Neural correlates of Traditional Chinese Medicine induced advantageous risk-taking decision making

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Abstract
This fMRI study examined the neural correlates of the observed improvement in advantageous risk-taking behavior, as measured by the number of adjusted pumps in the Balloon Analogue Risk Task (BART), following a 60-day course of a Traditional Chinese Medicine (TCM) recipe, specifically designed to regulate impulsiveness in order to modulate risk-taking behavior. The 14 participants recruited for this study were randomly assigned to the experimental and control groups and the TCM recipe (Panax, 520 mg; Astragalus membranaceous Bunge, 520 mg; Masnetitum, 840 mg; Ostrea gigas Thumb, 470 mg; Thinleaf Milkwort Root Radix Polygalae, 450 mg; and Os Draconis, 470 mg) was administered, as a diet supplement, to the seven participants in the experimental group. The neural activity of the two groups was monitored by a 3T MRI scanner, before and after the 60-day treatment. Associated with the improved advantageous risk-taking behavior seen in the experimental group, significantly stronger blood oxygenation level dependent (BOLD) responses were observed in the bilateral dorsolateral prefrontal cortex (DLPFC), left putamen, left thalamus, right insula, and right anterior cingulate cortex (ACC), regions which have previously been reported as being involved in risk-taking decision making. The effect of the TCM in improving advantageous risk-taking decision making appears to have been related to the enhanced efficiency of the cognitive affective system, the PFC–ACC–insula–striatum network, which functions to inhibit impulsiveness, to sensitize reward-related information, and to allow the opportunity, during risk estimation, to evaluate potential gains and losses. The findings of this study suggest that interventions acting on factors modulating risk-taking decision making could have a beneficial effect in terms of optimizing risk-taking behavior.

1. Introduction
Risk taking is an instinctive behavior in one's attempt to maximize the probability of accessing potential resources for survival in an uncertain environment. However, rushing into risk taking before carefully considering the possible outcomes could result in maladaptive behaviors, such as pathological gambling (Bechara & Damasio, 2002), substance abuse (Gilbert, Crauthers, Mooney, McClenon, & Jensen, 1999; Henderson, Galen, & DeLuca, 1998), and unsafe sexual practices (DiClemente, Hansen, & Ponton, 1995; Hoyle, Fejfar, & Miller, 2000; Schafer, Blanchard, & Fals-Stewart, 1994). The identification of possible ways to enhance advantageous risk-taking behaviors is of both theoretical and practical significance. Numerous reports have discussed the strong association between impulsiveness and risk-taking decision making in humans (Butler & Montgomery, 2004; Hanson, Luciana, & Sullwold, 2008) and in animals (Winstanley et al., 2009). Hence, the level of impulsiveness is an important factor that modulates risk-taking decision making.

Strategies that help regulate impulsiveness would undoubtedly facilitate advantageous risk-taking decision making. In this connection, we used a Traditional Chinese Medicine (TCM) recipe, specially designed to regulate impulsiveness, in order to understand its effects on risk-taking behavior, using 14 participants who had been recruited by the Chinese Astronaut Research and Training for a laboratory study of the effects of prolonged bed rest on physiological indices. This TCM recipe contains 520 mg of Panax
et al., 2002). The BART has been validated by Lejuez et al. (2002) by the adjusted number of pumps in the BART (that is the average siveness Scale (Barratt, 1985), the Sensation Seeking Scale (Zucker- have significant relationships with the scores on the Barratt Impuls- ions (Lejuez et al., 2007). The BART was specifically chosen for this study because it is designed in such a way that each pump incor- porates a progressive risk of losing potential rewards instead of losing accumulated rewards; it, therefore, encourages participants to focus on reward estimation rather than risk aversion (Bornoval- por, 2002). Advantageous risk-taking behavior is then defined by the adjusted number of pumps in the BART (that is the average number of pumps of the balloons that did not explode) (Lejuez et al., 2002). The BART has been validated by Lejuez et al. (2002) using several risk-related constructs. Specifically, the BART scores have significant relationships with the scores on the Barratt Impul- siveness Scale (Barratt, 1985), the Sensation Seeking Scale (Zuck- erman, Eysenck, & Eysenck, 1978), and the Eysenck Impulsiveness Scale (Eysenck, Pearson, Easting, & Allsopp, 1985), as well as with self-reported risk-taking measures, such as the Gambling Attitudes and Beliefs Scale (Breen & Zuckerman, 1994, 1999) and questionnaires (Lejuez et al., 2002). Also, the BART was found to be an effective measure in assessing risk-taking behaviors among adolescents (Lejuez et al., 2007).

To understand the neural activation associated with advanta- geous risk-taking decision making, as measured by the BART fol- lowing the consumption of the TCM recipe, we conducted a functional magnetic resonance imaging (fMRI) study on the neural activity accompanying the different risk-taking decision making of both the participants that had taken the TCM recipe and those that had not. Previous neuroimaging studies on healthy participants have revealed that major brain areas, such as the orbitalfrontal cortices (Hsu, Bhatt, Adolphs, Tranel, & Camerer, 2005; Lee et al., 2008; Liu et al., 2007), medial prefrontal cortex (Kuhnen & Knut- son, 2005; Xue et al., 2009), striatum (Breiter, Aharon, Kahneman, Dale, & Shizgal, 2001; Delgado, Nystrom, Fissell, Noll, & Fiez, 2000; Tom, Fox, Trepel, & Poldrack, 2007), insula (Krain, Wilson, Ar- buckle, Castellanos, & Milham, 2006; Lee et al., 2008), anterior cingulate cortex (De Martino, Kumaran, Seymour, & Dolan, 2006), and the parietal cortex (Lee et al., 2008), have a significant correlation with risk-taking tasks. Activation in the insula cortex, dorsolateral prefrontal cortex (DLPFC), frontal regions, anterior cingulate cortex (ACC), and striatum has been observed when participants performed the BART (Rao et al., 2008) and activity in the lateral prefrontal cortex and the ACC has been observed in relation to inhibitory control (e.g. MacDonald, Cohen, Stenger, & Carter, 2000; Lee et al., 2005, 2006; Liddell, Kiehl, & Smith, 2001). We also examined whether the neural activation pattern of the TCM group resembled that observed in individuals with high versus low impulsiveness, where the activation of the insula-orbitofrontal-parietal regions was significantly stronger in the high impulsiveness group (Lee et al., 2008). As such, given the intervention of the TCM recipe in terms of promoting advantageous risk taking, we hypothesized that there would be stronger brain activation in the areas related to risk-taking, namely the insula, dorsolateral prefrontal cortex (DLPFC), anterior cingulate cortex (ACC), and striatum, in the TCM group than in the control group.

2. Materials and methods

2.1. Participants

The participants were 14 healthy males from mainland China, who were recruited for this study while they were taking part in a laboratory experiment studying the physiological indices associated with prolonged bed rest. All of the participants were assessed as right-handed, using the Edinburgh Handedness Inventory, and had normal or corrected-to-normal vision. The exclusion crite- ria were as follows: a history of psychiatric and neurological disor- ders; head injuries; physical disabilities; and current use of any medication (including Chinese medicine). Written informed con- sent was obtained from the participants and the study was approved by the Institutional Review Board of the China Astronaut Research and Training Center.

The participants were randomly assigned to two groups, seven to the Traditional Chinese Medicine (TCM) group, which was provided with the TCM recipe as a diet supplement for 60 days, and seven to the control group, which was provided with the same diet for 60 days but without the TCM supplement. The diet and other social–environmental factors of the two groups were fully matched; the participants resided and were monitored in the labor- atory of the Chinese Astronaut Research and Training Center for the full duration of the experiment. The experimental Balloon Analogue Risk Task (BART) was administered before and after the 60-day experiment. Participants’ brain activity associated with performing the BART was monitored by a 3T MRI scanner in the pre- and the post-experiment fMRI sessions. To ascertain the specific- ity of the TCM effect on risk-taking behaviors (mainly subserved by the frontal regions), the Test of Judgment of Line Orientation (JOLO) assessing the parietal-cerebellum pathway for visual spatial functioning (Lee et al., 2005) was administered. If the TCM effect was specific to the frontal risk-taking behaviors, non-significant differences between the experimental and control groups would be observed.

The age, education, and intellectual levels of the two groups were matched. In the control group and the TCM group, respectively, the mean ages were 30.14 (SD = 3.39; range = 26–35) and 28.83 (SD = 5.71; range = 24–39), the mean education levels were 10.71 years (SD = 1.60; range = 9–12) and 11 years (SD = 2.45; range = 9–15), and the mean score of the participants’ intellectual levels (as assessed by Raven’s Progressive Matrices) were 43.14 (SD = 10.73) and 48.83 (SD = 6.27).

Before the experiment, the participants were assessed on their arousal and pleasure levels, using the Affect Grid. No significant differences between the groups (p > 0.05) [Arousal scores: TCM group = 7.50 ± 1.23 (range = 5–8); control group = 7.57 ± 1.62 (range = 5–9); Pleasure scores: TCM group = 7.00 ± 1.67 (range = 5– 9); control group = 7.43 ± 1.62 (range = 5–9)] were observed. To measure their impulsive personality traits, the Barrett’s Impulsiv- ity Scale (BIS) was used. Again there was no significant between- group differences [TCM group: 55.33 ± 4.59 (range: 52–64); control group: 54.29 ± 7.43 (range: 46–68)] (p > 0.05). Their mood states, measured by the Profile of Mood States (POMS), were also comparable (p > 0.05).
2.2. Experimental design

The task used to tap the participants’ risk-taking tendencies was modified from Lejuez et al. (2002) Balloon Analogue Risk Task (BART) to suit fMRI scanning. There were two blocks in the paradigm: the experimental and the control blocks.

At the beginning of the experimental block, participants were presented with a very small balloon and were asked to press a button repeatedly to inflate the balloon. Each button press inflated the radius of the balloon by 1 mm and the participant gained one point, which was indicated on the screen. However, each balloon had a predetermined explosion point, randomly selected from within the range of 1–30 presses. If the balloon exploded, the participant lost all of the points accumulated for that balloon. Alternatively, participants could opt to collect the cumulated points by pressing a designated button; the points gained would then be automatically transferred to a temporary account, the balance of which was shown on the screen. Meanwhile, a new balloon would appear and the participant had 30 s, in the experimental block, to pump an unlimited number of balloons; their mission was to gain as many points as possible (i.e., to pump a balloon as large as possible and collect the points before it exploded).

In the experimental block, participants had to decide repeatedly whether to press the pump button (to inflate the balloon in order to increase the magnitude of reward) or the collect button (to collect the points for the balloon in order to avoid losing the points gained). Therefore, they were continually deciding for themselves how far they should go and how much risk they were willing to take. In order to provide an incentive for the participants to take risks, they were told that they needed to gain over a particular score in order to receive a $100 bonus; however, this score was unknown to them. Eventually, all of the participants received the $100 bonus.

As in the experimental block, participants had 30 s in the control block to press the button as many times as they wanted to. The only difference was that the balloon shown on the screen was of a fixed size and the button presses would not cause any changes to the size of the balloon nor the number of points in the bank.

All blocks lasted for 30 s with inter-stimulus intervals of 6 s between the blocks. The blocks were presented alternately for four cycles. A simple condition cue was presented at the beginning of each block to signify to the participant which block they were about to perform (see Fig. 1).

Fig. 1. The flowchart shows 1 cycle of the control and the experimental tasks. In the control block, the participants were required to keep pressing the pump button. The number of pumps was show on the screen while the size of balloon and the points accumulated in bank remained unchanged. In the experimental block, the size of balloon increased upon each pump. If the subject pressed the collect button, the number of pumps would transfer to the bank and a new balloon would come up. If the number of pumps reached the balloon’s explosion point, the balloon would explode and no point would be transferred to the bank.

2.3. Image acquisition

After the participants were familiarized with the experimental task, the experiment was carried out in a 3T Siemens scanner with head coil in the pre-experiment occasion. After 60 days, the second fMRI session was conducted and the same experimental task was implemented. Functional images were acquired by a T2*-weighted gradient-echo echo-planar imaging pulse sequence with 32 interleaved slices acquired parallel to the AC–PC plane. The slice thickness was 4.0 mm and the voxel size was 3.3 mm × 3.3 mm (TR = 2000 ms, TE = 30 ms, FoV = 211 mm × 211 mm, matrix size = 64 × 64, flip angle = 90°). Structural images were obtained in a sagittal orientation by a T1-weighted spin-echo pulse sequence with slice thickness of 1.33 mm. (TR = 2530 ms, TE = 3.39 ms, FoV = 256 mm × 256 mm).

2.4. Data analysis

Initial imaging data were pre-processed and analyzed by Statistical Parametric Mapping software (SPM2, Wellcome Department of Cognitive Neurology, London, UK). Each individual’s functional images were realigned to correct for movements, as well as to form a mean image that coregistered with their structural images. The resulting images were normalized by matching them to a standard structural template (Talairach & Tournoux, 1988) and smoothed by an 8 mm full-width half-maximum (FWHM) Gaussian filter. Hemodynamic response function (HRF) was convolved in modeling the fMRI signal and the high-pass filter was set at 128 s to reduce the low frequency noise. Intra-subject analysis was conducted by contrasting the experimental block with the control block to produce individual contrast image files for group analysis. A one-sample t-test was carried out to analyze the brain activation of the two groups at p < 0.001, with a cluster correction of 15 contiguous voxels. Then, a two-sample t-test was carried out to obtain a comparison of the brain activations in the two groups. ROI analysis was carried out at p < 0.005, with voxel size correction of 30, in the insula, DLPFC, orbitofrontal cortex (OFC), ACC, and striatum. The WFU PickAtlas (Maldjian, Laurienti, Kraft, & Burdette, 2003) was used to define the regions of interest with the Automated Anatomical Labeling (AAL) tool.

3. Results

3.1. Behavioral data

The behavioral data of the TCM group (n = 7), relative to the control group (n = 7), clearly indicated, in terms of the adjusted
number of pumps in the BART, the facilitation of advantageous risk-taking decision making. This was reflected by a significant interaction effect \((F = 4.829, df = 1.12, p = .048;\) Bonferroni corrected) in a two-way ANOVA repeated measures model with group (TCM group, control group) and time (pre- and post-experiment) as factors; neither group nor time had significant main effects. Although, at pre-experiment stage, the two groups had no significant mean differences (mean difference = −1.935, SD = 7.926, \(t = −2.48, df = 12, p = .080\)), group difference at post-experiment stage was significant (mean difference = 18.857, SD = 6.089, \(t = 3.097, df = 12, p = .009\)), with the TCM group having a higher adjusted number of pumps (mean = 55.234, 50044 = 12.796) than the control group (mean = 36.378, SD = 9.786). Within group comparison showed a significant time effect (\(t = −2.829, df = 6, p = .03\)) for the TCM group only, with post-experiment (mean = 55.23; SD = 12.80) having more adjusted number of pumps than pre-experiment stage (mean = 35.76; SD = 11.07); whereas for the control group, there was no significant difference (\(t = .203, df = 6, p = .846\)) between the post-experiment (mean = 36.38; SD = 9.79) and the pre-experiment stage (mean = 37.70; SD = 17.39). For performance on the JOLO, no significant differences between the experimental and control groups in both pre-experiment (\(t = −1.137, df = 12, p = .278\)) and post-experiment (\(t = 0.920, df = 12, p = .376\)) occasions were observed. This observation strongly indicates that the effect of TCM receipt was unlikely a global one but specific to the frontal risk-taking behaviors.

### 3.2. Neuroimaging data

#### 3.2.1. General risk-taking pattern

The pattern of neural activations in both the experimental (TCM) and the control group was consistent with that found in previous literatures on risk-taking, in that the DLPC (Paulus, Rogalsky, Simmons, Feinstein, & Stein, 2003; Rao et al., 2008), insula (Lee et al., 2008; Paulus et al., 2003; Rao et al., 2008), and OFC (Lee et al., 2008) were all significantly activated. At the pre-experiment stage (i.e., the baseline), a two-sample \(t\)-test analysis found no significant group contrast, in terms of areas of brain activation, between the two groups.

#### 3.2.2. Between group ROI analysis

The results from the post-experiment stage indicated that, relative to the control group, the TCM group had significantly stronger activation in the bilateral dorsolateral prefrontal cortex, left putamen, left thalamus, right insula, and right anterior cingulate cortex (Table 1; Fig. 2). Among the regions of interest, only the orbitofrontal cortex region did not show suprathreshold activation in the TCM versus control group contrast. No significant activation was observed in the control versus TCM group contrast. The strong DLPFC activation in the TCM group suggests enhanced cognitive evaluation for planning subsequent actions in when to withdraw from increasing risk and hence collect the points. To the best of our knowledge, this is the first study to investigate the neural activity associated with improved advantageous risk-taking behavior after taking a TCM recipe specifically designed to regulate impulsiveness in order to modulate risk-taking behaviors.

### 4. Discussion

Consistent with Rao's study (2008) examining the neural correlates of risk-taking decision making measured by the BART, the DLPC, insula, and other frontal regions were identified in both the TCM and the control group, indicating that both groups were involved in active voluntary risk taking. Our findings clearly showed that, relative to the control group, significantly stronger activation was observed in the bilateral DLPC, the right ACC, the right insula, the left putamen, and the left thalamus in the TCM group; this is consistent with our \(a\ priori\) hypothesis. Previous functional neuroimaging studies on the risk-taking behavior of healthy adults have reported the activation of the orbitofrontal cortex (Elliott, Newman, Longe, William, & Deakin, 2003; Krain et al., 2006; Liu et al., 2007; Rogers, Owen, et al., 1999), the prefrontal cortex (inferior prefrontal cortex: Paulus et al., 2001, 2003; the ventrolateral and ventromedial frontal cortices: Elliott et al., 1999, Elliott, Friston, & Dolan, 2000; Rogers, Everitt et al., 1999), the insula (Critchley, Mathias, & Dolan, 2001; Fishbein et al., 2005), and the anterior cingulate cortex (Elliott et al., 2000), which is largely consistent with the regions of activation observed in this study. Also, previous neuroimaging studies on maladaptive risk-takers, such as heroin abusers and adolescents, have revealed decreased neural activations in the anterior cingulate, prefrontal, and striatum regions (Bjork et al., 2004; Lee et al., 2005; Potenza, 2008). To map these previous neuroimaging findings to the data observed in this study, it seems that the prolonged consumption of the TCM recipe facilitated the neural activity of the regions believed to be involved in risk-taking decision making. To the best of our knowledge, this is the first study to investigate the neural activity associated with improved advantageous risk-taking behavior after taking a TCM recipe specifically designed to regulate impulsiveness in order to modulate risk-taking behaviors.

### Table 1

Summary of the post-experiment areas of brain activation obtained in the ROI analyses of the TCM group relative to control group in the experimental block versus the control block contrast. No significantly stronger activation was observed in the control group relative to the TCM group contrast.

<table>
<thead>
<tr>
<th>TCM &gt; control</th>
<th>Activation areas</th>
<th>BA</th>
<th>Side</th>
<th>MNI coordinates</th>
<th>Cluster (t)</th>
<th>(t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prefrontal cortex</td>
<td>Experimental block versus control block</td>
<td>46</td>
<td>L</td>
<td>−32 38 14</td>
<td>144</td>
<td>5.29</td>
</tr>
<tr>
<td>46</td>
<td>L</td>
<td>−32 40 16</td>
<td>107</td>
<td>5.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>44/48</td>
<td>L</td>
<td>−30 14 32</td>
<td>78</td>
<td>6.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>47</td>
<td>R</td>
<td>32 44 8</td>
<td>34</td>
<td>4.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior cingulate cortex</td>
<td>−</td>
<td>R</td>
<td>6 12 26</td>
<td>41</td>
<td>4.33</td>
<td></td>
</tr>
<tr>
<td>Insula</td>
<td>−</td>
<td>R</td>
<td>−36 12 −10</td>
<td>33</td>
<td>3.86</td>
<td></td>
</tr>
<tr>
<td>Putamen</td>
<td>−</td>
<td>L</td>
<td>−22 14 4</td>
<td>69</td>
<td>4.96</td>
<td></td>
</tr>
<tr>
<td>Thalamus</td>
<td>−</td>
<td>L</td>
<td>−28 −8 2</td>
<td>46</td>
<td>3.66</td>
<td></td>
</tr>
</tbody>
</table>

BA = Brodmann area; side: (R) = right hemisphere (L) = left hemisphere.
situations of delayed reward gratification (McClure, Laibson, Loewenstein, & Cohen, 2004). Therefore, the improved risk-taking behavior observed in the TCM group may relate to the regulation of impulsiveness, which allows the prefrontal brain regions the opportunity to invoke the executive function of evaluating choices under ambiguity (Platt & Huettel, 2008), to manipulate cognitive representations, and to evaluate outcome utilities (Trepel & Poldrack, 2005). When applied to performing the BART, the facilitation of DLPFC activity may have inhibited the urge to collect the points when the balloon was insufficiently inflated and also may have resulted in a better evaluation of the trade-off between the abstract scores and the delayed actual monetary reward.
is associated with processing affective information in risk estimation (Zhao, & Gabrieli, 2002; Lee et al., 2005) and in the insula (which is involved in the subcortical integration of visceral responses and emotion arousal to provide information to the cortical regions during decision making (Canli, Desmond, Jessica, Leigh, & Jonathan, 2003). Thus, activity in the insula may heavily involved (Brown & Braver, 2008), to aid outcome judgment and to correct for reward prediction errors.

4.2. Insula and thalamus

The literature has suggested that the insula plays a significant role, at an implicit level, in estimating risks in uncertain situations and in guiding behavior based upon the anticipation of aversive emotional consequences (Hastie & Dawes, 2001; Sanfey, James, Jessica, Leigh, & Jonathan, 2003). Thus, activity in the insula may be associated with the anticipation of making a risky response. Indeed, we reported in our previous study that the rate of risky responses correlated with the strength of the neural activity in the insula (Lee, Chan, Leung, Fox & Gao, 2009). Therefore, the stronger blood oxygenation level dependent (BOLD) responses in the insula of the TCM group, relative to the control group, suggests improved self-monitoring and error-detection, in which the ACC is heavily involved (Brown & Braver, 2008), to aid outcome judgment and to correct for reward prediction errors.

4.3. Striatum

Previous studies have consistently reported the DLPFC–ACC network in exercising inhibitory control in the regulation of impulsiveness (e.g. Lee et al., 2005, 2006; Liddle et al., 2001), which, in the advantageous risk-taking decision-making process, is essential to providing opportunities for careful consideration. Having the ability to detect impulse urges and thereby monitor the consequences of adverse behavioral outputs is essential to advantageous risk-taking decision making. The stronger activation in the ACC observed in the TCM group, relative to the control group, suggests improved self-monitoring and error-detection, in which the ACC is heavily involved (Brown & Braver, 2008), to aid outcome judgment and to correct for reward prediction errors.

4.4. Orbitofrontal cortex

In this study, no significant difference in BOLD responses was observed in the orbitofrontal region between the TCM group and the control group. Previous research has suggested that, during the process of decision making, activity in the orbitofrontal region is an important neural substrate of the goal-directed system (Walls, 2007), in terms of the valuation of action options by assigning a goal and decision values to an action (Hare, O’Doherty, Camerer, Schultz, & Rangel, 2008). Hence, the fact that no difference in BOLD responses in the orbitofrontal region was observed between the two groups suggests that it is unlikely that the advantageous risk-taking behavior associated with the consumption of the TCM recipe is related to changes in activity in this goal-directed system. Alternatively, it has also been thought that the orbitofrontal region is activated in situations of loss rather than gain (Trepel & Poldrack, 2005) and the BART as designed in such a way that risk-taking, but not risk-aversion, behavior was encouraged; therefore, the weak BOLD responses in the orbitofrontal region when performing the BART were expected. This may also explain why such activity was not observed in Rao et al.’s study (2008).

4.5. Limitations

Our findings clearly indicate the beneficial effect of the TCM recipe on the BART adjusted pumps. However, the findings are unable to decode the underlying mechanisms of the observed between-group differences, i.e., which neural substrates and connection on which the TCM ingredients are working to regulate the degree of impulsiveness and how such reduction of impulsiveness then facilitates the advantageous risk-taking behavior to increase the number of adjusted pumps. Future studies should be pursued to address this important question. Although we had control measures for possible confounding factors, the power of this study was limited by its relatively small sample size and the involvement of participants of one gender. Future studies should include more participants and involve both gender groups to allow more generalization on the effect of the TCM recipe on advantageous risk-taking. Also, studies involving the application of the TCM recipe to clinical groups that tended to be more risk-averse (e.g. people with anxiety disorder) or risk-prone (e.g. substance abusers) may further verify the beneficial effect of the current TCM recipe on advantageous risk-taking.
A sample size larger than that of this study should be employed, and a cross-over experimental design that incorporates risk-averse and risk-prone groups taking either the TCM or a normal diet should be incorporated. Due to practical constraints, a double-blind experimental design could not be adopted for this study. Future research should consider employing a double-blind experimental design for control of possible experimenter bias.

5. Conclusions

This study examined the neural activity accompanying the observed improvement in advantageous risk-taking decision making following a 60-day course of a TCM recipe. Our findings indicate stronger BOLD responses in the PFC–ACC–insula–striatum regions in people taking the TCM, suggesting that the TCM recipe may function to enhance the efficiency of the cognitive-affective regulation system that, during risk estimation, inhibits impulsiveness in the evaluation of potential gains and losses. The enhanced activity in the striatum suggested the sensitization of the reward-related information accompanying the use of the TCM, which encouraged engagement in advantageous risk-taking behavior. Implication of our findings is that the modulation of risk-taking decision making to promote advantageous risk-taking behavior is feasible via possible interventions which act on the factors that mediate the process of risk taking.

Acknowledgments

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