

## The Brain that Understands Different Cultures: Brain Microstructure Measured by MRI Correlates with Cultural Intelligence

Keisuke Kokubun<sup>1\*</sup>, Kiyotaka Nemoto<sup>2</sup>, Yoshinori Yamakawa<sup>3</sup>

<sup>1,3</sup> Open Innovation Institute, Kyoto University, Kyoto, Japan

<sup>1,7</sup> Graduate School of Management, Kyoto University, Kyoto, Japan

<sup>2</sup> Department of Psychiatry, Institute of Medicine, University of Tsukuba, Tsukuba, Japan

<sup>3</sup> Institute of Innovative Research, Tokyo Institute of Technology, Meguro, Tokyo, Japan

<sup>3</sup> ImPACT Program of Council for Science, Technology and Innovation (Cabinet Office, Government of Japan), Chiyoda, Tokyo, Japan

<sup>3</sup> Office for Academic and Industrial Innovation, Kobe University, Kobe, Japan

<sup>3</sup> Brain Impact, Kyoto, Japan.

\*Corresponding Author: [kokubun.keisuke.6x@kyoto-u.jp](mailto:kokubun.keisuke.6x@kyoto-u.jp)

**Citation:** Kokubun, K., Nemoto, K. & Yamakawa, Y. (2025). The Brain that Understands Different Cultures: Brain Microstructure Measured by MRI Correlates with Cultural Intelligence, *Journal of Cultural Analysis and Social Change*, 10(4), 3488-3499. <https://doi.org/10.64753/jcasc.v10i4.3579>

**Published:** December 23, 2025

### ABSTRACT

In today's world of increasing globalization, the importance of cultural intelligence (CQ), a necessary ability for cross-cultural adaptation, is becoming more and more recognized. Therefore, the purpose of this paper is to clarify the relationship between brain microstructure and CQ. In this study, we analyzed the relationship between fractional anisotropy (FA) of the posterior thalamic radiation (PTR), inferior cerebellar peduncle (ICP), and fornix and CQ using data from 310 healthy men and women collected in Japan. The results showed that Motivational CQ, Behavioral CQ, and Overall CQ were significantly related to FA of PTR, ICP and fornix. Results indicate that brain microstructure involved in motivation, behavior, and cognition correlates with motivational and behavioral aspects of CQ. This is the first study to clarify the relationship between cultural intelligence and brain structure.

**Keywords:** Cultural Intelligence; Inferior Cerebellar Peduncle; Fornix; Fractional Anisotropy; Posterior Thalamic Radiation

### INTRODUCTION

As the world becomes more interactive, the importance of cultural intelligence (CQ) is being recognized by more and more researchers. CQ is defined as an individual's ability to function and manage effectively in a culturally diverse environment and consists of four dimensions: Metacognitive CQ, Cognitive CQ, Motivational CQ, and Behavioral CQ (Ang et al., 2007). Metacognitive CQ refers to the ability to adjust one's thoughts in a cross-cultural environment. Therefore, individuals with high Metacognitive CQ can flexibly and highly apply cultural knowledge in diverse cultural interactions. Cognitive CQ reflects knowledge of norms, practices, and conventions used in various cultural environments. Individuals with high Cognitive CQ interact better with people from different cultures and understand similarities and differences between cultures. Motivational CQ is the ability to exert effort and energy to adapt to different cultures. High Motivational CQ leads to focused and sustained efforts to adapt and adjust to different cultural environments. Finally, Behavioral CQ refers to exhibiting appropriate behaviors in diverse cultures. High Behavioral CQ includes verbal and nonverbal behaviors, such as culturally appropriate words, tone, gestures, facial expressions, and body language (Ang et al., 2007). These four CQ facets and their

average score, Overall CQ, have been used extensively in previous studies and have been related to intercultural adaptation and performance (e.g., Ang et al., 2007; Butkovic et al., 2024; Chen et al., 2024; Tripathi et al., 2023). For example, in an analysis using objective evaluations by supervisors, CQ developers showed that Motivational and Behavioral CQ were correlated with interactional and work adjustment, while Metacognitive and Behavioral CQ were correlated with task performance (Ang et al., 2007).

In previous studies, the neuroscientific basis of CQ have been proposed regarding cortical regions as neurological mediators of Cognitive (i.e., medial-temporal/diencephalic and neocortical regions), Metacognitive (i.e., anterior rostral media frontal cortex, including the paracingulate cortex), Motivational (i.e., orbitofrontal cortex), and Behavioral CQ (i.e., posterior rostral medial frontal cortex and dorsal anterior cingulate cortex) (Ang et al., 2015; Rockstuhl et al., 2010). In the field of neuroscience, research has been conducted using functional magnetic resonance imaging (fMRI) to examine brain responses when exposed to different cultures (Chang, 2017; Hedden et al., 2008). For example, a study conducted by Hedden et al. (2008) showed that, when engaged in a task that was not congruent with their cultural values, people required increased attention, and their frontal and parietal regions that control attention were activated to a greater extent. On the other hand, a recent MRI study focused on brain structure and showed, using a small sample, that people who are favorable to accepting different races and LGBTQ people have larger gray matter volume in the triple brain network consisting of the central executive network, saliency network, and default mode network compared to those who are not (Otsuka et al., 2024). They argue that globalized societies are more diverse, and therefore humans with higher survival rates may have brains that are better able to understand and utilize diversity, as evidenced by the fact that brain regions involved in problem solving and decision-making, as well as those that understand the mental states of others, are correlated with diversity understanding (Otsuka et al., 2024). A similar idea is also found in the cultural neuroscience debate, which argues that culture may shape the human brain by providing a systematically different set of experiences (Kwon et al., 2021; Posner & Rothbart, 2017).

We would like to propose a different approach, which is to focus on the white matter of the brain. Brain tissue can be divided into gray and white matter, with gray matter being composed of neuronal cell bodies, while white matter is composed of axons that connect the gray matter of various regions. Since cognitive and emotional functions involve multiple brain regions and function in the form of a network, it is necessary to study the role of not only the gray matter of a specific region, but also the role of white matter that connects different brain regions. Kokubun et al. (2020) found that previous studies dealing with the relationship between gray matter and happiness were inconsistent, and proposed a study focusing on white matter instead of gray matter, revealing the relationship between happiness and fractional anisotropy (FA), which reflects the fine structure of white matter in areas including the posterior thalamic radiation (PTR). Similarly, Hodgetts et al. (2020) found that previous studies of the association between hippocampal gray matter volume and navigational ability in healthy adults were inconsistent, arguing that variation in broader neuroanatomical systems, rather than local volumetric variation, may be particularly sensitive to interindividual differences in navigational learning, and revealed a relationship between fornix and navigational learning. Other studies have shown that time spent using a second language significantly modulates white matter microstructure in bilateral cingulate frontal clusters, which encompass structures primarily related to language control (Del Maschio et al., 2020).

In this study, we focus on the FA of the PTR, inferior cerebellar peduncle (ICP), and fornix. Among these, the PTR connects the caudal part of the thalamus to the occipital/parietal lobes (Wang et al., 2019). Because the thalamus is involved in motivation and emotion processing, dysfunction of the PTR is associated with impaired motivation (Henderson et al., 2013). Coloigner et al. (2019) reported reduced FA of the PTR in patients with major depressive disorder (MDD), a debilitating illness characterized by low mood, decreased interest, sleep disorders and loss of appetite (Otte et al., 2016), and lack of motivation and happiness (Jamshaid et al., 2023). Therefore, we expect that the PTR will be related to Motivational CQ, which measures interest and motivation to learn about different cultures. Next, the ICP is a thick, rope-like nerve bundle that connects the medulla oblongata and the cerebellum (Osborn, & Poppele, 1983), and by transmitting sensory information to the cerebellum, it is involved in motor functions such as maintaining and regulating body posture (Gera et al., 2020), walking (Afifi & Bergman, 1998), and articulation (Johnson et al., 2022; Jossinger et al., 2021). From the above, it is expected that the ICP is related to Behavioral CQ, which is verbal or non-verbal communication ability in a cross-cultural environment.

The fornix is a central white matter bundle in the hippocampal-limbic circuit (Catani et al., 2013), connecting the hippocampus to mammillary bodies, thalamic nuclei, and the prefrontal cortex (Aggleton et al., 2016), and is involved in the formation and control of spatial and episodic memory, executive functions (Senova et al., 2020), semantic learning (Herbet et al., 2018, Hodgetts et al., 2015), and the construction of cognitive maps (Hinman et al., 2018; Hodgetts et al., 2020). The fornix has also been implicated in the development of psychiatric disorders such as first-episode psychosis (Alkan et al., 2020) and schizophrenia (Kuroki et al., 2006). These mental disorders are often accompanied by impairments in metacognition, which refers to the ability to recognize one's own thoughts and observe and detect errors in cognitive processes (Flavell, 1979), and abnormalities in functional

abilities (Boyer et al., 2012; Davies & Greenwood, 2020; James et al., 2016; Lysaker et al., 2010). Therefore, fornix is expected to be related to Metacognitive CQ.

From the above, this study aims to clarify the relationship between Motivational, Behavioral, and Metacognitive CQ and PTR, ICP, and fornix FA, respectively. The three hypotheses to be tested in this study are as follows:

- H1. PTR has a positive and significant correlation with Motivational CQ.
- H2. ICP has a positive and significant correlation with Behavioral CQ.
- H3. fornix has a positive and significant correlation with Metacognitive CQ.

Because Cognitive CQ mainly measures knowledge about foreign cultures, it was difficult to predict its relationship with the function of white matter that connects nerve cells. Therefore, no hypotheses were set regarding Cognitive CQ in this study.

## MATERIALS AND METHODS

### Participants

310 participants (195 men, 115 women) aged 22 to 83 years (mean = 43.09, SD = 11.57) were recruited to the Tokyo Institute of Technology from September 2019 to November 2023. Respondents were randomly recruited from the public by the BHQ Consortium, a study group aiming to utilize brain information in industry. Screening results, based on self-reported information, showed that none of the participants had a record of any medical condition that could affect the central nervous system. Brain images were taken using MRI, and the participants then answered a questionnaire. This study was approved by the Ethics Committee of Kyoto University (Approval Number 27-P-13) and Tokyo Institute of Technology (Approval Number A16038; A23195) and was conducted following the institutes' guidelines and regulations. Participants' anonymity was maintained throughout the study, and all participants signed written informed consent prior to participation.

### Cultural Intelligence

The CQ scale was adapted from Ang et al. (2007). A total of 20 CQ items comprise four facets: Metacognitive CQ (four items, e.g., "I check the accuracy of my cultural knowledge as I interact with people from different cultures",  $\alpha = 0.846$ ); Cognitive CQ (six items, e.g., "I know the rules for expressing non-verbal behavior in other cultures",  $\alpha = 0.917$ ); Motivational CQ (five items, e.g., "I enjoy interacting with people from different cultures",  $\alpha = 0.926$ ); and Behavioral CQ (five items, e.g., "I change my verbal behavior when a cross-cultural interaction requires it",  $\alpha = 0.866$ ). All items were rated on a 7-point Likert scale (1 = strongly disagree; 7 = strongly agree), and the items were averaged to calculate a value for each variable. The Japanese translation of CQ was taken from Nakao (2019).

### Fractional Anisotropy

For FA, we used the fractional anisotropy brain healthcare quotient (FA-BHQ) developed by Nemoto et al (2017). The calculation method of FA-BHQ, which has been correlated positively with cognitive function (Kokubun et al., 2020) and happiness (Kokubun et al., 2022) and negatively with anxiety (Pineda et al., 2021) and fatigue (Yan et al., 2024), has been approved as an international standard (H.861.1: International Telecommunication Union Telecommunication Standardization Sector, 2018). Unlike many other studies that have primarily involved morbid or elderly individuals, these studies have primarily involved healthy adults, which is the primary motivation for using the FA-BHQ in this study, which also involves healthy adults. MRI data acquisition and analysis methods for calculating FA-BHQ were identical to those used in our recent study (Kokubun et al., 2024) and therefore will be omitted in this paper.

### Control Variables

Sex (male = 1; female = 0), age (years old, for which respondents entered the exact number), educational background (years, for which respondents entered the exact number), and Cognitive CQ converted to a binary variable (b-Cognitive CQ: 4.5 or greater = 1; less than 4.5 = 0) were used as control variables. The reason why the watershed for Cognitive CQ was set at 4.5 is because, as shown in Figure 1, the data from 220 participants indicated that the number of years of overseas experience increases significantly from this point onwards. Overseas experience was calculated as the sum (in months) of the following three questions introduced by Kokubun et al. (2023), and 220 of the 310 participants answered the questions to obtain reference information. "For how many

months have you lived in foreign countries for work?", "For how many months have you lived in foreign countries for study", and "For how many months have you lived in foreign countries for things other than work and study".

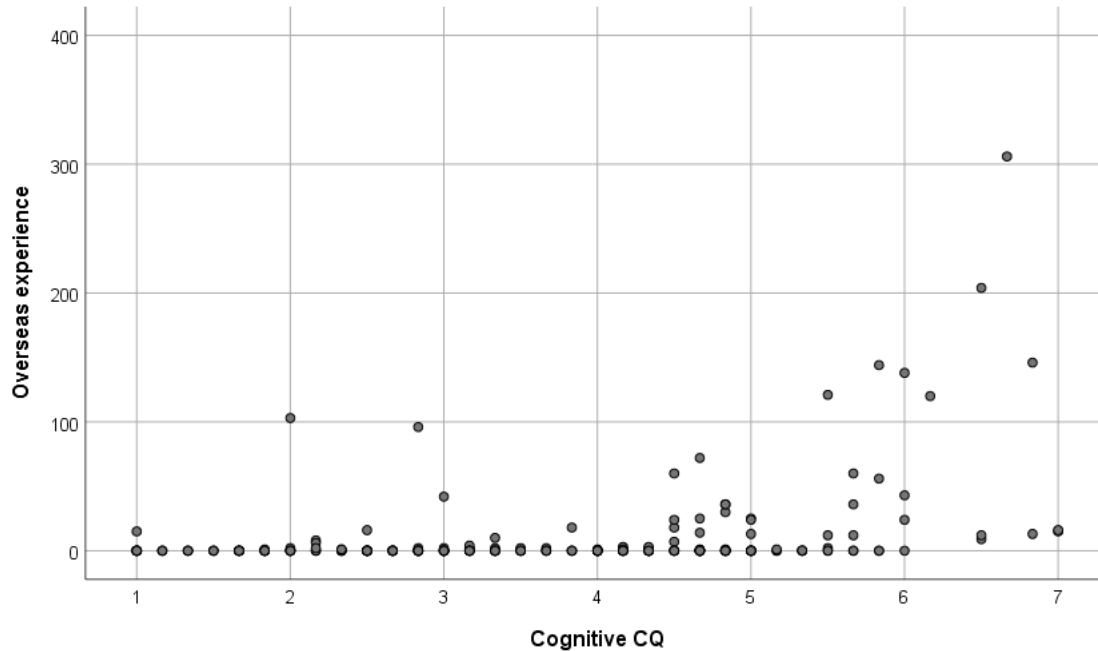


Figure 1. Scatter plot of Cognitive CQ and overseas experience. N = 210.

Data Analysis

We estimated the correlation coefficient between CQ (Metacognitive CQ, Cognitive CQ, Motivational CQ, and Behavioral CQ, and Overall CQ) and FA-BHQ (PTR, ICP, fornix, and whole-brain FA) from the perspective of regions of interest (ROI). Although Cognitive CQ, Overall CQ, and whole-brain FA are outside the ROI, they were included in the analysis for reference. Regarding correlation, in addition to the usual correlation coefficient, partial correlation coefficients were calculated controlling for gender, age, education, and b-Cognitive CQ. The significance level was set at 5% for a two-sided test. All statistical analyses have been performed using IBM SPSS Statistics/AMOS Version 26 (IBM Corp., Armonk, NY, USA).

RESULTS

Before proceeding with the main analysis, we used Harman's single factor analysis to check whether the variance in the data could be mainly attributed to a single factor, and used confirmatory factor analysis (CFA) to test whether the factors were related to the measurement. First, Harman's factor analysis showed that only 43.1% of the variance could be explained by a single factor, which was <50%. Thus, it was established that the data were not affected by common method variance (Podsakoff et al., 2003). Next, we conducted a CFA to evaluate the fit of the model. Here, we followed Kline (2023) who advocates the use of the chi-square test, CFI (comparative fit index), RMSEA (root mean square error of approximation), and SRMR (standardized root mean square residual). The acceptable range of index values is as follows: chi-square value from 0 to 3 (McIver & Carmines, 1981); CFI above 0.90 (Hu & Bentler, 1999); RMSEA < 0.06 (Hu & Bentler, 1999); SRMR < 0.08 (Hu & Bentler, 1999). As Table 1 shows, both the model in which the four facets were treated as independent factors and the model in which they were treated as one common factor met the acceptable requirements. This indicates that the use of the four facets, as well as the Overall CQ that combines them, is appropriate. In addition, for the scale CQ facets, we tested composite reliability (CR): Metacognitive CQ = 0.804; Cognitive CQ = 0.888; Motivational CQ = 0.885; Behavioral CQ = 0.795. All subsets exceeded the CR standard value of 0.70 (Nunnally & Bernstein, 1994), confirming high convergent validity.

Table 1 Summary of confirmatory factor analysis

Construct	X <sup>2</sup>	df	X <sup>2</sup> /df	CFI	RMSEA	SRMR
Four-factor model	315.711	154	2.050	0.962	0.058	0.048
One-factor model	262.746	134	1.961	0.970	0.056	0.067

**Four-Factor Model:** A model that treats Metacognitive CQ, Cognitive CQ, Motivational CQ, and Behavioral CQ as independent factors. **One-factor model:** A model that treats the above four facets as a common factor.

CFI: comparative fit index. X2: chi-square test. df: degree of freedom.  
 RMSEA: root mean square error of approximation.  
 SRMR: standardized root mean square residual.

Table 2 shows correlation coefficient results. Below the diagonal are the usual correlation coefficients. Above the diagonal are the partial correlation coefficients controlled for gender, age, education, and b-Cognitive CQ. Below, we mainly look at partial correlation coefficients, but normal correlation coefficients also show similar trends. The hypothesis tests were conducted on three pairs: PTR and Motivational CQ (H1), ICP and Behavioral CQ (H2), and fornix and Metacognitive CQ (H3). To help interpret the results, we also show significant results for other pairs. First, PTR showed significant positive correlations with Motivational CQ ( $r = 0.133$ ;  $p = 0.020$ ) and Overall CQ ( $r = 0.135$ ;  $p = 0.018$ ). Next, ICP showed significant positive correlations with Motivational CQ ( $r = 0.138$ ;  $p = 0.016$ ), Behavioral CQ ( $r = 0.156$ ;  $p = 0.006$ ), and Overall CQ ( $r = 0.132$ ;  $p = 0.021$ ). Finally, fornix showed significant positive correlations with Motivational CQ ( $r = 0.146$ ;  $p = 0.011$ ), Behavioral CQ ( $r = 0.140$ ;  $p = 0.014$ ), and Overall CQ ( $r = 0.125$ ;  $p = 0.029$ ). Among these, the correlations between PTR and Motivational CQ, and ICP and Behavioral CQ support H1 and H2, respectively. However, fornix did not show a significant correlation with metacognitive CQ ( $r = 0.026$ ;  $p = 0.654$ ), so H3 is rejected. These results were unchanged by multiple comparisons using the Benjamini & Hochberg (BH) method. Figures 2, Figure 3, and Figure 4 show the scatter plots of these hypothesized relations, H1, H2, and H3.

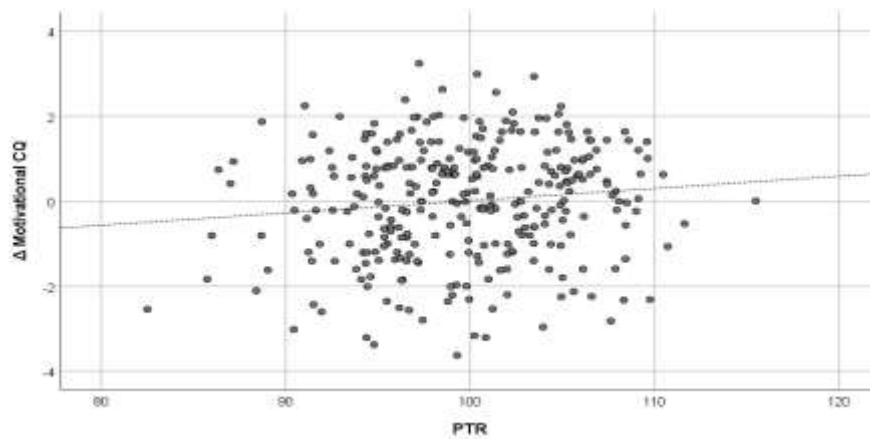
In the normal correlation analysis, unlike the partial correlation, there was a significant correlation between PTR and Behavioral CQ ( $r = 0.138$ ;  $p = 0.015$ ). On the other hand, there was no significant correlation between ICP and Overall CQ ( $r = 0.093$ ;  $p = 0.101$ ) and fornix and Overall CQ ( $r = 0.109$ ;  $p = 0.055$ ). Despite these differences, a conventional correlation analysis without control variables, like the partial correlation analysis, supported H1 and H2 and rejected H3. Whole-brain FA was not significantly correlated with any CQ variables in either partial or normal correlation. Similarly, Metacognitive CQ and Cognitive CQ were not significantly correlated with any FA variables in either partial or normal correlation. Furthermore, when we examined the correlation between the CQ facets and brain areas other than the three hypothesized regions in this study, we found no areas that were significantly correlated with any of the CQ facets.

**Table 2** Descriptive statistics and correlation coefficient results

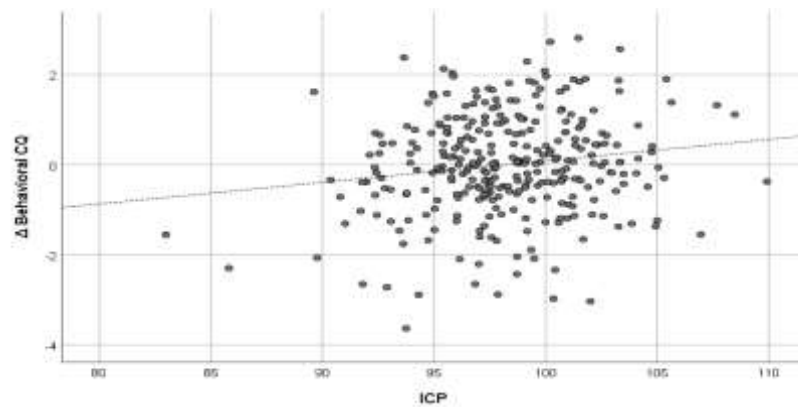
		Mean	SD	1	2	3	4	5	6	7	8	9	10	11	12	13
1	Metacognitive CQ	4.778	1.120		0.323**	0.297**	0.381**	0.665**	0.074	0.003	0.026	0.014				
2	Cognitive CQ	3.573	1.451	0.477**		0.374**	0.317**	0.640**	0.099	0.072	0.027	0.036				
3	Motivational CQ	4.495	1.453	0.379**	0.485**		0.574**	0.812**	0.133*	0.138*	0.146*	0.092				
4	Behavioral CQ	4.632	1.187	0.433**	0.408**	0.619**		0.793**	0.084	0.156**	0.140*	0.071				
5	Overall CQ	4.370	1.013	0.710**	0.784**	0.819**	0.781**		0.135*	0.132*	0.125*	0.077				
6	PTR	99.638	5.409	0.063	0.100	0.135*	0.126*	0.138*		0.321**	0.412***	0.719***				
7	ICP	98.251	3.607	-0.002	0.036	0.118*	0.133*	0.093	0.307***		0.261***	0.545***				
8	Fornix	100.44	5.315	0.004	0.029	0.136*	0.167**	0.109	0.565***	0.249**		0.614***				
9	Whole-brain FA	99.936	3.252	0.003	0.035	0.081	0.081	0.067	0.768***	0.526**	0.684***					
10	Age	43.090	11.572	0.01	-0.055	-0.021	-0.087	-0.05	-0.487**	-0.065	-0.526**	-0.407**				
11	Sex	0.629	0.484	0.070	0.110	-0.055	-0.153*	-0.006	-0.141*	0.058	-0.196**	-0.025	0.229**			
12	Education	16.255	2.528	0.058	0.188**	0.162**	0.044	0.154**	0.036	0.034	0.055	0.066	0.010	0.231**		
13	b-Cognitive CQ	0.323	0.468	0.374**	0.794**	0.340**	0.289**	0.595**	0.022	-0.020	-0.023	-0.019	0.005	0.101	0.138*	
14	Overseas experience	10.125	33.959	0.129	0.357**	0.209**	0.190**	0.296**	0.037	0.081	-0.002	0.048	-0.03	-0.040	0.059	0.312**

$N = 310$ . \* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ .

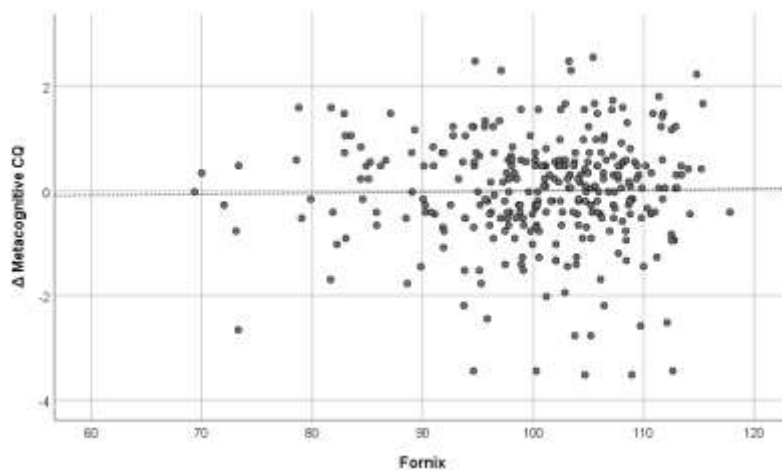
Below the diagonal are the usual correlation coefficients without controlling. Above the diagonal are the partial correlation coefficients controlled for gender, age, education, and b-Cognitive CQ. Both age and education are in years. b-Cognitive CQ: Cognitive CQ  $\geq 4.5 = 1$ , Cognitive CQ  $< 4.5 = 0$ . ICP = inferior cerebellar peduncle; PTR = posterior thalamic radiation. Sex: male = 1, female = 0.



**Figure 2.** Scatter plot of PTR and Motivational CQ.  $N = 310$ . The dashed line is the regression line. PTR = posterior thalamic radiation. The vertical axis shows the residuals from a regression with sex, age, education, and b-Cognitive CQ as independent variables.



**Figure 3.** Scatter plot of ICP and Behavioral CQ.  $N = 310$ . The dashed line is the regression line. ICP = inferior cerebellar peduncle. The vertical axis shows the residuals from a regression with sex, age, education, and b-Cognitive CQ as independent variables.



**Figure 4.** Scatter plot of fornix and Metacognitive CQ.  $N = 310$ . The dashed line is the regression line. The vertical axis shows the residuals from a regression with sex, age, education, and b-Cognitive CQ as independent variables.

## DISCUSSION

This study showed that Motivational CQ and Behavioral CQ, the ability to motivate people to understand different cultures and choose actions to adapt to different cultures, are correlated with PTR, ICP, and fornix, which plays an important role in sensory, motor, and cognitive functions, respectively.

Of these, the correlation between PTR and motivational CQ is reasonable considering previous studies arguing that the thalamus, to which the PTR connects, is involved in motivation and emotion processing and therefore that PTR dysfunction may be associated with motivation disorders (Henderson et al., 2013), as well as a recent study reporting reduced FA in the PTR in patients with MDD, one of whose characteristics is decreased motivation

(Coloigner et al., 2019). The correlation between Behavioral CQ and ICP is also easy to understand when we consider that ICP transmits sensory information to the cerebellum and is involved in maintaining body posture and movement (Afifi & Bergman, 1998; Gera et al., 2020), and articulation (Connally et al., 2014; Johnson et al., 2022; Jossinger et al., 2021; Kronfeld-Duenias et al., 2016; Tourville & Guenther, 2011).

In addition, ICP was correlated with Motivation CQ. Similarly, PTR was correlated with Behavioral CQ before controlling for demographic variables. These seemingly contradictory results are understandable because sensory and motor connections are interconnected within white matter fibers. For example, previous studies have shown that abnormalities in PTR in children with cerebral palsy born prematurely are associated with motor as well as sensory impairments, possibly through damage to the sensory pathways altering connections to the motor cortex (Hoon et al., 2009). In this context, postural control in patients with traumatic brain injury (Zampieri et al., 2023) and multiple sclerosis (Gera et al., 2020) was associated with PTR in addition to ICP. On the other hand, the ventral tegmental area, which receives projections from the cerebellar nuclei, houses dopaminergic neurons and plays an important role in reward and motivation (Novello et al., 2024). It is therefore possible that abnormalities in ICP may be related to motivation by altering these connections. Relatedly, MDD, which has reduced motivation as one of its symptoms, has been associated with ICP as well as PTR in a recent study (Lee & Lee, 2024).

The fornix, which connects the hippocampus and the prefrontal cortex and mainly controls the formation of spatial memory, episodic memory, and executive functions (Senova et al., 2020), is involved in the development of psychiatric disorders with metacognitive impairment, in addition to Alzheimer's disease (Badea et al., 2016) and visual/spatial memory disorders (Fitzsimmons et al., 2009). A relationship with Metacognitive CQ was expected, but the actual correlation was with Motivation CQ and Behavioral CQ, as well as PTR and ICP. Considering that the fornix is a corridor of neurons moving between the hippocampus and the septum (Wirtshafter et al., 2021), which is involved in various functions such as emotional, motivational, and spatial behavior (Watanabe et al., 2020), damage to the fornix may manifest as a lack of motivation or behavior. Furthermore, given that fornix-related metacognitive impairments are associated with abnormalities in social and motor functioning (Boyer et al., 2012; Davies & Greenwood, 2020; James et al., 2016; Lysaker et al., 2010), the results of this study may suggest that respondents who were prone to metacognitive impairments due to fornix damage may have had difficulty improving their Motivational CQ and Behavioral CQ due to lack of sufficient social and motor functioning.

According to self-regulated learning (SRL) theory, a self-regulated learner can recognize, control, and manage the learning environment (Zimmerman, 1990). This learning process involves the learner engaging cognitively, metacognitively, motivationally, and behaviorally (Zimmerman, 1990). As can be easily noticed from the structure of CQ, the concepts of SRL and CQ are surprisingly similar. In SRL theory, metacognition develops through repeated motivation and behavior, and the gap between the two is monitored and evaluated (Zimmerman, 1990). Conversely, if the development of metacognition is hindered, motivation and executive function are also hindered (Marulis & Nelson, 2021). Therefore, as mentioned above, if damage to the fornix hinders the development of metacognition, resulting in low Motivational CQ and Behavioral CQ, this is consistent with SRL theory. On the other hand, the fact that fornix did not correlate with Metacognitive CQ may reflect a discrepancy between metacognition as assumed by neuroscience and metacognition as assumed by pedagogy or SRL theory, as pointed out in a recent review (Fleur et al., 2021). For example, metacognition, which is a topic of education, is thought to be acquired as people learn while reflecting on the past, but when neuroscience studies metacognition in the laboratory, such reflection is usually not considered (Fleur et al., 2021). As a result, according to a recent review, neuroscience research investigating how metacognition is related to motivation and behavior in the brain and how it is mapped is limited to one study by Boldt & Gilbert (2022), and is still in its infancy (Fleur et al., 2021).

PTR is sensitive to the effects of white matter lesions such as autism, leukoaraiosis, and type 2 diabetes mellitus (Cheon et al., 2011; Hoon Jr et al., 2009; Tan et al., 2016). Likewise, the ICP is susceptible to injury due to tumors, infarction, and trauma (Gera et al., 2020; Hong et al., 2009; Jang & Kwon, 2023; Kim et al., 2021; Odom et al., 2021). Therefore, people who have damaged their PTR or ICP due to congenital influences or living environment may find it difficult to improve their Motivational CQ or Behavioral CQ. Although CQ has been thought to be enhanced by training and overseas experiences, the effects of these vary from person to person and are not sufficient to explain the variance of CQ (Ang et al., 2007; Ott & Michailova, 2018). Furthermore, intercultural education can sometimes have negative effects, such as instilling prejudices against foreigners in students (Chang, 2017). Consistent with these findings, the results of this study are negative for the optimistic view that training and overseas experience will always improve CQ and lead to successful intercultural adaptation if his/her brain is not good at increasing CQ. This may be difficult to accept for those who believe in the infinite possibilities of education, for example, that any student should be able to improve their CQ. However, the results of this study also pave the way for students to know their strengths and weaknesses at an early stage and use brain information to prevent them from choosing jobs that they are not good at. Fortunately, previous studies have shown that certain interventions can improve the FA of PTR (Kokubun, et al., 2024), ICP (Abbawi et al., 2023), and fornix (Hofstetter, et al., 2013), so there is still a possibility that appropriate training can improve students'

CQ. Such methods may be a relief for students who are not suited to working abroad but have a strong desire to do so. In any case, as research into the relationship between the brain and CQ or brain and cultural adaptation/performance progresses and it becomes possible to use brain information as a biomarker for education and career selection in the future, it has the potential to increase people's work motivation and well-being.

The results of this study showed that Motivational, Cognitive, and Overall CQ had a significant positive correlation with PTR, ICP, and fornix. To the best of our knowledge, this is the first study to clarify the relationship between CQ and brain structure, and it makes a unique interdisciplinary contribution to academia by bridging the gap between brain research and cross-cultural research.

## LIMITATION

This paper shows the relationship between FA, which reflects the brain's microstructure, and CQ, but does not show the relationship between FA and the cross-cultural adaptation or performance of students or business persons in a cross-cultural environment. Furthermore, as shown in the scatter plots, the correlation between FA and CQ is not very strong. Therefore, the discussion about the possibility that abnormalities in the brain's microstructure may affect cross-cultural adaptation and performance is merely speculative and should be verified by future research. Further, this paper was unable to clarify the relationship between Metacognitive CQ and the brain. This suggests that an approach focusing on FA is not sufficient as a method for clarifying the neural basis of CQ. Since the relationship between metacognition and motivation and behavior, not limited to CQ, is an area in brain science that is largely unexplored, future research using interdisciplinary and diverse approaches is necessary. Let us look at other, more general but important limitations. This study was conducted using a cross-sectional analysis, so the causal relationship of the variables is unclear. In addition, because the participants were those living in Japan, caution is required when applying to people living in a different cultural environment or from other countries. Another point that should be improved is that intercultural experience was not included in the covariates although it was replaced by Cognitive CQ converted to a binary value. Therefore, future research should verify the results of this study through longitudinal studies that include participants of various nationalities and with intercultural experiences.

## Declarations

### Ethics Approval and Consent to Participate

This study was approved by the Ethics Committee of Kyoto University (Approval Number 27-P-13) and Tokyo Institute of Technology (Approval Number A16038; A23195) and was conducted following the institute's guidelines and regulations. All participants provided written informed consent before participation, and their anonymity was maintained.

### Consent for Publication

All participants gave consent for the publication of the results of this study.

### Availability of Data and Materials

The datasets generated during the current study are not publicly available but are available from the corresponding author upon reasonable request.

### Competing Interests

The authors have declared that no competing interests exist.

### Funding

This work was funded by the ImPACT Program of the Council for Science, Technology and Innovation (Cabinet Office, Government of Japan) and supported by JSPS KAKENHI (Grant Number JP17H06151; JP19K01833; JP21K12153; JP22K01695).

### Authors' Contributions

K.K. did conceptualization, a formal analysis, and wrote the original draft; K.N. and Y.Y. did methodology development, data curation, funding acquisition, investigation, administration, supervision, writing review, and editing. All authors reviewed the final manuscript.

## ACKNOWLEDGMENTS

Some of the data used in this paper overlaps with that used by Kokubun et al. (2025).

## REFERENCE

- Abbawi, M., Stanley, J. A., Yu, B., Myers, E., Fritz, N. E. (2023). Backward walking training induces structural changes in the superior cerebellar peduncle: A pilot myelin water imaging study. *Multiple Sclerosis and Related Disorders*, 73, 104644. <https://doi.org/10.1016/j.msard.2023.104644>
- Afifi, A. K., & Bergman, R. A. (1998). *Functional neuroanatomy: text and atlas* (Vol. 10). New York: McGraw-hill.
- Aggleton, J. P., Pralus, A., Nelson, A. J., & Hornberger, M. (2016). Thalamic pathology and memory loss in early Alzheimer's disease: moving the focus from the medial temporal lobe to Papez circuit. *Brain*, 139(7), 1877-1890. <https://doi.org/10.1093/brain/aww083>
- Alkan, E., Davies, G., Greenwood, K., & Evans, S. L. (2020). Brain structural correlates of metacognition in first-episode psychosis. *Schizophrenia Bulletin*, 46(3), 552-561. <https://doi.org/10.1093/schbul/sbz116>
- Ang, S., Van Dyne, L., Koh, C., Ng, K. Y., Templer, K. J., Tay, C., & Chandrasekar, N. A. (2007). Cultural intelligence: Its measurement and effects on cultural judgment and decision making, cultural adaptation and task performance. *Management and Organization Review*, 3(3), 335-371. <https://doi.org/10.1111/j.1740-8784.2007.00082.x>
- Ang, S. Van Dyne, L. & Rockstuhl, T. (2015). Cultural intelligence: Origins, conceptualization, evolution, and methodological diversity. In *Handbook of Advances in Culture and Psychology*; Gelfand, M.J., Chiu, C.Y., Hong, Y.Y., Eds.; Oxford University Press: New York, NY, USA, Volume 5, pp. 273–323.
- Badea, A., Kane, L., Anderson, R. J., Qi, Y., Foster, M., Cofer, G. P., Medvitz, N., Buckley, A. F., Badea, A. K., Wetsel, W. C., & Colton, C. A. (2016). The Fornix provides multiple biomarkers to characterize circuit disruption in a mouse model of Alzheimer's disease. *Neuroimage*, 142, 498-511. <https://doi.org/10.1016/j.neuroimage.2016.08.014>
- Boldt, A., & Gilbert, S. J. (2022). Partially overlapping neural correlates of metacognitive monitoring and metacognitive control. *Journal of Neuroscience*, 42(17), 3622-3635. <https://doi.org/10.1523/JNEUROSCI.1326-21.2022>
- Boyer, L., Aghababian, V., Richieri, R., Loundou, A., Padovani, R., Simeoni, M. C., Auquier, P., & Lançon, C. (2012). Insight into illness, neurocognition and quality of life in schizophrenia. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, 36(2), 271-276. <https://doi.org/10.1016/j.pnpbp.2011.10.008>
- Butkovic, A., Brkovic, I., & Buretic, I. (2024). The role of openness and cultural intelligence in students' intention to study abroad. *Journal of Applied Research in Higher Education*, 16(1), 236-245. <https://doi.org/10.1108/JARHE-06-2022-0201>
- Catani, M., Dell'Acqua, F., & De Schotten, M. T. (2013). A revised limbic system model for memory, emotion and behaviour. *Neuroscience & Biobehavioral Reviews*, 37(8), 1724-1737. <https://doi.org/10.1016/j.neubiorev.2013.07.001>
- Chang, W. W. (2017). Approaches for developing intercultural competence: An extended learning model with implications from cultural neuroscience. *Human Resource Development Review*, 16(2), 158-175. <https://doi.org/10.1177/1534484317704292>
- Chen, X., Liu, D., & Portnoy, R. (2012). A multilevel investigation of motivational cultural intelligence, organizational diversity climate, and cultural sales: evidence from US real estate firms. *Journal of Applied Psychology*, 97(1), 93-106. <https://doi.org/10.1037/a0024697>
- Chen, Y., Yang, Z., Liu, B., Wang, D., Xiao, Y., & Wang, A. (2024). How cultural intelligence affects expatriate effectiveness in international construction projects. *Engineering, Construction and Architectural Management*, 31(4), 1696-1714. <https://doi.org/10.1108/ECAM-03-2022-0247>
- Cheon, K. A., Kim, Y. S., Oh, S. H., Park, S. Y., Yoon, H. W., Herrington, J., Nair, A., Koh, Y. J., Jang, D. P., Kim, Y. B., Leventhal, B. L., Cho, Z. H., Castellanos, F. X., & Schultz, R. T. (2011). Involvement of the anterior thalamic radiation in boys with high functioning autism spectrum disorders: a diffusion tensor imaging study. *Brain research*, 1417, 77-86. <https://doi.org/10.1016/j.brainres.2011.08.020>
- Coloigner, J., Batail, J. M., Commowick, O., Corouge, I., Robert, G., Barillot, C., & Drapier, D. (2019). White matter abnormalities in depression: A categorical and phenotypic diffusion MRI study. *Neuroimage: Clinical*, 22, 101710. <https://doi.org/10.1016/j.nicl.2019.101710>
- Connally, E. L., Ward, D., Howell, P., & Watkins, K. E. (2014). Disrupted white matter in language and motor tracts in developmental stuttering. *Brain and Language*, 131, 25-35. <https://doi.org/10.1016/j.bandl.2013.05.013>
- Davies, G., & Greenwood, K. (2020). A meta-analytic review of the relationship between neurocognition, metacognition and functional outcome in schizophrenia. *Journal of Mental Health*, 29(5), 496-505. <https://doi.org/10.1080/09638237.2018.1521930>

- Del Maschio, N., Sulpizio, S., Toti, M., Caprioglio, C., Del Mauro, G., Fedeli, D., & Abutalebi, J. (2020). Second language use rather than second language knowledge relates to changes in white matter microstructure. *Journal of Cultural Cognitive Science*, 4(2), 165-175. <https://doi.org/10.1007/s41809-019-00039-z>
- Fitzsimmons, J., Kubicki, M., Smith, K., Bushell, G., Estepar, R. S. J., Westin, C. F., Nestor, P.G., Niznikiewicz, M.A., Kikinis, R., McCarley, R.W. & Shenton, M. E. (2009). Diffusion tractography of the fornix in schizophrenia. *Schizophrenia Research*, 107(1), 39-46. <https://doi.org/10.1016/j.schres.2008.10.022>
- Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive–developmental inquiry. *American Psychologist*, 34(10), 906–911. <https://doi.org/10.1037/0003-066X.34.10.906>
- Fleur, D. S., Bredeweg, B., & van den Bos, W. (2021). Metacognition: ideas and insights from neuro- and educational sciences. *npj Science of Learning*, 6(1), 13. <https://doi.org/10.1038/s41539-021-00089-5>
- Gera, G., Fling, B. W., & Horak, F. B. (2020). Cerebellar white matter damage is associated with postural sway deficits in people with multiple sclerosis. *Archives of Physical Medicine and Rehabilitation*, 101(2), 258-264. <https://doi.org/10.1016/j.apmr.2019.07.011>
- Hedden, T., Ketay, S., Aron, A., Markus, H. R., & Gabrieli, J. D. (2008). Cultural influences on neural substrates of attentional control. *Psychological Science*, 19(1), 12-17. <https://doi.org/10.1111/j.1467-9280.2008.02038.x>
- Henderson, S. E., Johnson, A. R., Vallejo, A. I., Katz, L., Wong, E., & Gabbay, V. (2013). A preliminary study of white matter in adolescent depression: relationships with illness severity, anhedonia, and irritability. *Frontiers in Psychiatry*, 4, 152. <https://doi.org/10.3389/fpsy.2013.00152>
- Herbet, G., Zemmoura, I., & Duffau, H. (2018). Functional anatomy of the inferior longitudinal fasciculus: from historical reports to current hypotheses. *Frontiers in Neuroanatomy*, 12, 77. <https://doi.org/10.3389/fnana.2018.00077>
- Hinman, J. R., Dannenberg, H., Alexander, A. S., & Hasselmo, M. E. (2018). Neural mechanisms of navigation involving interactions of cortical and subcortical structures. *Journal of Neurophysiology*, 119(6), 2007-2029. <https://doi.org/10.1152/jn.00498.2017>
- Hofstetter, S., Tavor, I., Moryosef, S. T., & Assaf, Y. (2013). Short-term learning induces white matter plasticity in the fornix. *Journal of Neuroscience*, 33(31), 12844-12850. <https://doi.org/10.1523/JNEUROSCI.4520-12.2013>
- Hodgetts, C. J., Postans, M., Shine, J. P., Jones, D. K., Lawrence, A. D., & Graham, K. S. (2015). Dissociable roles of the inferior longitudinal fasciculus and fornix in face and place perception. *eLife*, 4, e07902. <https://doi.org/10.7554/eLife.07902>
- Hodgetts, C. J., Stefani, M., Williams, A. N., Kolarik, B. S., Yonelinas, A. P., Ekstrom, A. D., Lawrence, A. D., Zhang, J., & Graham, K. S. (2020). The role of the fornix in human navigational learning. *Cortex*, 124, 97-110. <https://doi.org/10.1016/j.cortex.2019.10.017>
- Hong, J. H., Kim, O. L., Kim, S. H., Lee, M. Y., & Jang, S. H. (2009). Cerebellar peduncle injury in patients with ataxia following diffuse axonal injury. *Brain Research Bulletin*, 80(1-2), 30-35. <https://doi.org/10.1016/j.brainresbull.2009.05.021>
- Hoon Jr, A. H., Stashinko, E. E., Nagae, L. M., Lin, D. D., Keller, J., Bastian, A. M. Y., Campbell, M. L., Levey, E., Mori, S., & Johnston, M. V. (2009). Sensory and motor deficits in children with cerebral palsy born preterm correlate with diffusion tensor imaging abnormalities in thalamocortical pathways. *Developmental Medicine & Child Neurology*, 51(9), 697-704. <https://doi.org/10.1111/j.1469-8749.2009.03306.x>
- Hu, L. T., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal*, 6(1), 1-55. <https://doi.org/10.1080/10705519909540118>
- International Telecommunication Union Telecommunication Standardization Sector (ITU-T) 2018. *An international standard (H.861.1)*. Retrieved from: <https://handle.itu.int/11.1002/1000/13572> (Accessed: 14 October, 2024)
- James, A. V., Hasson-Ohayon, I., Vohs, J., Minor, K. S., Leonhardt, B. L., Buck, K. D., George, S., & Lysaker, P. H. (2016). Metacognition moderates the relationship between dysfunctional self-appraisal and social functioning in prolonged schizophrenia independent of psychopathology. *Comprehensive Psychiatry*, 69, 62-70. <https://doi.org/10.1016/j.comppsy.2016.05.008>
- Jamshaid, S., Bahadar, N., Jamshed, K., Rashid, M., Imran Afzal, M., Tian, L., Umar, M., Feng, X., Khan, I., & Zong, M. (2023). Pre- and Post-Pandemic (COVID-19) Mental Health of International Students: Data from a Longitudinal Study. *Psychology Research and Behavior Management*, 16, 431–446. <https://doi.org/10.2147/PRBM.S395035>
- Jang, S. H., & Kwon, H. G. (2023). Cerebellar peduncle injuries in patients with mild traumatic brain injury. *Journal of Integrative Neuroscience*, 22(5), 121. <https://doi.org/10.31083/j.jin2205121>
- Johnson, C. A., Liu, Y., Waller, N., & Chang, S. E. (2022). Tract profiles of the cerebellar peduncles in children who stutter. *Brain Structure and Function*, 227(5), 1773-1787. <https://doi.org/10.1007/s00429-022-02471-4>

- Jossinger, S., Kronfeld-Duenias, V., Zislis, A., Amir, O., & Ben-Shachar, M. (2021). Speech rate association with cerebellar white-matter diffusivity in adults with persistent developmental stuttering. *Brain Structure and Function*, 226, 801-816. <https://doi.org/10.1007/s00429-020-02210-7>
- Kim, Y., Kim, S. H., Hong, B. Y., Oh, J., & Chang, S. Y. (2021). Integrity of the inferior cerebellar peduncle correlates with ambulatory function after hemorrhagic stroke. *Journal of Stroke and Cerebrovascular Diseases*, 30(12), 106164. <https://doi.org/10.1016/j.jstrokecerebrovasdis.2021.106164>
- Kline, R. B. (2023). *Principles and practice of structural equation modeling*. Guilford publications, New York, United States.
- Kokubun, K., Nemoto, K., & Yamakawa, Y. (2020). Fish intake may affect brain structure and improve cognitive ability in healthy people. *Frontiers in Aging Neuroscience*, 12, 76. <https://doi.org/10.3389/fnagi.2020.00076>
- Kokubun, K., Nemoto, K., & Yamakawa, Y. (2022). Brain conditions mediate the association between aging and happiness. *Scientific Reports*, 12(1), 4290. <https://doi.org/10.1038/s41598-022-07748-6>
- Kokubun, K., Nemoto, K., & Yamakawa, Y. (2023). The Association between Lifestyles (Walking/Diet) and Cultural Intelligence: A New Attempt to Apply Health Science to Cross-Cultural Research. *Behavioral Sciences*, 14(1), 28. <https://doi.org/10.3390/bs14010028>
- Kokubun, K., Nemoto, K., & Yamakawa, Y. (2024). Smartphone app for lifestyle improvement improves brain health and boosts the vitality and cognitive function of healthy middle-aged adults. *Brain and Behavior*, 14(5), e3500. <https://doi.org/10.1002/brb3.3500>
- Kokubun, K., Nemoto, K., & Yamakawa, Y. (2025). The brain that understands different cultures: MRI-measured brain structure correlates with cultural intelligence. *Acta Psychologica*, 258, 105166. <https://doi.org/10.1016/j.actpsy.2025.105166>
- Kronfeld-Duenias, V., Amir, O., Ezrati-Vinacour, R., Civier, O., & Ben-Shachar, M. (2016). The frontal aslant tract underlies speech fluency in persistent developmental stuttering. *Brain Structure and Function*, 221, 365-381. <https://doi.org/10.1007/s00429-014-0912-8>
- Kuroki, N., Kubicki, M., Nestor, P. G., Salisbury, D. F., Park, H. J., Levitt, J. J., Woolston, S., Frumin, M., Niznikiewicz, M., Westin, C.-F., Maier, S.E., McCarley, R.W., & Shenton, M. E. (2006). Fornix integrity and hippocampal volume in male schizophrenic patients. *Biological Psychiatry*, 60(1), 22-31. <https://doi.org/10.1016/j.biopsych.2005.09.021>
- Kwon, J. Y., Wormley, A. S., & Varnum, M. E. (2021). Changing cultures, changing brains: A framework for integrating cultural neuroscience and cultural change research. *Biological Psychology*, 162, 108087. <https://doi.org/10.1016/j.biopsycho.2021.108087>
- Lee, J. H., & Lee, D. K. (2024). A Machine Learning Model for Predicting Major Depressive Disorder Using Diffusion-Tensor Imaging Data. *European Psychiatry*, 67(S1), S617-S618. <https://doi.org/10.1192/j.eurpsy.2024.1283>
- Lysaker, P. H., Dimaggio, G., Carcione, A., Procacci, M., Buck, K. D., Davis, L. W., & Nicolò, G. (2010). Metacognition and schizophrenia: the capacity for self-reflectivity as a predictor for prospective assessments of work performance over six months. *Schizophrenia Research*, 122(1-3), 124-130. <https://doi.org/10.1016/j.schres.2009.04.024>
- Marulis, L. M., & Nelson, L. J. (2021). Metacognitive processes and associations to executive function and motivation during a problem-solving task in 3-5 year olds. *Metacognition and Learning*, 16(1), 207-231. <https://doi.org/10.1007/s11409-020-09244-6>
- McIver, J., & Carmines, E. G. (1981). *Unidimensional scaling* (No. 24). Sage.
- Nakao, G. Personality and cognitive traits of intercultural competence. Doctoral dissertation, Kyoto University, Kyoto, Japan, 2019.
- Nemoto, K., Oka, H., Fukuda, H., & Yamakawa, Y. (2017). MRI-based Brain Healthcare Quotients: A bridge between neural and behavioral analyses for keeping the brain healthy. *PLoS One*, 12(10), e0187137. <https://doi.org/10.1371/journal.pone.0187137>
- Novello, M., Bosman, L. W., & De Zeeuw, C. I. (2024). A systematic review of direct outputs from the cerebellum to the brainstem and diencephalon in mammals. *The Cerebellum*, 23(1), 210-239. <https://doi.org/10.1007/s12311-022-01499-w>
- Nunnally, J. C., & Bernstein I.H. (1994). *Psychometric theory*. McGraw-Hill series in psychology, Vol. 3, McGraw-Hill, New York.
- Odom, A. D., Richmond, S. B., & Fling, B. W. (2021). White matter microstructure of the cerebellar peduncles is associated with balance performance during sensory re-weighting in people with multiple sclerosis. *Cerebellum*, 20(1), 92-100. <https://doi.org/10.1007/s12311-020-01190-y>
- Osborn, C. E., & Poppele, R. E. (1983). Cross-correlation analysis of the response of units in the dorsal spinocerebellar tract (DSCIT) to muscle stretch and contraction. *Brain Research*, 280(2), 339-342. [https://doi.org/10.1016/0006-8993\(83\)90064-1](https://doi.org/10.1016/0006-8993(83)90064-1)

- Otsuka, T., Kokubun, K., Okamoto, M., & Yamakawa, Y. (2024). The relationship between understanding diversity and brain health, Focusing on the triple network. *Preprints 2024*, 2024091989. <https://www.preprints.org/manuscript/202409.1989>
- Ott, D. L., & Michailova, S. (2018). Cultural intelligence: A review and new research avenues. *International Journal of Management Reviews*, 20(1), 99-119. <https://doi.org/10.1111/ijmr.12118>
- Otte, C., Gold, S. M., Penninx, B. W., Pariante, C. M., Etkin, A., Fava, M., Mohr, D. C., & Schatzberg, A. F. (2016). Major depressive disorder. *Nature Reviews Disease Primers*, 2(1), 1-20. <https://doi.org/10.1038/nrdp.2016.65>
- Pineda, J. C. D., Kokubun, K., Ikaga, T., & Yamakawa, Y. (2021). Housing quality and behavior affect brain health and anxiety in healthy Japanese adults. *Scientific Reports*, 11(1), 11999. <https://doi.org/10.1038/s41598-021-91363-4>
- Podsakoff, P. M., MacKenzie, S. B., Lee, J. Y., & Podsakoff, N. P. (2003). Common method biases in behavioral research: a critical review of the literature and recommended remedies. *Journal of Applied Psychology*, 88(5), 879-903. <https://psycnet.apa.org/doi/10.1037/0021-9010.88.5.879>
- Posner, M. I., & Rothbart, M. K. (2017). Integrating brain, cognition and culture. *Journal of Cultural Cognitive Science*, 1, 3-15. <https://doi.org/10.1007/s41809-017-0001-7>
- Rockstuhl, T., Hong, Y. Y., Ng, K. Y., Ang, S., & Chiu, C. Y. (2010). The culturally intelligent brain: From detecting to bridging cultural differences. *NeuroLeadership Institute*, 3(1-15).
- Senova, S., Fomenko, A., Gondard, E., & Lozano, A. M. (2020). Anatomy and function of the fornix in the context of its potential as a therapeutic target. *Journal of Neurology, Neurosurgery & Psychiatry*, 91(5), 547-559. <https://doi.org/10.1136/jnnp-2019-322375>
- Tan, X., Fang, P., An, J., Lin, H., Liang, Y., Shen, W., Leng, X., Zhang, C., Zheng, Y., & Qiu, S. (2016). Microstructural white matter abnormalities in type 2 diabetic patients: a DTI study using TBSS analysis. *Neuroradiology*, 58, 1209-1216. <https://doi.org/10.1007/s00234-016-1752-4>
- Tourville, J. A., & Guenther, F. H. (2011). The DIVA model: A neural theory of speech acquisition and production. *Language and Cognitive Processes*, 26(7), 952-981. <https://doi.org/10.1080/01690960903498424>
- Tripathi, C. M., Kaurav, R. P. S., & Singh, T. (2023). How does your cultural intelligence contribute to your adjustment? Unveiling the link between cultural intelligence and cross-cultural adjustment using meta-analysis. *Journal of Global Mobility: The Home of Expatriate Management Research*, 12(1), pp. 167-197. <https://doi.org/10.1108/JGM-01-2023-0006>
- Wang, J., Liang, Y., Chen, H., Wang, W., Wang, Y., Liang, Y., & Zhang, Y. (2019). Structural changes in white matter lesion patients and their correlation with cognitive impairment. *Neuropsychiatric Disease and Treatment*, 15, 1355-1363. <https://doi.org/10.2147/NDT.S194803>
- Watanabe, K., Takebayashi, H., & Sato, N. (2020). The fornix acts as a permissive corridor for septal neuron migration beyond the diencephalic-telencephalic boundary. *Scientific Reports*, 10(1), 8315. <https://doi.org/10.1038/s41598-020-65284-7>
- Wirtshafter, H. S., & Wilson, M. A. (2021). Lateral septum as a nexus for mood, motivation, and movement. *Neuroscience & Biobehavioral Reviews*, 126, 544-559. <https://doi.org/10.1016/j.neubiorev.2021.03.029>
- Yan, N., Kokubun, K., Nemoto, K., & Yamakawa, Y. (2024). Examination of the impact of curiosity and fatigue on brain condition. *Research Square* (preprint). <https://doi.org/10.21203/rs.3.rs-4381116/v1>
- Yoshida, S., Hayakawa, K., Yamamoto, A., Okano, S., Kanda, T., Yamori, Y., Yoshida, N., & Hirota, H. (2010). Quantitative diffusion tensor tractography of the motor and sensory tract in children with cerebral palsy. *Developmental Medicine & Child Neurology*, 52(10), 935-940. <https://doi.org/10.1111/j.1469-8749.2010.03669.x>
- Zampieri, C., Leary, J. B., Shahim, P., Damiano, D., Ho, P. S., Pham, D. L., & Chan, L. (2023). Associations between white matter integrity and postural control in adults with traumatic brain injury. *PLoS One*, 18(11), e0288727. <https://doi.org/10.1371/journal.pone.0288727>