Does Resting-state EEG Band Power Reflect Fluid Intelligence?

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ABSTRACT

Fluid intelligence refers to the ability to engage in abstract reasoning, which is independent of life experiences and knowledge. Brain studies have associated fluid intelligence with resting-state electroencephalograms (EEGs). This study investigated the relationship between resting-state EEG band power and fluid intelligence. The resting-state EEGs of 39 healthy volunteers were recorded from 32 scalp locations with a linked ears reference while the subjects were positioned in a Faraday cage for 15 min (10 min, eyes open; 5 min, eyes closed). The same participants completed the Raven's Standard Progressive Matrices (RSPM) test. Brain electrical activity was divided into delta, theta, alpha, and beta bands, and correlation coefficients were calculated to identify associations between the resting-state EEG powers and RSPM scores. The mean RSPM score of the participants was 49.31 (females=50.43, males=48). No correlation between the resting-state EEG power values (delta, theta, alpha, and beta bands) and fluid intelligence was found. The results of correlation analyses showed no relationship between EEG data and intelligence scores. These results indicate that data on resting-state EEG power values do not contribute to an understanding of fluid intelligence. However, brain network studies may deepen our understanding of the neural mechanisms underpinning intelligence.

Key Words: Fluid Intelligence, RSPM, EEG, Resting-state EEG, Correlation

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Introduction

Fluid intelligence is the ability to reason and deal with complex information independent of previous specific experiences or instructions (Cattell, 1963). It reflects an ability to adapt to new situations and solve problems. Research in this domain has examined relationships between fluid intelligence and learning and other cognitive functions (Deary *et al*., 2007; Van den Bos *et al*., 2012). Raven's Standard Progressive Matrices (RSPM), which enables researchers to measure fluid intelligence using a nonverbal approach, is among the most reliable instruments used to measure this phenomenon (Carpenter *et al.,* 1990; Duncan *et al.,* 2000; Gray *et al.,* 2003; Gray and Thompson, 2004).

The relationships between human intelligence and brain activity have been examined with various medical imaging techniques. A previous functional magnetic resonance imaging (fMRI) study found a positive correlation between intelligence and brain volume at the 0.4 level of significance (Wickett *et al.,* 2000). Several fMRI studies have reported that activation in specific brain areas, including the frontal and parietal lobes, is strongly correlated with intelligence (Prabhakaran *et al.,* 1997; Duncan *et al.,* 2000). Moreover, Jung and Haier (2007) specified that the dorsolateral prefrontal cortex (Brodmann areas [BAs] 9, 45, 46, and 47) and the parietal cortex (BAs 7 and 40) could be considered the most important for human intelligence.

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Newer neuroanatomical studies have suggested that a complete understanding of intelligence requires an investigation of not only specific brain regions but also networks that are widely distributed throughout the whole brain (Luders *et al.,* 2009).

Electroencephalography is among the most widely used neuroimaging techniques in investigations of the neural mechanisms underlying intelligence. Research on intelligence has used different measures and methods, including event-related desynchronization/ synchronization (Doppelmayr *et al.,* 1998; Jausovec and Jausovec, 2004; Neubauer *et al.,* 1995), source localization (Jausovec and Jausovec, 2004), event-related potentials (ERPs) (Van Rooy *et al.,* 2001; Amin *et al.,* 2015), coherence (Jausovec and Jausovec, 2000; Jausovec and Jausovec, 2001), and resting-state electroencephalogram (EEG) measures (Schmid *et al.,* 2002; Thatcher *et al.,* 2005; Liu *et al.,* 2008; Choudhary, 2016).

A resting-state EEG study of school-aged children (Schmid *et al.,* 2002) found a significant negative correlation between intelligence and the power of low-frequency bands. Specifically, this study reported a positive correlation between subscale scores on an intelligence test and the spectral alpha power, and a negative association between such scores and the power of lower-frequency bands. Another study (Thatcher *et al.,* 2005) found that the absolute power of all bands was positively correlated with verbal and performance intelligence quotients (IQs). A study of the relationship between the powers of EEG bands and intelligence (Liu *et al.,* 2008) found a positive correlation between intelligence and delta power activity and a negative one between intelligence and alpha2 and beta1 power activities. It has also been reported that beta waves are positively correlated with high IQs (Choudhary, 2016).

However, the inconsistencies among both the results and the strengths of the correlations found by these studies underscore the need to further investigate the relationships between electrophysiological brain activity and intelligence. The purpose of the present study was to examine correlations between the powers of resting-state EEG bands and scores on the Raven's Standard Progressive Matrices (RSPM) test.

Methods

Participants

Thirty-nine healthy volunteers (18 males and 21 females) aged between 20 and 38 years, with a mean age of 21.13 years, participated in the present study. They were all medically fit and free from neurological and psychiatric disorders and were not using any medication. This study was approved by the Ethics Committee of Ankara Yildirim Beyazit University.

RSPM

Participants completed the RSPM test and underwent EEG recording at different times. For the purpose of establishing trust, participants self-administered the RSPM test, and the researchers reviewed and graded the test. A score of '1' was assigned to each correct answer, and a score of '0' was assigned to each incorrect answer. The RSPM was organized as five 12-item sets (A, B, C, D, and E) ordered from less to more difficult. Each question, which relied on a multiple-choice format, involved identification of the part that was missing from visual matrices (Figure 1).

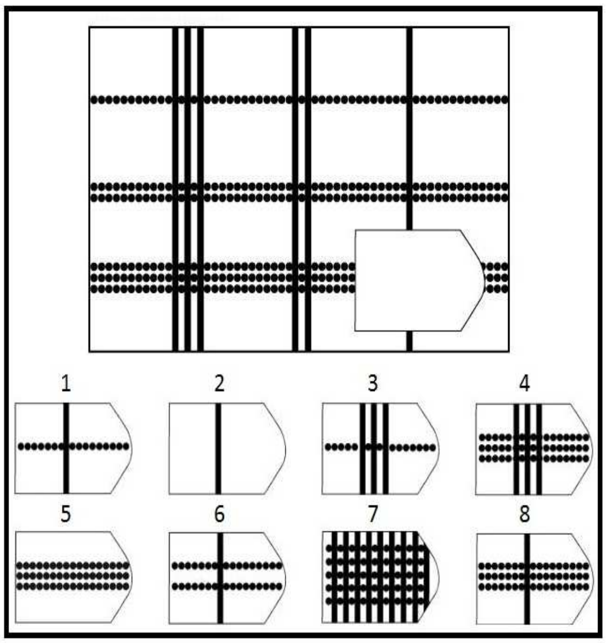

Figure 1. An RSPM question. Option no. 8 is the correct answer to this question

EEG Recording and Quantitative EEG (QEEG) Frequency Analysis

Resting-state brain electrical activity was recorded in a Faraday cage for 15 min (10 min, eyes open; 5 min, eyes closed) using a 32-channel ActiCAP (Brain Products GmbH, Gilching, Germany) electrode cap. Impedances at each electrode site were held below 5 kΩ. The EEG was amplified with a brain recorder (BrainAmp Amplifiers; Brain Products GmbH) and digitized at a 1-kHz sampling rate. The EEGs were amplified with a half-amplitude band-pass of 0.16–100 Hz.

An analysis was performed with the BESA Research Software Package (version 6.0; BESA Software, Gräfelfing, Germany). For the quantitative analysis, data from 45 2-s artifact-free epochs (30 with eyes open, 15 with eyes closed) were divided according to band: delta (1.0–4.0 Hz), theta (4.0–8.0 Hz), alpha (8.0–14.0 Hz), and beta (14.0–30.0 Hz). These epochs were carefully checked for artifacts with very strict criterion in order to make remaining epochs not associate with any small changes in horizontal and vertical eye movements and muscle artifacts. The power values of the monopolar montages (A1 and A2 as a reference) of the aforementioned bands were analyzed in all 32 channels. The total power values were calculated by summing the power values of the delta, theta, alpha, and beta bands. The number of variables was reduced by calculating the regional means from the original variables: frontal area (Fp1, Fp2, Fz, F3, F4, F7, and F8), temporal area (T3, T4, T7, and T8), parietocentral area (P3, P4, Pz, P7, P8, C3, and C4), and occipital area (O1, Oz, and O2).

Statistical Analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences 22.0 for Windows (IBM Corp., Armonk, NY). An independent-samples *t*-test was used to identify sex differences in the mean values of the variables of interest. Relationships between the EEG band power values and fluid intelligence were determined using Pearson's correlation coefficients.

Results

The average score of the participants on the RSPM was 49.31 points. The average score of females was 50.43 (standard deviation [SD]=4.37), whereas that of males was 48 (SD=5.51). The mean RSPM scores of females and males, as well as the SDs, t-values, and p-values, are shown in Table 1.

The results do not reflect a significant sex difference in RSPM scores (t=1.535). Participants scored highest on set A (11.29) and lowest on set E (7.15). The test results are presented in Figure 2.

Table 1. RSPM results by sex

Group	N	Mean	SD	t	p
Females	21	50.43	4.37	1.535	0.133
Males	18	48.00	5.51		

N: Number of particapant SD: standard deviation

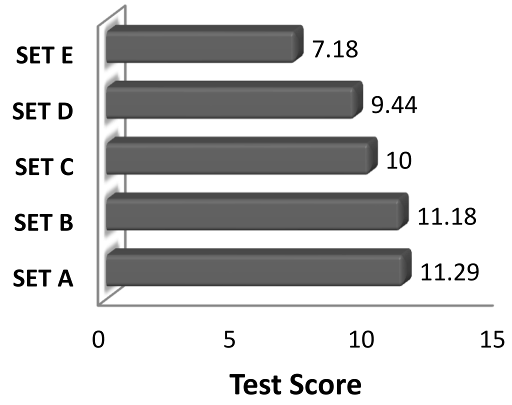

Figure 2. Graph of RSPM scores according to set.

Pearson's correlation coefficients were calculated to determine correlations between EEG power bands and RSPM scores. No statistically significant correlations were found between EEG power bands and fluid intelligence in either the whole-brain analysis or in the analysis based on brain areas (Table 2).

Table 2. Correlations between EEG band powers and RSPM scores for brain areas and the whole brain

Brain Area	Delta	Theta	Alpha	Beta
Frontal	0.141	0.155	0.046	0.066
Temporal	0.081	0.123	0.115	0.023
Centro-Parietal	-0.086	0.032	0.181	0.049
Occipital	-0.243	0.084	0.150	0.090
Whole Brain	-0.071	0.146	0.119	0.117

The Pearson's correlation coefficient was highest for the relationship between the occipital region and delta power and lowest for that between the temporal region and beta power. The correlation coefficients for the associations of the occipital and centro-parietal regions and the whole brain with the delta band were negative.

Discussion

Comprehensive research is required to identify relationships between the electrical activity of the brain and intelligence. However, it remains difficult to identify relationships between EEGs and intelligence because resting-state EEG data reflect brain activity over a short period of time.

The present study found no correlation between resting-state EEG and fluid intelligence.

In his review, Court (1983) summarized 118 studies of sex differences in the RSPM, most of which reported no significant difference between the mean scores of males and females. However, several studies did find sex differences in fluid intelligence (Lynn, 1994; Lynn, 1999; Colom and García-López, 2002). Colom and García-López (2002) reported that males outperformed females in the Raven Advanced Progressive Matrices test, and they interpreted this result to mean that this test is not an appropriate measure of fluid intelligence. However, we administered the RSPM and found no differences between males and females in terms of performance. We conclude that the RSPM is one of the best tests of fluid intelligence.

In a resting-state EEG study, Jausovec (1997) found that gifted respondents displayed lower alpha power than average students. However, a second study by Jausovec (1996) found that highly intelligent participants showed higher alpha activity compared to average individuals. Another study (Schmid *et al.,* 2002) obtained resting-state EEG data from 155 healthy children who had also completed The Wechsler Intelligence Scale for Children-Revised (WISC-R). They found that intelligence was negatively correlated with low-frequency waves. Another resting-state EEG study reported a positive correlation between WISC-R scores and the absolute power of all bands (Thatcher *et al.,* 2005). The same study also found that the size of the effect of EEG power (e.g., absolute power, relative power, and power ratios) in the relationship between electrical brain activity and intelligence was smaller than that of EEG phase, EEG coherence, and EEG amplitude asymmetry. Such inconsistencies among studies may indicate that it is inappropriate to use resting-state EEG power values to understand the mechanisms underlying intelligence. Indeed, our results show no correlation between resting-state EEG power values and intelligence.

One EEG study (Anokhin *et al.,* 1999) recorded EEGs while participants were resting and while they were performing the Intelligence Structure Test. Most of the significant correlations involved the performance of tasks rather than resting. Our results are consistent with this finding as we did not find any relationship between resting-state EEG power and intelligence.

Marosi *et al.,* (1999) analyzed the relationships between the absolute power of EEGs and scores on the Wechsler Adult Intelligence Scale (WAIS). They found correlations between subscales of the WAIS and EEG power at different electrodes. For instance, they reported a negative correlation between scores on the digit span subscale and the absolute power of the beta band at the C4 electrode, and a positive correlation between scores on the arithmetic subscale and the absolute power of the beta band at the T3 electrode. As EEGs have good temporal but poor spatial resolution, we cannot analyze data on two parameters obtained from a single electrode, and our regional correlation analysis did not indicate any relationship between resting-state EEG power and intelligence.

Investigations of the relationships between intelligence and electrophysiological brain activity must carefully consider the structure of human intelligence. Indeed, intelligence is multifaceted, and there are hundreds of tests that purport to measure intelligence in standardized ways (Jensen, 1980). In this context, the problems underlying the difficulty of accurately measuring intelligence may also interfere with efforts to elucidate its structure. In addition to the difficulty of measuring intelligence objectively, resting-state EEG parameters are probably transiently influenced by various factors, including mood during EEG recording, thoughts triggered by environmental stimuli, and physical fatigue. Our review of the relevant literature as well as the results of the present study suggest that the findings of studies of relationships between intelligence and resting-state EEGs are contradictory and that resting-state EEG parameters are less predictive of future performance than are other EEG parameters (coherence, ERPs, event-related desynchronization/synchronization, and source localization).

With the exception of resting-state EEGs, EEGs that rely on advanced quantitative analytic methods may help to identify the neural mechanisms underlying intelligence. Specifically, we suggest that research designed to improve our understanding of intelligence focus on networks in the brain instead of localization.

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