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The Correlation between a New Online Cognitive Test (the Brain Assessment) and Widely Used In-Person Neuropsychological Tests

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Keywords
Brain assessment · Correlation · Mini-mental state examination · Raven's colored progressive matrices

Abstract
Introduction: There are several problems with standard in-person neuropsychological assessments, such as habituation, necessity of human resources, and difficulty of in-person assessment under societal conditions during the outbreak of coronavirus disease 2019. Thus, we developed an online cognitive test (the Brain Assessment [BA]). In this study, we investigated the correlation between the results of the BA and those of established neuropsychological tests. ***Participants and Methods:*** Seventy-seven elderly persons (mean 71.3 ± 5.1 years old; range 65–86; male:female = 45:32) were recruited through the internet. Correlations were evaluated between the BA and the following widely used neuropsychological tests: the mini-mental state examination (MMSE), the Raven's colored progressive matrices (RCPM), the logical memory I and II of the Rivermead Behavioral Memory Test, the word fluency (WF) test, and the Trail-Making TestA/B. ***Results:*** We found moderate correlations between the total cognitive score of the BA and the total score of the MMSE ($r = 0.433$, $p < 0.001$), as well as between the total BA score and the total RCPM score ($r = 0.582$, $p < 0.001$) and time to complete the RCPM ($r = 0.455$, $p < 0.001$). Moderate correlations were also observed between the cognitive score of the memory of words BA subtest and the LM-I ($r = 0.518$, $p < 0.001$), the mental rotation subtest and figure drawing ($r = 0.404$, $p < 0.001$), the logical reasoning subtest and total RCPM score ($r = 0.491$, $p < 0.001$), and the memory of numbers and words subtests and WF (memory of numbers and total WF: $r = 0.456$, $p < 0.001$; memory of words and total WF: $r = 0.571$, $p < 0.001$). ***Discussion:*** We found that the BA showed moderate correlations between established neuropsychological tests for intellect, memory, visuospatial function, and frontal function. The MMSE and the RCPM reflect Spearman's s-factor and g-factor, respectively, and thus the BA also covered both factors. ***Conclusion:*** The BA is a useful tool for assessing the cognitive function of generally healthy elderly persons.

Introduction

To assess cognitive function, neuropsychological examinations are performed. In particular, the mini-mental state examination (MMSE) [1] is frequently used across

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the world for screening cognitive decline. However, the COVID-19 pandemic has significantly altered the delivery of health care, including neuropsychological evaluations [2]. There are several problems with the standard in-person neuropsychological assessments. (i) The first is habituation; because most neuropsychological tests have only 1 version, the user can become accustomed to the contents of the test through repeated testing [3]. This habituation may allow the participant to achieve a higher score that surpasses their actual abilities and is not truly reflective of performance. (ii) The second limitation of in-person testing is cross-sectional evaluation. The cognitive function of a participant may be considered normal if the score is within a normal limit at a given timepoint, but the speed of cognitive decline over time is typically not assessed, and this parameter is better reflective of actual changes due to aging. (iii) The third limitation is a shortage of human resources. In order to carry out in-person neuropsychological assessments, professionals such as speech therapists are necessary. However, in most medical and care institutions, the availability of such professionals is insufficient. (iv) Finally, in-person assessment is difficult due to the outbreak of COVID-19. Perhaps a serendipitous effect of the COVID-19 crisis is the discovery that standard paper and pencil clinical neuropsychological evaluations can be administered electronically using a digital medium [2]. Recently, there have been several reports that evaluated cognitive function using digital devices such as iPads [4], digital pens [5], and a digital clock-drawing test [6]. Though the data in these papers show how digital technology can calculate potentially sensitive clinical neurocognitive biomarkers to flag early emergent neurodegenerative illness, the first and second limitations listed above (habituation and cross-sectional testing) are still problematic.

To resolve these problems, we have developed an online cognitive test named the Brain Assessment (BA) that covers 5 fields: number memory, word memory, mental rotation, working memory (N-back test), and judgment [3]. The cardinal features of the BA include 5 different versions to avoid habituation, conciseness (30 min), the automated scoring system, easy access on website without a risk of COVID-19, and the basic data based on a large population of 5,000 subjects with a wide age range of 40–89. Further, the differences in the levels of difficulties among the 5 versions were standardized by use of the cognitive score (to be specified in our previous paper [3]). By performing the BA every year, participants will be able to detect any abnormal rates of cognitive decline, even if the results at a given timepoint are within normal limits. This awareness may bring forth the motivation to improve aspects of an individual's lifestyle, which is critical for dementia prevention.

Table 1. Characteristics of participants

N = 77 (M:F = 45:32)	Mean ± SD
Characteristics	
Age, years	71.3±5.1
Education, years	15.3±1.9
Cognitive function	
MMSE	28.7±1.7
RCPM	
Score	31.7±3.8
Time, sec	275±86
RBMT	
LM-I	11.7±3.9
LM-II	10.6±3.8
Figure drawing	17.3±1.0
WF	57.0±13.1
TMT	
A, sec	113±34
B, sec	135±47

F, female; LM, logical memory; M, male; N, number; RBMT, Revermead behavioral memory test; RCPM, Raven's colored progressive matrices; SD, standard deviation; TMT, trail-making test; WF, word fluency.

In this study, we investigated the correlations between the results of the BA and those of established neuropsychological tests. As the primary outcomes, we examined the relationship between the BA and the MMSE as well as between the BA and the Raven's colored progressive matrices (RCPM) [7]. The RCPM is a cognitive test that reflects nonverbal intellect. The secondary outcomes were the correlations between the results of the BA and those of other neuropsychological tests frequently used in the clinic.

Participants and Methods

Participants

We recruited participants through the internet. Our initial plan was to conduct a nonpharmacological intervention of physical exercise, and we announced this by sending a direct e-mail to about 1 million elderly persons (≥65 years old), all of whom were members of SAISON Credit Card, which is the parent company of Research Institute of Brain Activation. Though we did not proceed with the physical exercise component of that study, we were able to collect the data from the cognitive test portion of the study, which is what is reported here. Participants were required to perform an online cognitive test created by our group (the BA) [3] as

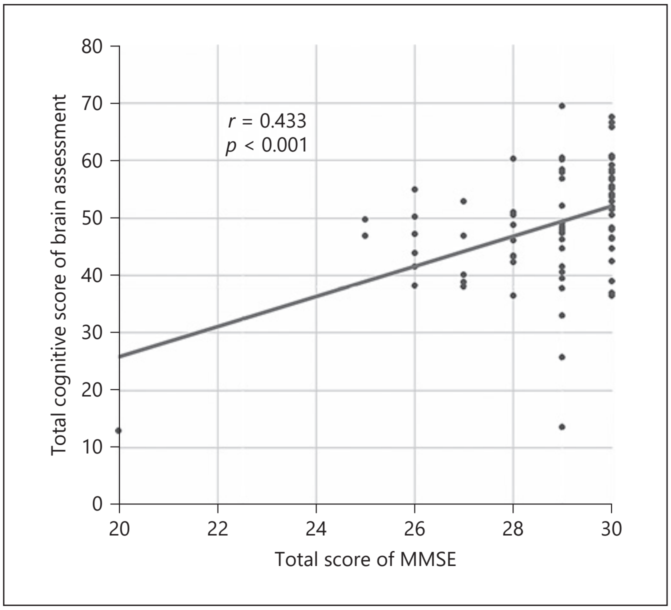

Fig. 1. The correlation between the total cognitive score of the BA and the total score of the MMSE. BA, brain assessment; MMSE, mini-mental state examination.

well as a battery of widely used neuropsychological tests. Seventy-seven elderly persons (mean 71.3 ± 5.1 years old; range 65–86; male: female = 45:32) agreed to participate in the examinations. Participant characteristics are summarized in Table 1.

Cognitive Assessments

The BA was invented by our group for the purpose of evaluating the degree of cognitive decline [3]. The BA has 5 versions and can be completed on the internet within 30 min. Based on the results of our preceding research, cognitive scores (CSs) were calculated using the following formula: CS = ([raw score] − [mean of raw scores])/(SD of raw scores) × 10 + 50. For more details, see our previous paper [3]. According to our previous studies [8–10], the following neuropsychological tests were administered. To quantify intellectual function, the MMSE and the RCPM [7] were administered. RCPM measures not only the score a participant can achieve but also the performance time, which reflects the psychomotor speed of the individual. Memory was evaluated using logical memory I and II of the Rivermead Behavioral Memory Test (RBMT) [11], which consists of immediate and delayed recall of a short story. The RBMT has 4 stories across which the difficulty and number of words and sentences are identical. The assessment of constructional ability was based on the method described by Strub and Black [12]. A 3-dimensional cube was shown to the examinees and they were asked to draw it. The hand-drawn on paper was recorded by video, and the drawing was scored by assigning 1 of 4 possible grades (0: poor, 1: fair, 2: good, and 3: excellent). Frontal function was assessed by 2 types of tasks: word fluency (WF) and the Trail-Making TestA/B (TMT-A/B). The WF test consisted of 2 domains: category and letters. For the categorical WF, participants were asked to name as many animals as possible in 1 min.

Table 2. Pearson's correlation coefficients between the results of the BA and neuropsychological examinations

Brain assessment			General intellect			Memory		Visuospatial	Frontal function			
cognitive domains	subtest		MMSE	RCPM		RBMT		Figure drawing	WF		TMT	
				score	time	LM-I	LM-II		letter	category	*A*	*B*
Memory	Numbers	*r*	0.365	0.421	0.399	0.323	0.199	0.307	0.414	0.352	–0.373	–0.389
		p	0.001	<0.001	<0.001	0.004	0.083	0.007	<0.001	0.002	0.002	0.002
	Words	*r*	0.342	0.433	–0.390	0.518	0.381	0.213	0.531	0.412	–0.419	–0.307
		p	0.002	<0.001	<0.001	<0.001	0.001	0.063	<0.001	<0.001	<0.001	0.014
Visuospatial	Mental rotation test	*r*	0.242	0.521	–0.373	0.098	0.084	0.404	0.248	0.266	–0.193	–0.172
		p	0.034	<0.001	0.001	0.398	0.468	<0.001	0.031	0.019	0.120	0.177
Working memory	N-back test	*r*	0.301	0.280	–0.278	0.242	0.261	0.170	0.157	0.370	–0.285	–0.296
		p	0.008	0.014	0.014	0.034	0.022	0.138	0.171	0.001	0.020	0.019
Judgment	Logical reasoning	*r*	0.396	0.491	–0.280	0.331	0.218	0.274	0.270	0.361	–0.242	–0.225
		p	0.000	<0.001	0.014	0.003	0.057	0.016	0.018	0.001	0.050	0.077
Total		*r*	0.433	0.582	–0.455	0.379	0.287	0.377	0.413	0.460	–0.398	–0.368
		p	<0.001	<0.001	<0.001	0.001	0.011	0.001	<0.001	<0.001	0.001	0.003

The yellow and red boxes indicate fair and moderate correlation, respectively (small: 0.0–0.2, fair: 0.2–0.4, moderate: 0.4–0.7, and strong: 0.7–1.0). LM, logical memory; MMSE, mini-mental state examination; RBMT, Revermead behavioral memory test; RCPM, Raven's colored progressive matrices; TMT, trail-making test; WF, word fluency; BA, brain assessment.

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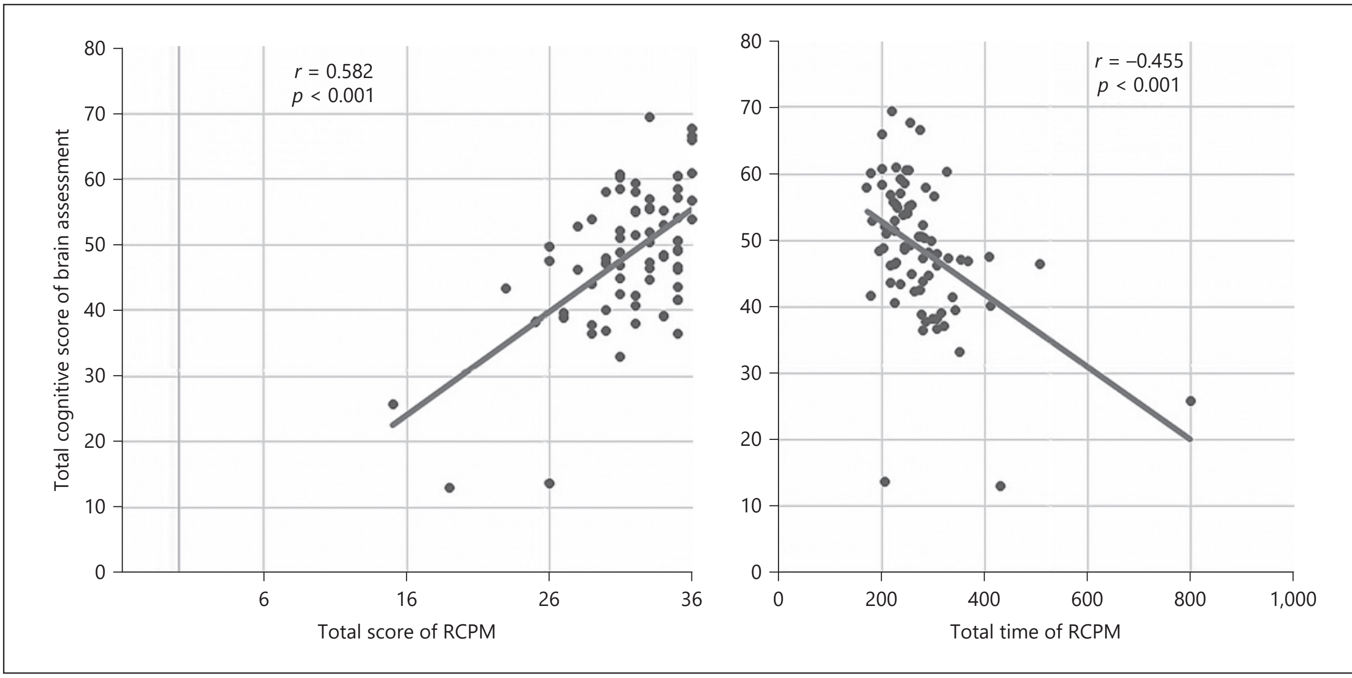

Fig. 2. The correlation between the total cognitive score of the BA and the total score and the total time taken to complete the RCPM. BA, brain assessment; RCPM, Raven's colored progressive matrices.

For the letter WF, for each of 4 phonemes *ka*, *sa*, *ta*, and *te*, the participants were asked to name objects with that phoneme at the beginning of the word [13]. These phonemes are the most frequently used in Japanese language. We used the average scores of these 4 phonemes for statistical analysis. It is generally accepted that the cognitive processing of categorical and letter WF is somewhat different, categorical WF being more reflective of memory function than letter WF.

Statistical Analyses

We calculated correlation coefficients between the CSs of the BA and the results of each neuropsychological assessment. The data were distributed parametrically, thus Pearson's correlation coefficient was used. The results were interpreted as indicative of small (0.0–0.2), fair (0.2–0.4), moderate (0.4–0.7), and strong (0.7–1.0) associations. We regarded the results as significant if the p value was under 0.05. All statistical analyses were performed using IBM SPSS Statistics 23 software.

Results

The results of the statistical analyses are summarized in Table 2. The primary outcomes are shown in Figures 1 and 2. There was a moderate association between the total CS of the BA and the total score of the MMSE (Fig. 1, $r = 0.433$, $p < 0.001$), as well as between the total CS of the BA and the total score of the RCPM (Fig. 2, left. $r = 0.582$, $p < 0.001$) and performance time of the RCPM (Fig. 2, right. $r = 0.455$, $p < 0.001$). As for the secondary analyses, significant correlations were observed between the results of the BA subtests and those of the related neuropsychological examinations (Table 2; Fig. 3–7). There were moderate associations between the CS of the memory of words and the LM-I (Fig. 3; $r = 0.518$, $p < 0.001$), the mental rotation and figure drawing (Fig. 4; $r = 0.404$, $p < 0.001$), the logical reasoning and total score of RCPM (Fig. 5; $r = 0.491$, $p < 0.001$), and the memory of numbers and words subtests and WF (memory of numbers and total WF: $r = 0.456$, $p < 0.001$; memory of words and total WF: $r = 0.571$, $p < 0.001$) (Fig. 6).

Discussion

We investigated the correlations between the results of the BA and those of established neuropsychological tests, and found moderate correlations between them for intellect, memory, visuospatial function, and frontal function. The results of the present study are summarized as follows: (i) there were moderate correlations between the BA total score and the MMSE total score, as well as between the BA total score and the RCPM score and RCPM

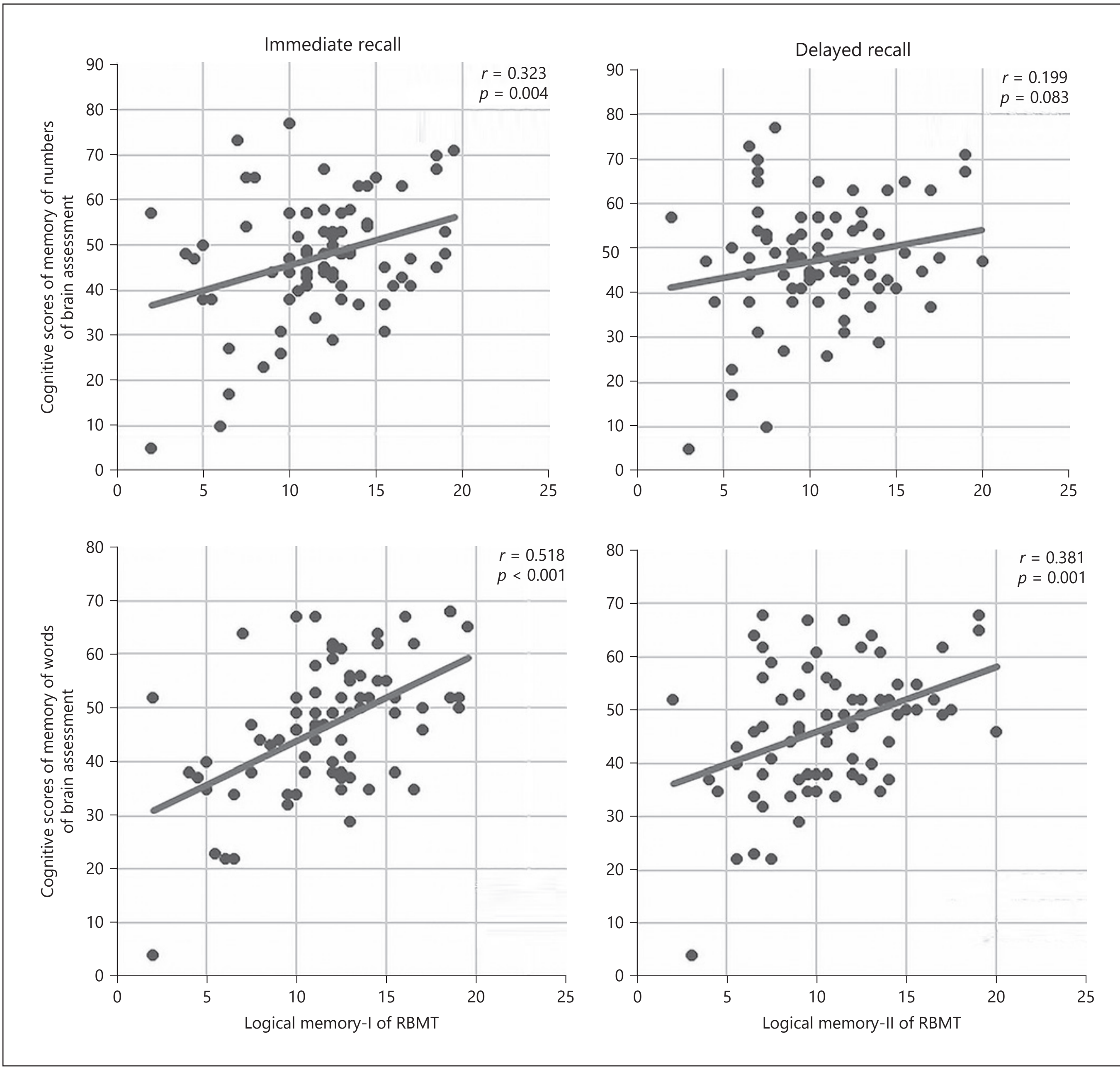

Fig. 3. The correlation between cognitive scores of the memory of numbers/words subtest of the BA and the scores of LM-I/-II of the RBMT. BA, brain assessment; RBMT, Rivermead behavioral memory test; LM-I/-II, logical memory-I and II.

time; (ii) there were moderate correlations between the memory of words of the BA and the LM-I, and the BAs mental rotation subtest and the figure drawing test; and (iii) the results of memory of words and numbers of the BA showed moderate correlations with the letter and category WF. Based on these findings, we believe that the BA is relevant to the assessment of the cognitive function.

According to Spearman [14], the intellect can be divided into 2 factors, that is, the specific (s-factor) and the general factor (g-factor). The former refers to the cognitive function of each cognitive domain – for example, language, calculation, visuospatial function – while the latter shows the cognitive functions of reasoning and thinking, which regulate and integrate the s-factors of the cognitive domains. The

MMSE and the RCPM are thought to reflect the function of the s-factor and g-factor, respectively. Moreover, the total performance time of the RCPM reflects the psychomotor speed. Therefore, we suggest that as the BA was correlated with the MMSE and RCPM, it may also be considered a measure of the multifaceted aspects of cognitive function.

It was not surprising that there were significant correlations between the BA memory of words subtest and the LM-I results, and between the mental rotation subtest of the BA and the figure drawing task. Both the memory of words and the LM-I tests are based on the memory of language, and reflect the recent memory. The mental rotation and the figure drawing test reflect visuospatial function, that is, the perception of visual stimuli, as well as one's ability to maintain and manipulate this information. We also observed significant correlations between the results of memory of words and numbers of the BA with the results of the letter and category WF. It is understood that both tasks depend on a common process of retrieving the targets from memory storage.

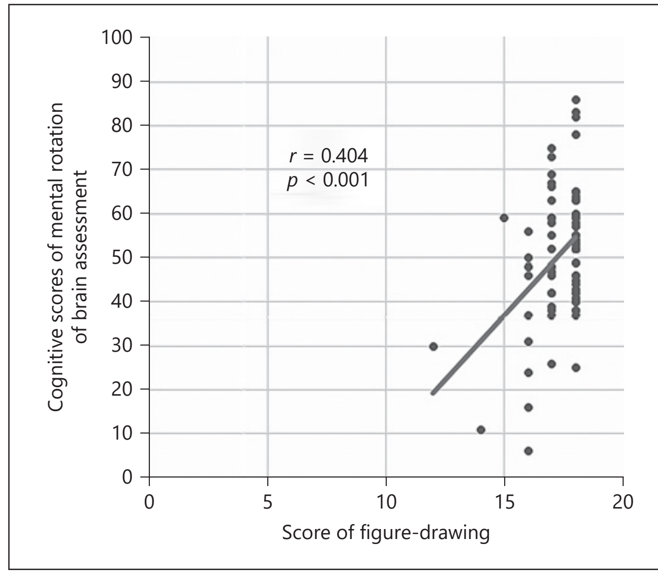

Fig. 4. The correlation between the cognitive score of the BA mental rotation subtest and the figure drawing score. BA, brain assessment.

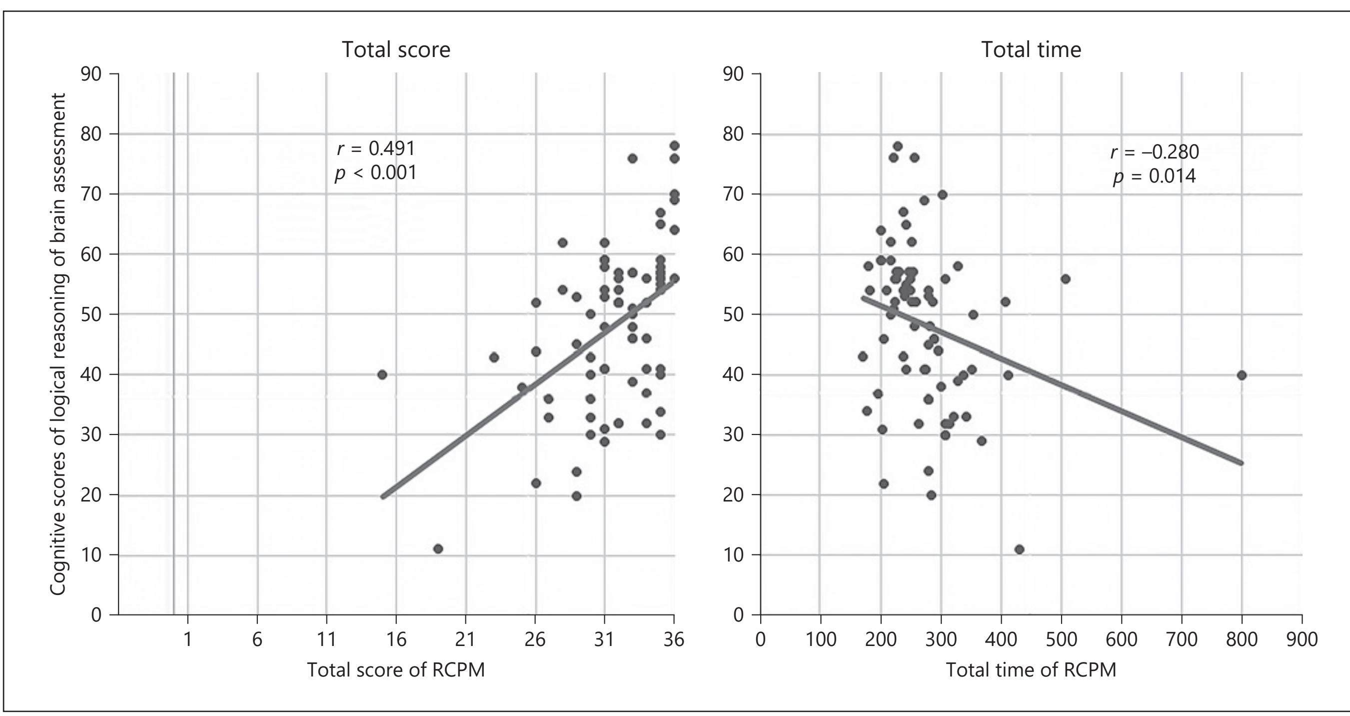

Fig. 5. The correlation between cognitive scores of the BA logical reasoning subtest and the total RCPM score and time taken to complete the RCPM. BA, brain assessment; RCPM, Raven's colored progressive matrices.

Fig. 6. The correlations between cognitive scores of the memory of numbers/words of the BA and the total, letter, and category WF. BA, brain assessment; WF, word fluency.

(For figure see next page.)

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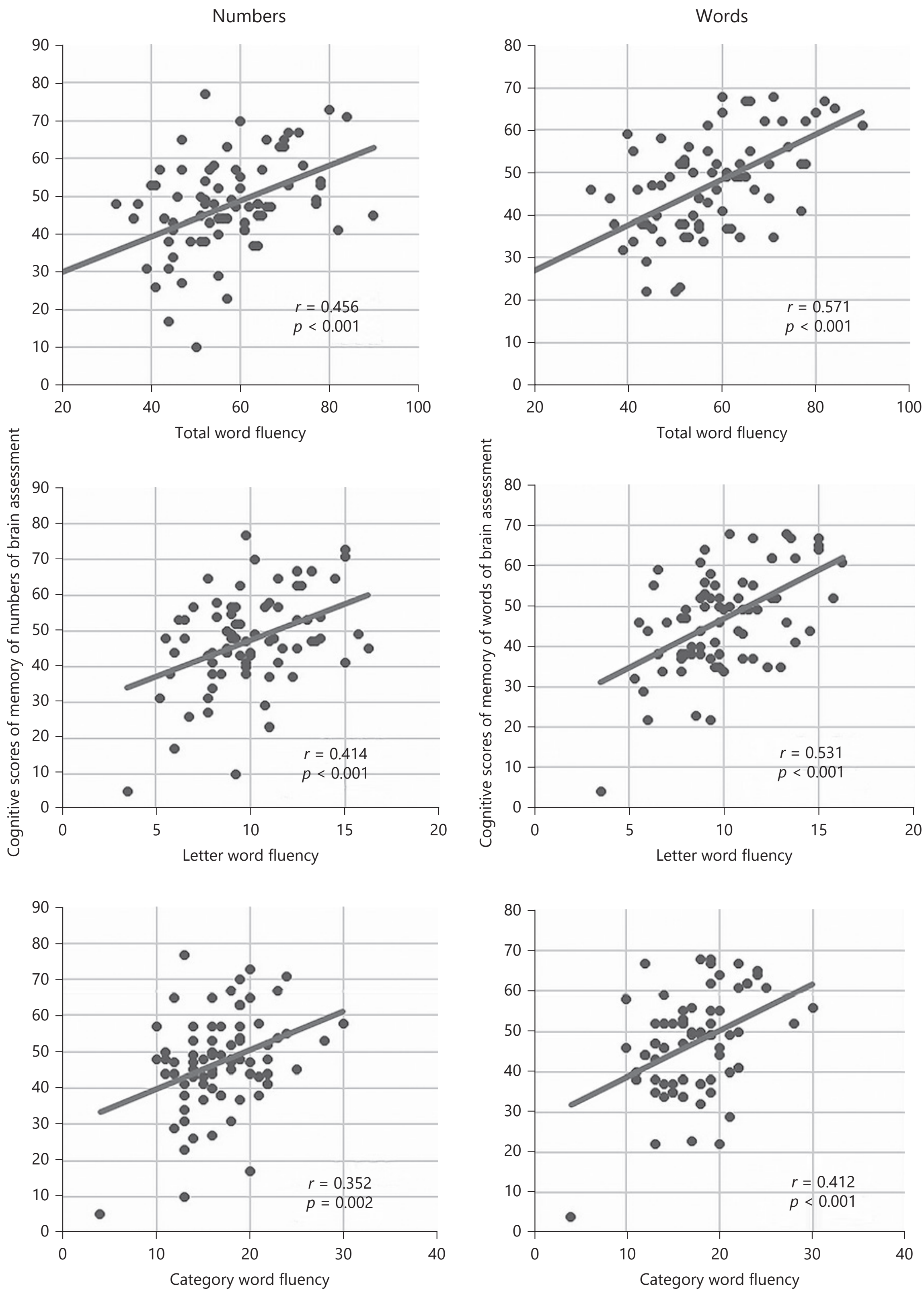
Numbers
Words
Cognitive scores of memory of numbers of brain assessment
Cognitive scores of memory of words of brain assessment
Total word fluency
Letter word fluency
Category word fluency
r = 0.456
p < 0.001
r = 0.571
p < 0.001
r = 0.414
p < 0.001
r = 0.531
p < 0.001
r = 0.352
p = 0.002
r = 0.412
p < 0.001

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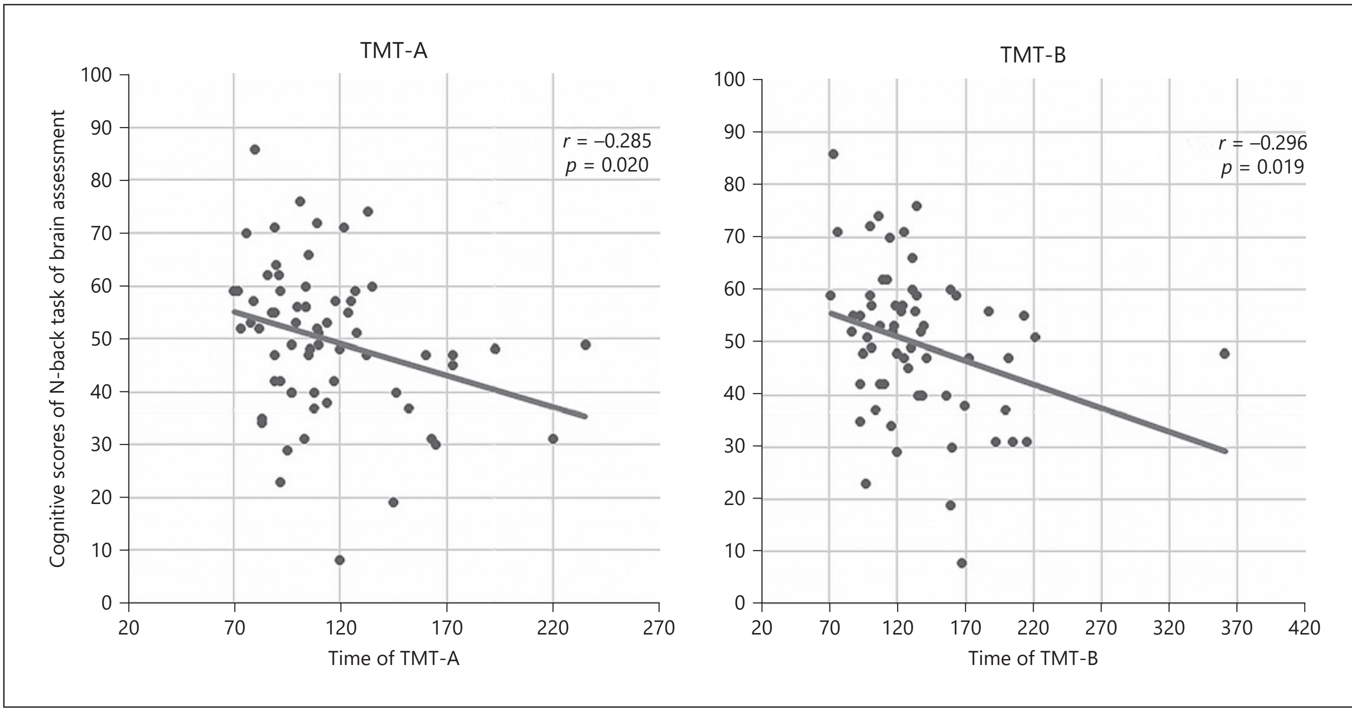

Fig. 7. The correlations between cognitive scores of the N-back task of the BA and the time to complete the TMT-A/B. BA, brain assessment; TMT, trail-making test.

This study has several limitations. First, the number of participants was not so large. This study dealt with the results of 77 participants. The reason for this is that due to the ongoing outbreak of COVID-19, we could not perform in-person assessment in a larger population. Second, the participants in the present study were cognitively normal. We are now collecting data from patients with dementia and mild cognitive impairment. Lastly, the present study lacked temporal assessment over time that is mentioned in the introduction as one of the limitations of standard in-person neuropsychological assessments. Despite these limitations, we can reasonably conclude that the BA is a useful tool for assessing the cognitive function of normal elderly persons.

Statement of Ethics

This study received approval from the Advanced Institute of Industrial Technology Research Ethics Committee (Approval No.:19009) and was conducted in accordance with the Helsinki Declaration of 1975. All of the participants provided informed consent in writing or by clicking a button on the internet site used to run the assessment and collect the data.

Conflict of Interest Statement

The Department of Dementia and Neuropsychology, Master Program of Innovation for Design and Engineering, Advanced Institute of Industrial Technology, was established using donations provided by the Research Institute of Brain Activation.

Funding Sources

The study was conducted without any funding sources.

Author Contributions

Masayuki Satoh took part in design of this study, interpretation of data, and writing the manuscript. Ken-ichi Tabei was involved in interpretation of data and revision for important intellectual content. Makiko Abe and Chiaki Kamikawa took part in acquisition and interpretation of data. Saiko Fujita took part in analyses of data. Yoshinori Ota was involved in design of this study and acquisition of data.

Data Availability Statement

All data analyzed during this study are included in this article. Further enquiries can be directed to the corresponding author.

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