Dialectical thinking is linked with smaller bilateral nucleus accumbens and right amygdala: the mediating role of sensitivity to reward

Authors: Huixian Li, Xiaomeng Hu, Xiaomeng Hu

Date: 2021-02-09T00:00:00+00:00

Abstract

Our current work examined the interface of thinking style and mental health at both behavioral and neuropsychological levels which describe a predisposition to psychopathology. Thirty-nine Chinese participants were divided into high and low holistic thinkers based on the triad task scores, completed the Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ), and performed structural and resting-state functional magnetic resonance imaging. We found that high holistic thinkers were much less sensitive to reward than low holistic thinkers. Furthermore, their bilateral nucleus accumbens and right amygdala volumes were smaller than those of low holistic thinkers. Our integrated results showed that the relationship between holistic thinking tendency and the amygdala volume was mediated by the nucleus accumbens and the sensitivity to reward. Finally, resting-state functional connectivity results showed increased FC between left nucleus accumbens and bilateral amygdala in high holistic thinkers. The present synthetical results suggest that dialectical thinking may lead to better mental health outcomes.

Full Text

Preamble

Dialectical Thinking is Linked with Smaller Bilateral Nucleus Accumbens and Right Amygdala: The Mediating Role of Sensitivity to Reward

Hui-Xian Li[1],[2], Xiao Meng Hu[3]*

[1]CAS Key Laboratory of Behavioral Science, Institute of Psychology, Beijing, China
[2]Department of Psychology, University of Chinese Academy of Sciences, Beijing,

China
[3]Department of Psychology, Renmin University of China, Beijing, China

*Corresponding author: Xiao Meng Hu, Department of Psychology, Renmin University of China, No. 59 Zhongguancun Street, Haidian District, Beijing 100872, China.
E-mail address: xiaomeng825@gmail.com

Abstract

Our current work examined the interface of thinking style and mental health at both behavioral and neuropsychological levels, which describe a predisposition to psychopathology. Thirty-nine Chinese participants were divided into high and low holistic thinkers based on triad task scores, completed the Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ), and underwent structural and resting-state functional magnetic resonance imaging. We found that high holistic thinkers were significantly less sensitive to reward than low holistic thinkers. Furthermore, their bilateral nucleus accumbens and right amygdala volumes were smaller than those of low holistic thinkers. Our integrated results showed that the relationship between holistic thinking tendency and amygdala volume was mediated by the nucleus accumbens and sensitivity to reward. Finally, resting-state functional connectivity results demonstrated increased FC between left nucleus accumbens and bilateral amygdala in high holistic thinkers. These synthetic results suggest that dialectical thinking may lead to better mental health outcomes.

Keywords: Dialectical thinking; Holistic thinking; Reinforcement Sensitivity Theory; Amygdala; Nucleus Accumbens; Resting-State Functional Connectivity; Psychopathological Predisposition; Mental Health

Introduction

A growing body of research has illuminated profound differences between East Asians and Westerners in attention, perception, and cognition. East Asians tend to think holistically while Westerners think analytically. Holistic thinking involves understanding a system by sensing its larger-scale patterns and giving broader attention to context, relationships, and background elements. In contrast, analytical thinking involves understanding a system by examining its parts and how they work together to produce larger-scale effects, with a narrow focus on foreground objects and a tendency to disentangle phenomena from their contexts. Holistic thinkers attend to the entire field, assign causality to it, make relatively little use of categories and formal logic, and rely on "dialectical" reasoning.

Dialectical thinking influences how East Asians evaluate themselves, their lives, and their subjective well-being. Cross-cultural research demonstrates that East Asians report less positive affect, lower life satisfaction, and reduced psychologi-

cal well-being compared to Westerners. Although most researchers have shown that dialecticism correlates with lower psychological well-being, it remains unclear whether dialecticism has positive or negative impacts on mental health. Holistic thinking cultures accept constant change and contradiction, and holistic thinkers embrace the coexistence of positive and negative emotions (emotional complexity), exhibiting higher levels of emotional complexity than North Americans. Non-dialectical thinkers tend to polarize their emotional experiences, maximizing positive emotions while minimizing negative ones, whereas dialectical thinkers maintain a balance between moderate emotions and prefer emotional moderation. Therefore, a dialectical thinker may report less frequent high arousal of positive affect not because of lower subjective well-being, but because high arousal positive affect does not align with their conceptualizations of well-being.

A critical question concerns the relationship between dialectical thinking and mental health—specifically, whether dialectical thinking is associated with better or poorer mental health outcomes. However, the dominant concept of subjective well-being consists of positive emotions and the absence of negative emotions, reflecting European and American cultural values. Dialectical thinkers, who discourage extreme emotions, may balance positive emotions by accepting negative ones, and their tendency to accept negative emotional experiences may lead to lower subjective well-being. Therefore, it is preferable to measure positive and negative affect as separate dimensions and examine indicators more closely related to mental health.

In our current work, we proposed examining the associations among thinking style, emotional experiences, and behavioral reactivity as a means to resolve these issues. Gray' s Reinforcement Sensitivity Theory (RST), a prominent neuroscience theory of personality, consists of three major brain systems that regulate the intensity of approach and withdrawal behavior in response to emotional stimuli: the Behavioral Inhibition System (BIS), the Behavioral Activation System (BAS), and the Fight-Flight-Freeze System (FFFS). The BAS is responsible for approach behavior in response to pleasant stimuli and positive emotional experiences. The BIS controls behavior in response to goal conflict, becoming activated when a goal conflict stimulus is presented and producing anxiety that inhibits otherwise dominant behavior while seeking the best resolution. The FFFS system is activated by all conditioned and unconditioned aversive stimuli, regulating defensive avoidance behavior along with negative emotional experiences (fear). These systems reflect brain structures that influence sensitivity to reinforcing events and control emotional experiences.

RST identifies two general traits that can be assessed with self-report questionnaires. The first is punishment sensitivity (SP), which reflects the responsiveness of the FFFS and BIS, and the second is reward sensitivity (SR), which reflects the responsiveness of the BAS. Individuals with high SR/BAS experience more positive emotions and exhibit more approach behavior to achieve positive reinforcement, whereas individuals with high SP/BIS experience more negative

emotions and exhibit more behavioral inhibition. Thus, RST provides meaningful information for understanding individuals' positive and negative emotional experiences and behavioral responses, allowing assessment of the extent to which individuals pursue positive emotions (BAS) and avoid negative emotions (BIS) separately using well-validated questionnaires.

Prior research has demonstrated that SP/BIS and SR/BAS are valid predictors of various forms of psychopathology. Studies have shown that higher SP generalizes to anxiety disorders, anxiety-depression mixed disorders, obsessive-compulsive disorders, and longer duration of schizophrenia, while lower punishment sensitivity can predict unipolar depression. Furthermore, higher BAS can predict hyperactive-impulsive attention-deficit/hyperactivity disorder behaviors and addictive behaviors. At the opposite extreme, some researchers have linked depression disorders to lower BAS activity. Therefore, RST can provide an effective assessment of the psychopathological vulnerability of holistic and analytical thinkers.

The responsiveness of the BIS/BAS system depends on environmental inputs, while the sensitivity of the system is biologically based. Self-report questionnaires measure more of an individual' s responsiveness or perception of a stimulus, whereas biometric measures are direct indicators of individual sensitivity. Neurobiological factors such as brain structure and function play a vital role in understanding different thinking styles and their mental health risk. Of particular interest, the nucleus accumbens and amygdala are involved in social and emotional processing as well as reward and punishment processing, and their structural alterations have been associated with psychopathology. One pathway by which holistic/dialectical thinking may confer mental health risk is through changes to the amygdala and nucleus accumbens. Thus, examining structural and functional differences in these regions between holistic and analytical thinkers may provide insights into the emergence of psychopathology, as these structures can directly reflect how individuals with different thinking styles sensitize to positive and negative emotions.

Therefore, our work aimed to investigate the relationship between thinking styles and mental health from two perspectives. First, we linked thinking styles to Gray' s Reinforcement Sensitivity Theory as a predictor of psychopathology. Second, we examined whether structural and functional differences of the nucleus accumbens and amygdala exist between holistic and analytical thinkers. Finally, we integrated thinking styles, reinforcement sensitivity, and neural substrates. We examined group differences in participants with holistic versus analytical thinking styles using the triad task, where participants selected one of two images that matched a target image. One selection type belongs to the same abstract category (analytical thinking) as the target picture (e.g., chickens and cattle belong to the animal category), and the other has a functional relationship (holistic thinking) with the target picture (e.g., cattle eats grass). A disadvantage of cross-cultural research comparing these styles is the difficulty controlling for other culture-specific variables that might covary with analytical-

holistic cognitive styles. Therefore, we studied holistic and analytical participants within Chinese culture, as there exists a spectrum of individuals with analytical to holistic cognitive styles within each culture. We calculated the ratio of selected relational pairings to overall selections, representing individuals' holistic thinking tendency. We used the Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ) to evaluate the extent and sensitivity to which individuals experience positive and negative emotions, as this questionnaire is suitable for assessing self-reported sensitivity to social reward and punishment and social tendency and avoidance behavior. Furthermore, we collected structural and resting-state functional images using magnetic resonance imaging to examine the structure and function of the nucleus accumbens and amygdala.

We first tested the hypothesis that holistic thinkers would be less prone to positive reward and negative threat. Then, we related thinking styles to the volume of the amygdala and nucleus accumbens and their functional connectivity in the resting state. Finally, we examined relationships among thinking style, reinforcement sensitivity, and neural substrates.

Materials and Methods

Participants

Fifty Chinese adult participants who were young and healthy completed the magnetic resonance imaging scanning experiment and the triad task. Thirty-nine of them (18 males; age range: 18–28 years; mean age: 21 years) completed the MRI scanning experiment, the triad task, and online survey. Exclusion criteria included neurological or psychiatric disorders, psychotropic medication use, and any history of substance or alcohol abuse. Approval was obtained from the Institutional Review Board of the Institute of Psychology, Chinese Academy of Sciences, and all participants provided written informed consent.

Questionnaires

The Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ) consists of 48 yes-no response items containing two independent 24-item scales: sensitivity to punishment (SP) and sensitivity to reward (SR). The Chinese version of SPSRQ (SPSRQ-CV) removed 12 items that were not closely related to Chinese life or inconsistent with Chinese ways of thinking but was basically consistent with the original SPSRQ scale structure. The internal consistency coefficients of SR (16-item) and SP (18-item) were 0.64 and 0.80, respectively, and the test-retest reliability of SR and SP were 0.89 and [value missing in original].

Assessment of Holistic-Analytical Thinking Styles

Participants were asked to freely select one of two images that they thought matched the target image (see Fig. 3A [Figure 3: see original paper]). Selected items included two types: one belonged to the same abstract category (i.e., analytical thinking) as the target picture (e.g., chickens and cattle belong to the animal category), and the other had a functional relationship (i.e., holistic thinking) with the target picture (e.g., cattle eats grass). The task consisted of 14 different selection trials (see supplementary materials for all stimuli). The task-fMRI experiment obtained the number of two types of pictures selected by participants. Results showed that thirty-nine participants chose more relational pairings (the number of relational pairings: 9.38 ± 2.84; the number of category pairings: 4.13 ± 2.92; $T_{38} = 5.74$, $p < .00001$). We calculated the ratio of selected relational pairings to overall selection. Participants in the top 1/3 of the ratio score were categorized into the high holistic thinker group/holistic thinking tendency (0.90 ± 0.07), while those in the bottom 1/3 were categorized into the low holistic thinker group/analytical tendency (0.51 ± 0.19). The difference between the two groups was considerable ($T_{20 \cdot 01} = 7.64$, $p < .00001$).

MRI Data Acquisition

MRI data were acquired on a GE MR750 3.0T scanner with 8-channel cranial coil at the MRI Research Center, Institute of Psychology, Chinese Academy of Sciences. T1-weighted anatomical images were acquired using a 3D-SPGR pulse sequence (192 sagittal slices, repetition time (TR) = 6.652 ms, echo time (TE) = 2.928 ms, flip angle (FA) = 12 degrees, field of view (FOV) = 256 mm × 256 mm, matrix size = 256 × 256, slice thickness = 1 mm, voxel size = 1 × 1 × 1 mm^3). Functional data were acquired with echo-planar imaging (EPI) sequence (37 axial slices, TR = 2000 ms, TE = 30 ms, FA = 90 degrees, FOV = 224 mm × 224 mm, matrix size = 64 × 64, slice thickness = 3.5 mm, voxel size = 3.5 × 3.5 × 3.5 mm^3).

MRI Data Analysis

Cortical and subcortical volumetric segmentation was performed with DPABISurf (http://rfmri.org/DPABISurf) based on Freesurfer 6.0.1 (http://surfer.nmr.mgh.harvard.edu). The volumes of bilateral nucleus accumbens and amygdala were extracted from Freesurfer. Resting-state functional MRI data preprocessing was performed using the toolbox for Data Processing & Analysis of Brain Imaging (Yan et al., 2016) (http://rfmri.org/DPABI) based on Statistical Parametric Mapping (http://www.fil.ion.ucl.ac.uk/spm). Preprocessing comprised slice-timing and head motion correction, normalization to MNI space by DARTEL. Band-pass temporal filter (0.01–0.1 Hz) and spatial smoothing (4mm FWHM kernel) were applied to normalized functional images. We defined bilateral amygdala and nucleus accumbens as anatomical regions of interest (Chao et al.) and extracted the average time series from each

ROI, calculating their functional connectivity (FC) between each ROI-pair by Pearson correlation.

Mediation Analysis

We used the PROCESS tool in SPSS (Hayes, 2017) to test relationships among holistic thinking tendency, sensitivity to reward (SR), bilateral nucleus accumbens, and amygdala. The bootstrap approach was used to test significance with 5000 bootstrap resampling to generate 95% confidence intervals.

Results

Group Differences in Sensitivity to Reward and Punishment

Holistic thinking tendency was negatively correlated with reward sensitivity (Spearman' s rho (39) = -0.366, p = 0.022) but not correlated with punishment sensitivity (Spearman' s rho (39) = 0.198, p = 0.228) (Table 1). Furthermore, high holistic thinkers were significantly less sensitive to reward than low holistic thinkers (Fig. 1A [Figure 1: see original paper]; T_{28} = -2.465, p = 0.020, Cohen' s d = -0.902, 95% CI = (-3.858, -0.356)), while sensitivity to punishment did not differ between groups (Fig. 1A; T_{28} = 1.336, p = 0.192, Cohen' s d = 0.489, 95% CI = (-1.047, 4.976)).

Nucleus Accumbens and Amygdala Volume Differences Between Groups

High holistic thinkers had smaller volumes in the left nucleus accumbens (Fig. 1B; T_{28} = -3.614, p = 0.001, Cohen' s d = -1.323, 95% CI = (-155.013, -42.866)) and right nucleus accumbens (Fig. 1B; T_{28} = -3.279, p = 0.003, Cohen' s d = -1.200, 95% CI = (-152.158, -35.142)) compared to low holistic thinkers. The volume of the right amygdala was also smaller in high holistic thinkers (Fig. 1C; T_{28} = -2.170, p = 0.039, Cohen' s d = -0.794, 95% CI = (-321.984, -9.286)). Left amygdala volumes were likewise smaller in high holistic thinkers, but the difference was not significant (Fig. 1C; T_{28} = -1.610, p = 0.119).

Correlation and Mediation Analysis

We examined relationships among holistic thinking tendency, sensitivity to reward and punishment, and volumes of nucleus accumbens and amygdala. Positive correlations existed between bilateral nucleus accumbens and bilateral amygdala volumes (Table 1; Pearson' s r = 0.420, p = 0.008; Pearson' s r = 0.490, p = 0.002; Pearson' s r = 0.494, p = 0.001; Pearson' s r = 0.556, p < .001). Holistic thinking tendency was negatively related to bilateral nucleus accumbens volumes (Table 1; Left: Spearman' s rho (39) = -0.523, p < .001; Right: Spearman' s rho (39) = -0.463, p = 0.003) and right amygdala volume (Table 1; Spearman' s rho (39) = -0.321, p = 0.047). Sensitivity to reward was positively correlated with left nucleus accumbens volume (Spearman' s rho (39)

= -0.379, p = 0.017), with the correlation between reward sensitivity and right nucleus accumbens volume being borderline significant (Spearman' s rho (39) = -0.311, p = 0.054). No significant correlation was found between punishment sensitivity and other variables.

Mediation analysis revealed that sensitivity to reward had a partial mediating effect between thinking tendency and left nucleus accumbens volume (Fig. 1D, Table 2). For the right nucleus accumbens, the mediating effect of SR was not significant, though the regulating effect was significant (Fig. S1). The relationship between holistic thinking tendency and bilateral amygdala volume was fully mediated by nucleus accumbens volume (Fig. 1D, Table 2, a2b2; Fig. S2). Moreover, reward sensitivity could influence this relationship through nucleus accumbens volume (Fig. 1D, Table 2, a1a3b2).

Resting-State Functional Connectivity

High holistic thinkers demonstrated increased FC between left nucleus accumbens and bilateral amygdala compared to low holistic thinkers (Fig. 1E; LNAcc-LAmy: T_{28} = 3.209, p = 0.003, Cohen' s d = 1.174, 95% CI = (0.069, 0.314); LNAcc-RAmy: T_{28} = 2.518, p = 0.018, Cohen' s d = 0.921, 95% CI = (0.027, 0.261)).

Discussion

To our knowledge, this is among the first studies to link Reinforcement Sensitivity Theory and neural substrates of holistic versus analytical thinking, providing behavioral and biological mechanisms to support the connection between different ways of thinking and mental health indicators.

We used the SPSRQ based on RST to evaluate individual sensitivity to positive and negative emotions. High holistic thinkers showed lower sensitivity to reward than low holistic thinkers, suggesting they are less likely to pursue extreme positive emotions. Different thinkers' beliefs about mental health may partially explain these results. Tsai et al.' s work shows that Hong Kong Chinese value high-arousal positive affect less and low-arousal positive affect more than European Americans. Since values influence behavior and people promote mental health by seeking experiences that fit their beliefs, holistic beliefs emphasizing moderation may result in lower levels of high-arousal positive affect and approach behavior, as the pursuit of positive affect is less relevant to these beliefs.

Substantial research has shown that SP/BIS and SR/BAS are associated with various psychological disorders, particularly punishment sensitivity. Reward sensitivity is less associated with mental illness and mainly manifests in addictive behaviors, where addicts show high reward sensitivity. An epidemiological study shows that BIS is a vulnerability factor for anxiety and depression, while BAS relates to drug abuse and non-comorbid alcohol diagnoses, though no relationship exists between BAS and depression diagnoses. However, distinguishing

subtypes of depressive symptoms reveals that low BAS predicts anhedonic depression but not mixed anxiety-depression symptoms. Since BIS and BAS are functionally interdependent with antagonistic effects, low BAS may exacerbate high BIS effects on anhedonic depressive symptoms. Hundt et al. show that when life stress is low, low BAS and high BIS predict anhedonic depression. We found no differences in punishment sensitivity between groups, whereas reward sensitivity was lower in high holistic thinkers, suggesting that high holistic thinkers may have a predisposition to anhedonic depression, particularly when life circumstances are generally good, as dialectical tendencies to "look for the bad in the good" and reduced pursuit of positive emotions may increase anhedonia.

The amygdala and nucleus accumbens are closely related to emotions and respond to both negative and positive signals, with structural alterations associated with psychopathology. Trait anxiety correlates positively with bilateral nucleus accumbens volume, and higher social anxiety predicts increased gray matter volume in the right amygdala and bilateral nucleus accumbens. Adolescents with major depressive disorder show larger nucleus accumbens volume compared to healthy controls. A meta-analysis of amygdala volume in mood disorders shows increased left amygdala volume in adults with bipolar disorder, with left amygdala volume larger in unipolar inpatients than controls, though no significant changes appear in unipolar outpatients. The largest MDD study did not detect differences in amygdala and nucleus accumbens volumes, though hippocampal volumes were lower. Our work suggests that bilateral nucleus accumbens and right amygdala are smaller in high holistic thinkers, indicating that individuals with a high holistic thinking style may be at lower risk for anxiety and depression. Based on neural mechanisms, we may state that individuals with dialectical thinking report lower subjective well-being, but this does not necessarily mean their thinking styles result in poor mental health outcomes.

Our results indicate that the relationship between holistic thinking tendency and amygdala volume is fully mediated by nucleus accumbens volume. Across various species, the amygdala and nucleus accumbens respond to both negative and positive signals, with the amygdala responding most dramatically to negative stimuli and the nucleus accumbens most consistently responsive to reward stimuli. Numerous neuronal connections between these regions have been implicated in cue-reward associations. Our results show that holistic thinking tendency is negatively correlated with reward sensitivity, which is positively related to nucleus accumbens volume, and there is a negative correlation between holistic thinking tendency and nucleus accumbens volume. Therefore, high holistic thinkers' insensitivity to reward could partly explain their smaller bilateral nucleus accumbens volumes, which further mediates the relationship between holistic thinking tendency and amygdala volume.

In addition to finding that high holistic thinking individuals are reward-insensitive and have smaller bilateral nucleus accumbens and right amygdala volumes, we also found significantly higher resting-state functional connectivity

between left nucleus accumbens and bilateral amygdala in high versus low holistic thinkers. Beyeler et al. demonstrate that projections between amygdala and nucleus accumbens preferentially encode positive valence, and optogenetic activation of bilateral amygdala terminals in nucleus accumbens drives positive reinforcement, which may facilitate approval behavior. Therefore, resting-state FC between these regions may reflect individual spontaneous responsiveness strength to reward-related stimuli. Although high holistic thinkers self-report reward insensitivity, their brain functions may be more authentic and credible. The increased functional connectivity may illustrate that high holistic thinkers are sensitive to reward stimulus responses, whereas self-reported reward insensitivity may reflect their beliefs about seeking positive emotions rather than actual sensitivity.

In conclusion, our study shows that individuals who score high on holistic thinking have lower sensitivity to reward. In terms of neural substrates, individuals with a high holistic thinking tendency had smaller volumes in bilateral nucleus accumbens and right amygdala than those with a low holistic thinking tendency. Furthermore, we found increased resting-state functional connectivity between bilateral amygdala and nucleus accumbens in high holistic thinkers. Taken together, these results manifest the complex relationships between dialectical thinking and mental health, which await future research to uncover.

References

Adrián-Ventura, J., Costumero, V., Parcet, M.A., Ávila, C., 2019. Linking personality and brain anatomy: a structural MRI approach to Reinforcement Sensitivity Theory. Soc Cogn Affect Neurosci 14, 329-338.

Bacha-Trams, M., Alexandrov, Y.I., Broman, E., Glerean, E., Kauppila, M., Kauttonen, J., Ryyppö, E., Sams, M., Jääskeläinen, I.P., 2018. A drama movie activates brains of holistic and analytical thinkers differentially. Soc Cogn Affect Neurosci 13, 1293-1304.

Beyeler, A., Namburi, P., Glober, G.F., Simonnet, C., Calhoon, G.G., Conyers, G.F., Luck, R., Wildes, C.P., Tye, K.M., 2016. Divergent Routing of Positive and Negative Information from the Amygdala during Memory Retrieval. Neuron 90, 348-361.

Boucher, H.C., Peng, K., Shi, J., Wang, L., 2009. Culture and Implicit Self-Esteem: Chinese Are "Good" and "Bad" at the Same Time. Journal of Cross-Cultural Psychology 40, 24-45.

Chao, M.M., Chen, J., Roisman, G.I., Hong, Y.-y., 2007. Essentializing race: Implications for bicultural individuals' cognition and physiological reactivity. Psychological Science 18, 341-348.

Chen, S.X., Benet-Martínez, V., Wu, W.C., Lam, B.C., Bond, M.H., 2013. The role of dialectical self and bicultural identity integration in psychological adjustment. Journal of Personality 81, 61-75.

Cheng, C., Jose, P.E., Sheldon, K.M., Singelis, T.M., Cheung, M.W.L., Tiliouine, H., Alao, A.A., Chio, J.H.M., Lui, J.Y.M., Chun, W.Y., Golec de Zavala, A., Hakuzimana, A., Hertel, J., Liu, J.-T., Onyewadume, M., Sims, C., 2011. Sociocultural Differences in Self-Construal and Subjective Well-Being: A Test of Four Cultural Models. Journal of Cross-Cultural Psychology 42, 832-855.

Corr, P.J., 2002. J. A. Gray' s reinforcement sensitivity theory: tests of the joint subsystems hypothesis of anxiety and impulsivity. Personality and Individual Differences 33, 511-532.

Corr, P.J., 2004. Reinforcement sensitivity theory and personality. Neurosci Biobehav Rev 28, 317-332.

En-jie, W., 2012. Reliability and validity of Chinese Version of SPSRQ in University Students. Chin J Sch Health, 60-62.

Ernst, M., Nelson, E.E., Jazbec, S., McClure, E.B., Monk, C.S., Leibenluft, E., Blair, J., Pine, D.S., 2005. Amygdala and nucleus accumbens in responses to receipt and omission of gains in adults and adolescents. Neuroimage 25, 1279-1291.

Franken, I.H.A., Muris, P., Georgieva, I., 2006. Gray' s model of personality and addiction. Addictive Behaviors 31, 399-403.

Fullana, M.A., Mataix-Cols, D., Caseras, X., Alonso, P., Manuel Menchón, J., Vallejo, J., Torrubia, R., 2004. High sensitivity to punishment and low impulsivity in obsessive-compulsive patients with hoarding symptoms. Psychiatry Research 129, 21-27.

Fussner, L.M., Luebbe, A.M., Smith, A.R., 2018. Social reward and social punishment sensitivity in relation to dietary restraint and binge/purge symptoms. Appetite 127, 386-392.

Gray, J.A., 1970. The psychophysiological basis of introversion-extraversion. Behav Res Ther 8, 249-266.

Gray, J.A., Mcnaughton, N., 2000. The neuropsychology of anxiety: an enquiry into the functions of the septo-hippocampal system. Oxford University Press.

Günther, V., Ihme, K., Kersting, A., Hoffmann, K.T., Lobsien, D., Suslow, T., 2018. Volumetric Associations Between Amygdala, Nucleus Accumbens, and Socially Anxious Tendencies in Healthy Women. Neuroscience 374, 25-32.

Hamamura, T., Heine, S.J., Paulhus, D.L., 2008. Cultural differences in response styles: The role of dialectical thinking. Personality and Individual Differences 44, 932-942.

Hamilton, J.P., Siemer, M., Gotlib, I.H., 2008. Amygdala volume in major depressive disorder: a meta-analysis of magnetic resonance imaging studies. Mol Psychiatry 13, 993-1000.

Hayes, A.F., 2017. Introduction to mediation, moderation, and conditional process analysis: A regression-based approach. Guilford Publications.

Hundt, N.E., Nelson-Gray, R.O., Kimbrel, N.A., Mitchell, J.T., Kwapil, T.R., 2007. The interaction of reinforcement sensitivity and life events in the prediction of anhedonic depression and mixed anxiety-depression symptoms. Personality and Individual Differences 43, 1001-1012.

Johnson, S.L., Turner, R.J., Iwata, N., 2003. BIS/BAS Levels and Psychiatric Disorder: An Epidemiological Study. Journal of Psychopathology and Behavioral Assessment 25, 25-36.

Keistler, C.R., Hammarlund, E., Barker, J.M., Bond, C.W., DiLeone, R.J., Pittenger, C., Taylor, J.R., 2017. Regulation of Alcohol Extinction and Cue-Induced Reinstatement by Specific Projections among Medial Prefrontal Cortex, Nucleus Accumbens, and Basolateral Amygdala. J Neurosci 37, 4462-4471.

Kelley, A.E., 2004. Ventral striatal control of appetitive motivation: role in ingestive behavior and reward-related learning. Neurosci Biobehav Rev 27, 765-776.

Kimbrel, N.A., Nelson-Gray, R.O., Mitchell, J.T., 2007. Reinforcement sensitivity and maternal style as predictors of psychopathology. Personality and Individual Differences 42, 1139-1149.

Kitayama, S., Ishii, K., Imada, T., Takemura, K., Ramaswamy, J., 2006. Voluntary settlement and the spirit of independence: evidence from Japan's "Northern frontier" . J Pers Soc Psychol 91, 369-384.

Kitayama, S., Markus, H.R., Kurokawa, M., 2000. Culture, Emotion, and Well-being: Good Feelings in Japan and the United States. Cognition and Emotion 14, 93-124.

Kühn, S., Schubert, F., Gallinat, J., 2011. Structural correlates of trait anxiety: reduced thickness in medial orbitofrontal cortex accompanied by volume increase in nucleus accumbens. J Affect Disord 134, 315-319.

Lee, K.H., Yoo, J.H., Lee, J., Kim, S.H., Han, J.Y., Hong, S.B., Shin, J., Cho, S.C., Kim, J.W., Brent, D.A., 2020. The indirect effect of peer problems on adolescent depression through nucleus accumbens volume alteration. Sci Rep 10, 12870.

Lee, S.-j., Wu, C.-h., 2008. Comparing the Level of Positive Tendency in a Life Satisfaction Evaluation between Chinese and Western People. Social Indicators Research 89, 147-153.

Lee, Y.-T., Seligman, M.E.P., 1997. Are Americans more Optimistic than the Chinese? Personality and Social Psychology Bulletin 23, 32-40.

Leu, J., Wang, J., Koo, K., 2011. Are Positive Emotions Just as "Positive" Across Cultures? Emotion 11, 994-999.

Maack, D.J., Tull, M.T., Gratz, K.L., 2012. Examining the incremental contribution of behavioral inhibition to generalized anxiety disorder relative to other Axis I disorders and cognitive-emotional vulnerabilities. J Anxiety Disord 26, 689-695.

May, J.C., Delgado, M.R., Dahl, R.E., Stenger, V.A., Ryan, N.D., Fiez, J.A., Carter, C.S., 2004. Event-related functional magnetic resonance imaging of reward-related brain circuitry in children and adolescents. Biol Psychiatry 55, 359-366.

McNaughton, N., Corr, P.J., 2004. A two-dimensional neuropsychology of defense: fear/anxiety and defensive distance. Neurosci Biobehav Rev 28, 285-305.

Mitchell, J.T., Nelson-Gray, R.O., 2006. Attention-Deficit/Hyperactivity Disorder symptoms in adults: Relationship to Gray' s Behavioral Approach System. Personality and Individual Differences 40, 749-756.

Miyamoto, Y., Ryff, C.D., 2011. Cultural differences in the dialectical and nondialectical emotional styles and their implications for health. Cognition and Emotion 25, 22-39.

Monk, C.S., Klein, R.G., Telzer, E.H., Schroth, E.A., Mannuzza, S., Moulton, J.L., 3rd, Guardino, M., Masten, C.L., McClure-Tone, E.B., Fromm, S., Blair, R.J., Pine, D.S., Ernst, M., 2008. Amygdala and nucleus accumbens activation to emotional facial expressions in children and adolescents at risk for major depression. Am J Psychiatry 165, 90-98.

Namburi, P., Beyeler, A., Yorozu, S., Calhoon, G.G., Halbert, S.A., Wichmann, R., Holden, S.S., Mertens, K.L., Anahtar, M., Felix-Ortiz, A.C., Wickersham, I.R., Gray, J.M., Tye, K.M., 2015. A circuit mechanism for differentiating positive and negative associations. Nature 520, 675-678.

Nisbett, R.E., Masuda, T., 2003. Culture and point of view. Proc Natl Acad Sci U S A 100, 11163-11170.

Nisbett, R.E., Miyamoto, Y., 2005. The influence of culture: holistic versus analytic perception. Trends Cogn Sci 9, 467-473.

Nisbett, R.E., Peng, K., Choi, I., Norenzayan, A., 2001. Culture and systems of thought: holistic versus analytic cognition. Psychol Rev 108, 291-310.

Pardo, Y., Aguilar, R., Molinuevo, B., Torrubia, R., 2007. Alcohol use as a behavioural sign of disinhibition: Evidence from J.A. Gray' s model of personality. Addictive Behaviors 32, 2398-2403.

Phelps, E.A., O' Connor, K.J., Gatenby, J.C., Gore, J.C., Grillon, C., Davis, M., 2001. Activation of the left amygdala to a cognitive representation of fear. Nat Neurosci 4, 437-441.

Piantadosi, P.T., Yeates, D.C.M., Wilkins, M., Floresco, S.B., 2017. Contributions of basolateral amygdala and nucleus accumbens subregions to mediating

motivational conflict during punished reward-seeking. Neurobiol Learn Mem 140, 92-105.

Schimmack, U., 2007. Methodological Issues in the Assessment of the Affective Component of Subjective Well Being. Oxford Handbook of Methods in Positive Psychology.

Schmaal, L., Pozzi, E., T, C.H., van Velzen, L.S., Veer, I.M., Opel, N., Van Someren, E.J.W., Han, L.K.M., Aftanas, L., Aleman, A., Baune, B.T., Berger, K., Blanken, T.F., Capitão, L., Couvy-Duchesne, B., K, R.C., Dannlowski, U., Davey, C., Erwin-Grabner, T., Evans, J., Frodl, T., Fu, C.H.Y., Godlewska, B., Gotlib, I.H., Goya-Maldonado, R., Grabe, H.J., Groenewold, N.A., Grotegerd, D., Gruber, O., Gutman, B.A., Hall, G.B., Harrison, B.J., Hatton, S.N., Hermesdorf, M., Hickie, I.B., Hilland, E., Irungu, B., Jonassen, R., Kelly, S., Kircher, T., Klimes-Dougan, B., Krug, A., Landrø, N.I., Lagopoulos, J., Leerssen, J., Li, M., Linden, D.E.J., MacMaster, F.P., A, M.M., Mehler, D.M.A., Nenadi, I., Penninx, B., Portella, M.J., Reneman, L., Rentería, M.E., Sacchet, M.D., P, G.S., Schrantee, A., Sim, K., Soares, J.C., Stein, D.J., Tozzi, L., van Der Wee, N.J.A., van Tol, M.J., Vermeiren, R., Vives-Gilabert, Y., Walter, H., Walter, M., Whalley, H.C., Wittfeld, K., Whittle, S., Wright, M.J., Yang, T.T., Zarate, C., Jr., Thomopoulos, S.I., Jahanshad, N., Thompson, P.M., Veltman, D.J., 2020. ENIGMA MDD: seven years of global neuroimaging studies of major depression through worldwide data sharing. Transl Psychiatry 10, 172.

Scholten, M.R.M., van Honk, J., Aleman, A., Kahn, R.S., 2006. Behavioral inhibition system (BIS), Behavioral activation system (BAS) and schizophrenia: Relationship with psychopathology and physiology. Journal of Psychiatric Research 40, 638-645.

Schultz, W., 2004. Neural coding of basic reward terms of animal learning theory, game theory, microeconomics and behavioural ecology. Curr Opin Neurobiol 14, 139-147.

Sheth, C., McGlade, E., Yurgelun-Todd, D., 2017. Chronic Stress in Adolescents and Its Neurobiological and Psychopathological Consequences: An RDoC Perspective. Chronic Stress 1.

Smillie, L.D., Pickering, A.D., Jackson, C.J., 2006. The new reinforcement sensitivity theory: implications for personality measurement. Pers Soc Psychol Rev 10, 320-335.

Spencer-Rodgers, J., Peng, K., 2018. The psychological and cultural foundations of East Asian cognition: Contradiction, change, and holism.

Spencer-Rodgers, J., Peng, K., Wang, L., 2010. Dialecticism and the Co-occurrence of Positive and Negative Emotions Across Cultures. Journal of Cross-Cultural Psychology 41, 109-115.

Spencer-Rodgers, J., Peng, K., Wang, L., Hou, Y., 2004. Dialectical self-esteem and East-West differences in psychological well-being. Pers Soc Psychol Bull 30,

1416-1432.

Talhelm, T., Zhang, X., Oishi, S., Shimin, C., Duan, D., Lan, X., Kitayama, S., 2014. Large-scale psychological differences within China explained by rice versus wheat agriculture. Science 344, 603-607.

Torrubia, R., Ávila, C., Moltó, J., Caseras, X., 2001. The Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ) as a measure of Gray' s anxiety and impulsivity dimensions. Personality and Individual Differences 31, 837-862.

Tottenham, N., Galván, A., 2016. Stress and the adolescent brain: Amygdala-prefrontal cortex circuitry and ventral striatum as developmental targets. Neurosci Biobehav Rev 70, 217-227.

Tsai, J.L., Knutson, B., Fung, H.H., 2006. Cultural variation in affect valuation. J Pers Soc Psychol 90, 288-307.

Whalen, P.J., Rauch, S.L., Etcoff, N.L., McInerney, S.C., Lee, M.B., Jenike, M.A., 1998. Masked presentations of emotional facial expressions modulate amygdala activity without explicit knowledge. J Neurosci 18, 411-418.

Wong, Y., Liu, T., 2018. Dialecticism and mental health: Toward a Yin-Yang vision of well-being.

Wong, Y.J., Ho, R.M., Li, P., Shin, M., Tsai, P.-C., 2011. Chinese Singaporeans' lay beliefs, adherence to Asian values, and subjective well-being. Personality and Individual Differences 50, 822-827.

Yan, C.G., Wang, X.D., Zuo, X.N., Zang, Y.F., 2016. DPABI: Data Processing & Analysis for (Resting-State) Brain Imaging. Neuroinformatics 14, 339-351.

Zisserson, R.N., Palfai, T.P., 2007. Behavioral Activation System (BAS) sensitivity and reactivity to alcohol cues among hazardous drinkers. Addictive Behaviors 32, 2178-2186.

Table S1. The tests of normality. Holistic thinking tendency (HT) reward sensitivity (SR) punishment sensitivity (SP) Left Nucleus Accumbens (LNAcc) Right Nucleus Accumbens (RNAcc) Left Amygdala (Bar-Haim, #1719) Right Amygdala (RAmy) * This is a lower bound of the true significance. Kolmogorov-Smirnova .200* .200* .200* .200* Statistic Shapiro-Wilk Statistic

Fig. S1. The effect of sensitivity between thinking tendency and nucleus accumbens volume: moderate effect (A) and partial mediating effect (B).

Fig. S2. The full mediating effect of right nucleus accumbens volume between thinking tendency and bilateral amygdala volume.

Note: Figure translations are in progress. See original paper for figures.