sample 1 ($N = 126$); **b** Replication results in Sample 2 ($N = 36$). This figure shows that the GM volume of overlapping region in rPPC robustly mediates the effect of PHTP on risk preference



Cross-sample validation results

In Sample 2, we also found that gambling rate was normally distributed (Kolmogorov-Smirnov $Z = 0.454$, $p = 0.986$). Similar to Sample 1, the relationship between PHTP and gambling rate reached the statistical significance ($r = 0.368$, $p < 0.05$). Spearman correlation analysis was then used to validate the former results. Results found that the GM volume of the overlapping region in the rPPC was negatively associated with both PHTP scores ($r = -0.421$, $p < 0.01$) and gambling rate ($r = -0.426$, $p < 0.01$). This indicated that the GM volume of the rPPC could reliably predict both PHTP and risk preference. Moreover, the mediation results in Sample 2 also revealed that the GM volume variation of the rPPC explained 45% of the effect that PHTP had on risk preference (mediated effect: a*b/c = 0.452. 95% confidence intervals: 0.020–0.437. see Fig. 6b). Together, these results suggested that the overlapping region of the rPPC could be the neural substrate accounting for the effect of PHTP on risk preference.

Discussion

In the current study, we sought to investigate the neuroanatomical bases of the effect that TP had on risk preference. The behavioral results found that PHTP independently predicted risk preference. Results from VBM analysis further

suggested that higher preference for risk was correlated with smaller GM volume in the rPPC. Moreover, PHTP was also negatively associated with the GM volume of a cluster in the rPPC. Then using conjunction analysis, we observed an overlapping region in the rPPC, the GM volume of which was related to both risk preference and PHTP. Finally, the mediation analysis in two samples demonstrated that the GM volume of the overlapping region in the rPPC robustly mediated the effect of PHTP on risk preference. Taken together, these results provide insights that structural variation in the rPPC might explain the impact of PHTP on risk preference.

The finding that PHTP was positively correlated with risk preference was as predicted. PHTP, as a relatively stable trait, reflects a hedonistic and sensation-taking attitude towards time and life (Fieulaine and Martinez 2010). With these characteristics, present hedonists are sensitive to risky activities. Concretely, the present hedonists being described as “stimulation-seekers”, will underestimate the potential risk that their current behaviors can entail (Nicholson et al. 2005; Przepiorka and Blachnio 2016). Such ill-considered estimates of risk levels could generally bias present hedonists towards risk-relevant behaviors. For example, it has been found that those with high PHTP prefer high-risk activities, such as drug use, addiction (Apostolidis et al. 2006; Robbins and Bryan 2004), and pathological gambling (Nigro and Cosenza 2016). Furthermore, there is also evidence that present hedonists underestimate the risk for loss and therefore make frequent risky choices in gambling decision-making (Cosenza et al. 2017; Cosenza and Nigro 2015). Accordingly, our results, which are in line with previous studies, reveal the unique predictive role that PHTP plays in risk preference.

Based on the neuroanatomical analysis, we found that risk preference was positively correlated with the GM volume of a cluster in the lIFG, and was negatively related to the GM volume of a cluster in the rPPC. There is evidence that supports the engagement of the IFG in risky behaviors. The findings that the IFG lesions are linked with high-risk behaviors including cocaine craving and repeated heroin use (Aron et al. 2003; Fu et al. 2008), are the cases in point. Moreover, the pathological gamblers characterized by risk-seeking in gambling decisions also show large GM volume in the left IFG (Koehler et al. 2015). This therefore suggests that high preference inducing risk-taking behaviors (Sitkin and Pablo 1992), may have some associations with the GM volume of the lIFG. On the other hand, the rPPC has long been implicated in risky decisions, making it a potential region that affects risk preference (Levy 2017). For example, previous research has proposed that the activity of the rPPC represents the probability of options, or the likelihood that one can win or lose in risky decisions (Symmonds et al. 2011; van Leijenhorst et al. 2006). This function of

the rPPC for estimating risk levels may impact risk preference to some extent. Likewise, the activation of the PPC is sensitive to risk levels, which generally makes sense to adjust the preference for risk (Christopoulos et al. 2009; Huettel et al. 2006). In some patient studies, patients with PPC damage also showed deficiencies in estimating the probability of winning, thereby results in a preference for high-risk options (Clark et al. 2014; Studer et al. 2013). Moreover, Gilaie-Dotan and colleagues have proposed directly that the GM volume of the rPPC is predictive of risk preference, and have further inferred that this is related to the involvement of the rPPC in estimating risk levels (Gilaie-Dotan et al. 2014). Consequently, these studies underscore that the rPPC plays a critical role in risk evaluation, and may therefore have associations with the risk preference.

Furthermore, we observed that the PHTP was positively related to the GM volumes of both the MTG and STG, and was also negatively correlated with the GM volume of the rPPC. It should be noted that individuals with high PHTP have poor impulsivity control (Daugherty and Brase 2010). Such impulsivity control problems are observed simultaneously in cohorts with large GM volume of the MTG (Pellecchia et al. 2013). What's more, a recent work suggests impulsivity as a underlying mediator of the relationship between PHTP and the GM volume in the MTG (Z. Chen et al. 2018). Thus impulsivity control may explain the links between PHTP and the GM volume of the MTG. On another flip side, there are many common aspects between the effects of PHTP and that of the rPPC in the context of decision making. This may help clarify why the GM volume of the rPPC accounts for the individual differences in PHTP. Changes in PHTP are associated with factors influencing decisions like time orientation (Arnold et al. 2011), temporal discounting (Daugherty and Brase 2010), impulsivity (Zimbardo and Boyd 2008), risk-taking and intention inconsistency (Sansone et al. 2013; Van Ittersum 2012).For the parietal cortex, it is a core part of neural system responsible for intentional behaviors (Andersen and Buneo 2002), time perception (Leon and Shadlen 2003), self-projection in the past, present and future (Oliveri et al. 2009), and subjective value comparison (Mcclure et al. 2007; McClure et al. 2004), as well as risk evaluation in decision-making (Studer et al. 2013). Hence, these findings suggest a potential association between the parietal cortex and PHTP. More importantly, it has been suggested that the activation of the parietal cortex increases when risky choices are frequently made by individuals with present-oriented perspective (Wittmann et al. 2011). Thus, the preliminary finding of the inverse association between the GM volume of the rPPC and the PHTP could be adopted.

Most importantly, the GM volume of the overlapping brain region in the rPPC was further found to play a mediating role in the effect of PHTP on risk

preference. This might be associated with the involvement of the PPC in the process of risk evaluation. Of note, the PPC, where the neuron activities involve the formations of decisions, activates strongly when estimating risk levels (Barraclough et al. 2004; Huettel et al. 2006). Such assessments concerning the risk levels of winning in decisions, or of current behaviors, have a direct bearing on one's preference for risk (Ernst and Paulus 2005; Smith et al. 2009). On the other hand, present hedonists are likely to pursue rewards that can bring maximum pleasure, but may be highly improbable to obtain (Boniwell and Zimbardo 2004; Boyd and Zimbardo 2006). These present hedonists will show an underestimation of the risk that they will likely lose or earn nothing. Such failures in risk evaluation might be attributed to the variance in neuron activities of the PPC (Qin and Han 2009). Supporting this view, it has been found that activation of the parietal cortex induces individuals who are present-biased to prefer much risky-choices (Wittmann et al. 2011). Thus, in view of the crucial engagement of the PPC in risk evaluation, these results indicate that the lower neural sensitivities in the rPPC might explain why those with high scores on PHTP make riskier choices.

Overall, our findings can have important implications. The results that structural variation of the rPPC can account for the effects that the PHTP has upon the risk preference complement previous studies, and may provide enlightenment for future work. However, the present findings nonetheless have some limitations. Primarily, our anatomical investigation is limited to reflect the brain activities when making risk-preferring choices. To identify which brain regions are involved in risk-preferring choice-making, future research is therefore warranted to employ the fMRI method. Next, the present study cannot draw a causal relation between TP and risk preference. Since risk preference is also indicative of high-risk behaviors, it is worth using the causality analysis to explore the causal relationship among TP, risk preference and risky behaviors.

As a whole, the current findings first suggest that only PHTP can significantly predict risk preference, and that high scores on PHTP are related to greater risk-preferring choices. Additionally, the VBM results reveal that the GM volume of rPPC is negatively associated with both risk preference and PHTP. More critically important, the mediation results found that the effect of PHTP on risk preference is mediated by the GM volume of the rPPC. Our results indicate that the rPPC is the neuroanatomical substrate accounting for the effect of PHTP on risk preference, and further provide a novel perspective for risk attitude research in decision settings.

Publisher's note

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Author contributions

Ting Xu and Zhiyi Chen conducted and analyzed the pilot studies. Ting Xu, Rong Zhang and Yaqi Yang collected and analyzed the data. Ting Xu, Zhiyi Chen, Fuschia Sirois and Tingyong Feng prepared and revised the manuscript.

Compliance with ethical standards

Conflict of interest All authors (including Ms. Ting Xu, Mr. Zhiyi Chen, Dr. Fuschia Sirois, Ms. Rong Zhang, Ms. Yaqi Yang and Dr. Tingyong Feng) declare they have no conflict of interest.

Informed consent statement All procedures followed were in accordance with the Helsinki Declaration of 1975, and the applicable revisions at the time of the investigation. Informed consent was obtained from all participants included in the study.

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