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Use of magnetic resonance spectroscopy to explore metacognitive ability and academic score

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Abstract

Background: Previous studies have reported the important roles of the precuneus in mediating metacognition and the prefrontal cortex in decision-making tasks. However, the underlying mechanisms of metacognition are still not fully elucidated. Long echo time proton magnetic resonance spectroscopy (MRS) was used to further explore the neurocognitive correlates of metacognition.

Methods: Metacognition was based on a self-report questionnaire of nursing students. Magnetic resonance (MR) spectra were recorded from bilateral precuneus and medial prefrontal cortex.

Results: Significant positive correlation was discovered between total metacognitive score and academic score ($p = 0.007$). Precuneus N-acetyl aspartate/creatine plus phosphocreatine (NAA/Cr+PCr) ratios were corresponded to metacognitive ability. Moreover, the correlation between precuneus NAA/Cr+PCr ratios and metacognitive ability was established for the right precuneus and not left precuneus. Furthermore, linear regression suggested that for every increase in the right precuneus NAA/Cr+PCr ratios, there is a predicted decrease in total metacognitive score ($p = 0.020$).

Conclusions: These findings further indicated that the right precuneal region plays an important role in metacognition and learning.

Keywords: Magnetic resonance spectroscopy, Metacognition, Precuneus, Prefrontal cortex, Learning

Background

Metacognitive ability is the capacity to introspectively monitor and control one's own cognitive processes, which is useful for the improvement of learning efficiency, social communication, and mental health [1-3]. Previous studies have confirmed the important role of the precuneus in mediating metacognition through repetitive transcranial magnetic stimulation [4-5]. Moreover, previous findings have also

reported that the prefrontal cortex is essentially involved in metacognition through decision-making tasks [6]. Lesions to anterior prefrontal cortex impair perceptual metacognitive accuracy while sparing memory metacognitive accuracy [7-8]. Macaque monkey's metacognitive capability of introspecting its own memory success is causally dependent on intact superior dorsolateral prefrontal cortices but not the orbitofrontal cortices [9]. Studies in the past have indicated that variation in memory metacognitive efficiency was correlated with the volume of the precuneus [10]. Despite recent studies indicating the neural architecture of metacognition in various cognitive domains [7-8,10-13], the complex relationships concerning metacognition are still not fully understood. Magnetic resonance spectroscopy (MRS) is a noninvasive technique increasingly used in recent times, which can provide information regarding the chemical or metabolic composition of the brain [14]. Some metabolite changes have been found in both patients with mild cognitive impairment and Alzheimer's disease, especially the latter [15-17]. We hypothesized that metabolite levels in related brain regions may be related to metacognitive ability. In contrast with earlier studies, MRS was used to further explore the complex neurocognitive correlates of metacognition.

Methods

Participants

A total of 117 nursing students (90 females; age range, 18 – 21 years) from Binzhou Medical University voluntarily participated in this study. All participants were healthy. The exclusion criteria were brain injury, encephalitis, and psychiatric disorders. The aims and objectives of the study were introduced to each participant, and written consents from all participants were obtained prior to the test. The study was approved by the Ethics Committee of Binzhou Medical University.

Survey tools

A 24-item metacognitive ability scale was used [18], involving four factors:

metacognitive planning (seven items, including 7, 9, 16, 17, 18, 21, 24), metacognitive monitoring (six items, including 8, 10, 12, 13, 22, 23), metacognitive regulating (six items, including 1, 2, 3, 4, 19, 20), and metacognitive evaluating (five items, including 5, 6, 11, 14, 15). The response alternatives were on a five-point Likert scale (1, never; 2, seldom; 3, sometimes; 4, often; and 5, always). The total score range was from 24 to 120, with higher scores indicating better metacognitive ability. The Cronbach's alpha for the total score has been reported to be 0.93/0.87 for metacognitive planning, 0.83 for metacognitive monitoring, 0.85 for metacognitive regulating, and 0.79 for metacognitive evaluating. The content validity (experts) and construct validity (exploratory and confirmatory factor analyses) of the scale have been shown to be acceptable. The four factors explained 66.9% of the variance [18-19]. All participants were trained in order to fully understand the survey process and the meaning of the scale items. All questionnaires were issued and taken back on the spot, taking a class as a unit. There were 117 questionnaires returned, and all of them had complete data. Academic score referred to the sum of test scores for all subjects of the current semester.

Magnetic resonance spectroscopy

Magnetic resonance (MR) examinations were performed by a SIEMENS Skyra 3.0 T MR scanner with a standard quadrature head coil. A standard two-dimensional (2D) chemical-shift imaging point-resolved spectroscopy (CSI-PRESS) was used with the following parameters: TR, 1700 ms; TE, 135 ms; thickness, 15 mm; matrix, 160 mm × 160 mm; bandwidth, 1200 Hz; flip angle, 90; and average, 3. Axial, sagittal, and coronal T2 weighted imaging (T2WI) scans were acquired for locating. A rectangular volume of interest (VOI, A>>P 120 mm; R>>L, 150 mm; F>>H 15 mm) was placed to cover the precuneus and medial prefrontal lobe. MR spectra were observed from the bilateral precuneus and medial prefrontal cortex (Fig. 1), with a voxel size of 10 mm × 10mm × 15mm. The voxel in the precuneus was selected in the front side of parietooccipital sulcus at the roof of the lateral ventricle level. The voxel in the prefrontal lobe was selected in the medial prefrontal cortex. The spectra were

analyzed using the Functool software package. Metabolite ratios, including N-acetyl aspartate/creatine plus phosphocreatine (NAA/Cr+PCr), phosphocholine plus glycerophosphocholine/creatine plus phosphocreatine (PC+GPC/Cr+PCr), and myo-inositol/creatine plus phosphocreatine (mI/Cr+PCr), were automatically calculated (Fig. 2).

Fig. 1. MRS location images. Axial ROIs of the right precuneus (a) and left medial prefrontal cortex (b).

Fig. 2. MR spectra. Metabolites, including NAA, PC+GPC, Cr+PCr, and mI of the right precuneus (a) and left medial prefrontal cortex (b).

Statistical methods

Statistical analysis was carried out using the Statistical Package for the Social Sciences (version 21.0). One-way ANOVA, pearson correlation analysis, and linear regression were utilized to describe the relationship between metacognitive scores, academic score, and metabolites ratios.

Results

Most students in the study population were female (76.9%; $n = 90$), and 23.1% were male ($n = 27$). The students' average age was 19.6 years (standard deviation [SD], 0.71), ranging from 18 to 21 years. The total score of the metacognitive ability of 117 nursing students was 81.45 ± 11.91 . And the scores of four factors were as follows: 22.96 ± 3.91 in metacognitive planning, 20.90 ± 2.99 in metacognitive monitoring, 19.68 ± 3.81 in metacognitive regulating, and 17.91 ± 2.92 in metacognitive evaluating, respectively. Although the dominant participants in this study were females, no statistical difference was observed between males and females in terms of metacognitive scores, including four factors ($p > 0.05$).

The Pearson correlation analysis with adjusted Bonferroni correction demonstrated a significant positive correlation between the total metacognitive score and academic score ($p = 0.007$; Table 1 and Fig. 3). Positive correlation was also observed between metacognitive evaluating score and academic score (Table 1).

Fig. 3. Relationship between the total metacognitive score and total academic score. Positive correlation was revealed ($r = 0.250$; $p = 0.007$).

Table 1 Associations between metacognitive scores and total academic score for 117 students

Metacognitive scores	Total academic score	
	r value	p value
Metacognitive planning score	0.203*	0.028
Metacognitive monitoring score	0.191*	0.040
Metacognitive regulating score	0.193*	0.038
Metacognitive evaluating score	0.299** Δ	0.001

Total metacognitive score	0.250** Δ	0.007
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Note: Pearson correlation analysis. **Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed). Δ , Adjusted Bonferroni correction: correlation is significant at the 0.05/5 level (2-tailed).

Precuneus NAA/Cr+PCr ratios were found to be correlated to metacognitive monitoring score ($p = 0.014$, Fig. 4a), metacognitive evaluating score ($p = 0.013$, Fig. 4b), and total metacognitive score ($p = 0.014$, Fig. 4c) respectively.

Fig. 4. Relationship between precuneus NAA/Cr+PCr ratios and metacognitive ability. Negative correlation were reported between precuneus NAA/Cr+PCr ratios and metacognitive monitoring score (a; $r = -0.238$, $p = 0.014$), metacognitive evaluating score (b; $r = -0.240$, $p = 0.013$), and total metacognitive score (c; $r = -0.237$, $p = 0.014$).

Moreover, the correlation between precuneus NAA/Cr+PCr ratios and metacognitive ability was observed for the right precuneus, but not the left precuneus. Right precuneus NAA/Cr+PCr ratios were correlated to metacognitive monitoring score ($p = 0.013$, Fig. 5a), metacognitive regulating score ($p = 0.034$, Fig. 5b), and total metacognitive score ($p = 0.020$, Fig. 5c).

Fig. 5. Relationship between right precuneus NAA/Cr+PCr ratios and metacognitive ability. Negative correlations were reported between the right precuneus NAA/Cr+PCr ratios and metacognitive monitoring score (a; $r = -0.241$, $p = 0.013$), metacognitive regulating score (b; $r = -0.206$, $p = 0.034$), and total metacognitive score (c; $r = -0.226$, $p = 0.020$).

Furthermore, linear regression suggested that for every increase in the right precuneus NAA/Cr+PCr ratios, there is a predicted decrease in total metacognitive score. Total metacognitive score = $94.493 - 6.819$ right precuneus NAA/Cr+PCr ratios ($t = -2.365$; $p = 0.020$).

Discussion

Metacognitive ability is a powerful predictor of academic achievement [3,20-21]. The results of this study are in agreement with results of previous studies. Significant positive correlation was found between metacognitive ability and academic score.

Self-monitoring of memory is necessary for successful learning and retention. It has been illustrated that metacognitive monitoring can be captured through Judgments of Learning (JOLs) [22]. Event-related potentials were used to compare neural correlates of JOLs and successful memory encoding. Therefore, ERP data indicate that JOLs do not reduce the encoding processes that predict the accuracy of memory judgments [23]. Previous findings reported that JOLs made during studying correlate with memory retrieval during test; however, this correlation is specific to recollection [24]. A previous study revealed that JOLs were accompanied by a positive slow wave over the medial frontal areas and a bilateral negative slow wave over occipital areas

[25]. A previous neuropsychological study indicated different processes for metacognitive and cognitive judgments in children by providing direct electrophysiological evidence of more negative slow wave over centroparietal areas [26]. The significant roles of the anterior prefrontal cortex in perceptual metacognition [7] and the precuneus in memory metacognition [8,10,27-28] have been previously elucidated. The link between memory metacognitive efficiency and the precuneal gray matter density has been identified [10]. A similar relationship was discovered between mnemonic metacognitive efficiency and resting-state functional connectivity between the precuneus and medial anterior prefrontal cortex [12].

In this study, MRS measurement of the medial prefrontal cortex was not found to be related to metacognitive ability, which was not consistent with previous research. The suggested explanation for this is that MR measurements of the medial prefrontal cortex were prone to artifact interference due to the anterior skull base and sinus. However, some meaningful discoveries have been achieved in the precuneus. Precuneus NAA/Cr+PCr ratios were correlated to metacognitive ability. Moreover, the correlation between precuneus NAA/Cr+PCr ratios and metacognitive ability was noted for the right precuneus, but not left precuneus. Further linear regression suggested that for every increase in the right precuneus NAA/Cr+PCr ratios, there is a predicted decrease in total metacognitive score. With regard to the relationship between the precuneus and metacognition, a possible circuit encompassing the precuneus and its mnemonic midbrain neighbor, the hippocampus, at the service of realizing our meta-awareness during memory recollection of episodic details has been presented [5]. NAA is commonly referred to as a neuronal marker, which is predominantly present in neurons [29]. NAA is a reasonably good surrogate marker of neuronal health in several neurologic and psychiatric disorders. Reduced NAA/Cr+PCr ratios have been manifested in Alzheimer's disease [16-17], which might reflect a loss of neuronal components and neuronal function disruption, or both [17]. However, this study reported negative correlations between the right precuneus NAA/Cr+PCr ratios and metacognitive ability. The suggested explanation for negative

correlations is that metacognitive activities may lead to increased oxygen consumption in the right precuneus, which then affects neuronal function.

There are several limitations to this present study. Participants in this study were mostly females and within a narrow age range. In addition, the MR spectra in this study were only recorded from the precuneus and medial prefrontal cortex. Further studies focusing on other regions, such as the anterior cingulate, are warranted.

Conclusion

In summary, cerebral metabolite levels are related to metacognitive ability. The right precuneal region plays an important role in metacognition and learning.

Abbreviations

MRS: Magnetic resonance spectroscopy; ROI: regions of interest; NAA: N-acetyl aspartate; PC+GPC: phosphocholine plus glycerophosphocholine; Cr+PCr: creatine plus phosphocreatine; mI: myo-inositol.

Declarations

Acknowledgements

Not applicable.

Authors' contributions

XZ and XL conceived and designed the study. XZ, and CH performed the experiments. XZ contributed to the writing of the original draft. CH and DW provided guidance for software and figures. XZ, CH and DW revised the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

The study was approved by the Ethics Committee of Binzhou Medical University, China under the registration number 2019018, participation into the study was only after written informed consent. All methods were performed in accordance with the relevant guidelines and regulations.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

References

- [1] Frith CD. The role of metacognition in human social interactions. *Philos Trans R Soc Lond B Biol Sci* 2012;367:2213-23.
- [2] Teasdale JD, Moore RG, Hayhurst H, Pope M, Williams S, Segal ZV. Metacognitive awareness and prevention of relapse in depression: empirical evidence. *J Consult Clin Psychol* 2002;70:275-87.
- [3] Schneider W. The development of metacognitive knowledge in children and adolescents: major trends and implications for education. *Mind Brain Educ* 2008;2:114-21.
- [4] Ye Q, Zou F, Dayan M, Lau H, Hu Y, Kwok SC. Individual susceptibility to TMS affirms the precuneal role in meta-memory upon recollection. *Brain Structure and Function* 2019;224:2407-19.

- [5] Ye Q, Zou F, Lau H, Hu Y, Kwok SC. Causal Evidence for Mnemonic Metacognition in Human Precuneus. *J Neurosci* 2018;38:6379-87.
- [6] Qiu L, Su J, Ni Y, Bai Y, Zhang X, Li X, Wan X. The neural system of metacognition accompanying decision-making in the prefrontal cortex. *PLoS Biol* 2018;16:e2004037.
- [7] Fleming SM, Ryu J, Golfinos JG, Blackmon KE. Domain-specific impairment in metacognitive accuracy following anterior prefrontal lesions. *Brain* 2014;137:2811-22.
- [8] Fleming SM, Weil RS, Nagy Z, Dolan RJ, Rees G. Relating introspective accuracy to individual differences in brain structure. *Science* 2010;329:1541-3.
- [9] Kwok SC, Cai Y, Buckley MJ. Mnemonic Introspection in Macaques Is Dependent on Superior Dorsolateral Prefrontal Cortex But Not Orbitofrontal Cortex. *The Journal of Neuroscience* 2019;39:5922-34.
- [10] McCurdy LY, Maniscalco B, Metcalfe J, Liu KY, de Lange FP, Lau H. Anatomical coupling between distinct metacognitive systems for memory and visual perception. *J Neurosci* 2013;33:1897-906.
- [11] Yokoyama Q, Miura N, Watanabe J, Takemoto A, Uchida S, Sugiura M, Horie K, Sato S, Kawashima R, Nakamura K. Right frontopolar cortex activity correlates with reliability of retrospective rating of confidence in short-term recognition memory performance. *Neurosci Res* 2010;68:199-206.
- [12] Baird B, Smallwood J, Gorgolewski KJ, Margulies DS. Medial and lateral networks in anterior prefrontal cortex support metacognitive ability for memory and perception. *J Neurosci* 2013;33:16657-65.
- [13] Rahnev D, Nee DE, Riddle J, Larson AS, D'Esposito M. Causal evidence for frontal cortex organization for perceptual decision making. *Proc Natl Acad Sci USA* 2016;113:6059-64.

- [14] Manganas LN, Zhang X, Li Y, Hazel RD, Smith SD, Wagshul ME, Henn F, Benveniste H, Djuric PM, Enikolopov G, Maletic-Savatic M. Magnetic resonance spectroscopy identifies neural progenitor cells in the live human brain. *Science* 2007;318:980-5.
- [15] Gao F, Barker PB. Various MRS application tools for Alzheimer disease and mild cognitive impairment. *AJNR Am J Neuroradiol* 2014;35:S4-11.
- [16] Graff-Radford J, Kantarci K. Magnetic resonance spectroscopy in Alzheimer' s disease. *Neuropsychiatr Dis Treat* 2013;9:687-96.
- [17] Kantarci K, Knopman DS, Dickson DW, Parisi JE, Whitwell JL, Weigand SD, Josephs KA, Boeve BF, Petersen RC, Jr CRJ. Alzheimer disease: postmortem neuropathologic correlates of antemortem 1H MR spectroscopy metabolite measurements. *Radiology* 2008;248:210-20.
- [18] Kang ZH, Zhang JS. The Preliminary Construction of the Scale for College Student' s Metacognitive Ability. Shan Xi University 2005; Shan Xi, China.
- [19] Zhang XY, Fan XZ. The Relationship among Meta-Cognition, Self-efficacy and Perceived Critical Thinking in Nursing Students. Shan Dong University 2012; Shan Dong, China.
- [20] Wang MC, Haertel GD, Walberg HJ. What influences learning? A content analysis of review literature. *J Educ Res* 1990;84:30-43.
- [21] Winne PH. A metacognitive view of individual differences in self-regulated learning. *Learn Individ Differ* 1996;8:327-53.
- [22] Koriati A. Monitoring one's own knowledge during study: a cue-utilization approach to judgments of learning. *J Exp Psychol: Gen* 1997;126:349-70.
- [23] Skavhaug IM, Wilding EL, Donaldson DI. Judgments of learning do not reduce to memory encoding operations: event-related potential evidence for distinct metacognitive processes. *Brain Res* 2010;1318:87-95.

- [24] Skavhaug IM, Wilding EL, Donaldson DI. Immediate judgments of learning predict subsequent recollection: evidence from event-related potentials. *J Exp Psychol Learn Mem Cogn* 2013;39:159-66.
- [25] Müller BCN, Tsalas NRH, van Schie HT, Meinhardt J, Proust J, Sodian B, Paulus M. Neural correlates of judgments of learning - An ERP study on metacognition. *Brain Res* 2016;1652:170-7.
- [26] Tsalas NRH, Müller BCN, Meinhardt J, Proust J, Paulus M, Sodian B. An ERP study on metacognitive monitoring processes in children. *Brain Res* 2018;1695:84-90.
- [27] Fleck MS, Daselaar SM, Dobbins IG, Cabeza R. Role of prefrontal and anterior cingulate regions in decision-making processes shared by memory and nonmemory tasks. *Cereb Cortex* 2006;16:1623-30.
- [28] Morales J, Lau H, Fleming SM. Domain-general and domain-specific patterns of activity supporting metacognition in human prefrontal cortex. *J Neurosci* 2018;38:3534-46.
- [29] Simmons ML, Frondoza CG, Coyle JT. Immunocytochemical localization of N-acetyl-aspartate with monoclonal antibodies. *Neuroscience* 1991;45:37-45.

Figures

Figure 1

MRS location images. Axial ROIs of the right precuneus (a) and left medial prefrontal cortex (b).

Figure 2

MRS spectra. Metabolites, including NAA, PC+GPC, Cr+PCr, and mI of the right precuneus (a) and left medial prefrontal cortex (b).

Figure 3

Relationship between the total metacognitive score and total academic score. Positive correlation was revealed ($r=0.250$; $p=0.007$).

Figure 4

Relationship between precuneus NAA/Cr+PCr ratios and metacognitive ability. Negative correlations were reported between precuneus NAA/Cr+PCr ratios

and metacognitive monitoring score (a; $r = -0.238, p = 0.014$), metacognitive evaluating score (b; $r = -0.240, p = 0.013$), and total metacognitive score (c; $r = -0.237, p = 0.014$).

Figure 5

Relationship between right precuneus NAA/Cr+PCr ratios and metacognitive ability. Negative correlations were reported between the right precuneus NAA/Cr+PCr ratios and metacognitive monitoring score (a; $r = -0.241, p = 0.013$), metacognitive regulating score (b; $r = -0.206, p = 0.034$), and total metacognitive score (c; $r = -0.226, p = 0.020$).