REVIEW ARTICLE

Handedness difference in cognitive performance decline from middle aged: Evidence from the Yakumo Study

Authors
Takeshi Hatta[1], Taketoshi Hatta[2], Junko Hatta[3], Akihiko Iwahara[4], & Kazumi Fujiwara[5]

Affiliations
[1] Kansai University of Welfare Sciences, Japan
[2] Gifu University of Medical Sciences, Japan
[3] Aichi Gakuin University, Japan
[4] Kyoto Women's University, Japan
[5] Toho University, Japan

Correspondence
Takeshi Hatta
Email: hatta@tamateyama.ac.jp

Abstract

Handedness difference in the age-related cognitive decline was examined. Participants were healthy middle aged left-handed (n = 22, 10 men and 12 women) and right-handed (22 men and 56 women). Digit cancellation performance decline ratios were calculated by the longitudinal Digit Cancellation Test data with an interval of 10 years. Performance decline ratios were compared for handedness and sex concerning to D-CAT1 (1-digit cancellation condition) and D-CAT3 (3-digits cancellation condition) performances. The results indicated first that the performance decline ratio in the left-handed was significantly larger than that in the right-handed both in D-CAT1 and D-CAT3, suggestive of low aging tolerance of executive function in left-handed people. Moreover, there was a significant sex difference such that men demonstrated a larger decline in D-CAT3, which demands more considerable cognitive resources, compared to D-CAT1, whereas this was not observed in women. Possible executive function mechanisms during aging were discussed in relation to handedness and sex.

Keywords: Handedness, digit cancellation, decline ratio, executive function, aging.

1. INTRODUCTION

Brain imaging studies have demonstrated differences between left- and right-handed people in various facets of behavior. Following this, the possibility of handedness differences in human cognitive functions has become a central topic among laterality researchers. [1-4] Much theoretical research has been conducted on this topic, which is described below. Among these, one exciting topic is related to the handedness effect on executive function, which is a core aspect of human cognitive behavior facets.[5] However, studies examining the handedness effect have remained controversial, with some finding reporting the relative inferiority of left-handedness,[6, 7] others reporting no significant handedness difference, [8-10] and yet others indicating superior performance in left-handed people.[11, 12] These differences could be partially attributed to different measures employed in these studies as behavioral measures for assessing executive function, such as the Wisconsin Card-sorting Test, Stroop Test, D-CAT, Trail-making Test, and the Letter-Number Sequencing, as well as the characteristics of the sample population.

Van der Elst et al [8] reported a study directly relevant to the current research question that examined the possible handedness effect on executive function in upper-middle aged people aged 50 years. They examined handedness differences of performance decline trajectories in the Stroop Test using three-year longitudinal data and reasonable sample size (left-handed sample = 72). The results failed to support the hypothesis that left-handedness is associated with more pronounced cognitive decline. Hatta[8] also compared the performances of 100 left-handed and 100 right-handed people (mean age 61.7 years, SD = 10.8) and failed to demonstrate a significant difference in color naming speed or interference effect size in the Stroop test measure. One possible reason for these null findings pertains to the Stroop Test. The Stroop Test is not a unique measure of executive function, but several other measures, including the Trail-making Test, Wisconsin Card-sorting Test, the Letter Cancellation Test, and the Letter-Number Sequencing Test are also employed for assessing executive function.

Miyake, et al[13] conducted a meta-analysis of earlier studies using latent variable analysis and proposed that Baddeley's executive function consists of three components: *Updating information, shifting,* and *inhibition.* Accordingly, it can be argued that the weighting of the three components might not be identical across different measures assessing executive function because different measures variably tap into different components of executive function. The Stroop Test might be weighted more on the *inhibition* components than the *updating information* and the *shifting* components compared to the Letter Cancellation Test, the Trail-making Test, or the Letter-Number Sequencing Test. On the other hand, participants in the letter (or digit) cancellation task mark designated letter(s) on a sheet of randomly arranged letter sequences as fast and accurately as possible, which reflects the *updating information* and the *shifting* components more strongly than the *inhibition* component. U*pdating information* goes beyond merely maintaining task-relevant information. It requires monitoring and coding incoming information for relevance to the task at hand, and revisiting items held in the working memory to replace old, no longer relevant, information with new, more relevant, information.[14]

Hatta[15] reexamined the handedness effect on the executive function in upper-middle aged people using the Digit Cancellation Test (D-CAT3) instead of the Stroop Test, and handedness effect in people approximately 60 years of age by demonstrating superior performance in right-handed than left-handed people. This finding is suggestive of differential aging effects on executive function that is associated with hand dominance.

It is well known that the aging effect on cognitive functions should be examined by cross-sectional methods to avoid the cohort difference bias. Longitudinal designs have advantages over cross-sectional designs in developmental research because the former does not involve confounding effects of maturational changes and cohort membership. In contrast, cross-sectional designs tend to overestimate the magnitude of actual age differences unidentified, cohort-related influences.[16, 17] Longitudinal designs also have specific shortcomings such as contamination of learning effects because the same cognitive test measures are employed at different developmental stages. Nevertheless, longitudinal studies provide more reliable prospective evidence than cross-sectional research.

In general, plural viewpoints should be adopted when examining the functional quality of an object. For example, when discussing a car's functions, we must consider the vehicle's performance over a short period and whether its functions are maintained over a long period. Similarly, a one-shot comparison of task performance is insufficient for judging human cognitive functions' quality because examining the performance's sustainability is crucial. Therefore, it is necessary to conduct longitudinal and one-shot comparisons of functional test results in comparing executive functions of left- and right-handed people. Therefore, this study conducted a longitudinal comparison of executive functions between left- and right-handed people. To the best of the author's knowledge, this is the only study investigating the effects of handedness difference on executive function associated with the aging, which was demonstrated by Hatta[15], Using longitudinal research methodology. In sum, the hypothesis that left-handed people's performance decline ratio is larger than that of right-handed people was examined in this study. I also hypothesized sex differences in the decline ratios between D-CAT1 and D-CAT3 based on the theory of sex-related brain functions and handedness described later.

2. METHOD

Participants

Participants were selected from a database of 6,893 people that participated in the Neuropsychology Section of Yakumo Study from 2001 to 2019. The selection was made on the following criteria: (1) Participated in the neuropsychology section of the Yakumo Study twice with a 10-year interval and administered the exact test twice, in 2001 and 2019; (2) Age over 40 years; physically and cognitively healthy without any signs of mild cognitive dementia as assessed by a score of over 23 points on the Mini-Mental State Examination (MMSE); (3) Handedness evaluated by using the H.N. handedness inventory or self-reports (because the handedness inventory was not administered every year).

The number of people meeting these criteria in 2001-2010, 2002-2011, 2003-2012, 2004-2013, 2005-2014, 2006-2015, 2007-2016, 2008-2017, 2009-2018, and 2010-2019 were 50, 89, 71, 55, 51, 56, 46, 72, 54, and 47, respectively. Of these, 591 people were tested with the exact cognitive test 10 years after the first test. Among these, the 22 left-handed people (10 men and 12 women) were selected as participants in the study. Also, right-handed participants were selected as the control group by matching the age at the first examination, sex, and years of education with the left-handed participants. There is a larger right-handed population; therefore, multiple right-handed individuals who corresponded to left-handed individuals on the three criteria were included to avoid selection bias. As a result, 78 right-handed people (22 men and 56 women) were selected as the control group. The characteristics of the participants are shown in Table 1.

Handedness was not a major survey item in the Yakumo Study, and it was assessed by the H.N. handedness Inventory or by self-reports depending on the survey year. The H. N. Handedness Inventory was used to assess the hand preference in 2011, 2012, and 2014. The H. N. Handedness Inventory, which is very similar to the

Edinburgh Handedness Inventory, has been standardized for Japanese people and scores range from -10 to +10. [18, 19] The correlations between the H. N. Handedness Inventory scores and self-reports of alternatives (left versus right-hand use) was reasonably high (r = 0.88) in 2011. Participants' handedness was assessed using a self-report of dichotomized handedness in other years.

Participants were administered the Nagoya University Cognitive Assessment Battery (NU-CAB), which includes test items assessing attention, memory, verbal, and spatial abilities. We examined the performances on the D-CAT that is one of the items of NU-CAB. A review by Coetzer and Balchin,[20] Lezak, Howieson, Bigler, and Tranel[21] has recommended the Letter Cancellation Tests as a comprehensive measure of attention. Moreover, Hatta *et al* [22] indicated that letter cancellation tests are simple and effective measures of attention that are cost-effective and applicable over a broad spectrum of age groups. These tests are usually paper-and-pencil tests, in which participants identify and cancel target items. The D-CAT consists of target stimuli (digits) that are distributed amongst distractor stimuli, similar to most cancellation tests. The target stimulus is a digit that participants must identify and cancel, while the distractor stimuli divert the participants' attention from target stimuli.

D-CAT test sheet consists of 12 rows of 50 digits. Each row contains five sets of numbers from 0 to 9 arranged in a random order such that each digit appears five times in each row, along with randomly determined neighbors. In the hierarchal model of attention of Solberg and Mateer[23], the D-CAT is regarded as an assessment of focused attention, sustained attention, and information processing speed. The D-CAT performance depends on the control of the frontal eye fields, which is a function of the dorsal attention network, consisting of the frontal eye field and parietal lobe connections. Furthermore, this task recruits the ventral attention network for object identification. These complex relationships represent the underpinnings of processing speed task performance that is not restricted to the frontal-parietal networks.[24, 25] The reliability, validity, and hypothesized neural mechanisms of the D-CAT3, including brain imaging evidence[25, 26] have been reported elsewhere. The relationship between handedness and other cognitive measures in the NU-CAB were also examined and reported elsewhere[8].

Participants conducting the D-CAT1 are instructed to search for a target digit (6), and in the D-CAT3, they are requested to search for three digits (8, 3, or 7) on a sheet of randomly arranged digit sequences, and slash as many target digits as they can for 60. The total number of digits searched to make the slash was measured in this study. The D-CAT1 employs a low-visual search load to assess elementary perceptual speed, whereas the D-CAT3 needs a high-visual search load and assesses executive function. The D-CAT3 imposes a more considerable cognitive burden in working memory requirements than the D-CAT1, as indicated by performance decline associated with aging[27] and stronger prefrontal cortex activation.[25, 26]

Sample size calculation method: As described in the contents, 591 people were given test twice with the interval of 10 years. Among those, there were 22 left-handed people (10 men and 12 women) who satisfied the condition. Much more right-handed satisfied the condition. Then the control right-handed was selected by the criteria 1) same age at the first examination, sex, and years of education to the left-handed. This is due to avoid selection bias.

Table 1: Characteristics of the participants.

	Left-handers N = 22		Right-handers N = 78	
	Women	Men	Women	Men
Number of participants	12	10	56	22
Mean age of the first attendance	56.5 years old	55.3 years old	57.7 years old	60.4 years old
Levels of education				
Higher elementary school (6 years)	10 %	0 %	1.8 %	4.5 %
Junior high school (9 years)	30 %	8 %	32.1 %	9.0 %
High school (12 years)	30 %	33.3 %	53.6 %	53.2 %
College (more than 15 years)	30 %	58.7 %	12.5 %	33.3 %

Table 2: Mean performance of the first year and 10 years later and individually calculated decline ratio for 10 years in D-CAT1 and D-CAT3 as a function of handedness group

	Left-handed		Right-handed	
	Women	Men	Women	Men
D-CAT1				
First year performance	313.60.	300.50	284.43	277.14
(SD)	(64.04)	(96.38)	(46.28)	(63.00)
Ten years after performance	268.20	274.33	254.77	265.05
(SD)	(64.67)	(95.28)	(55.35)	(55.14)
Mean decline ratio	0.08	0.05	0.06	0.03
SD	(0.06)	(0.10)	(0.09)	(0.09)
D-CAT3				
First year performance	183.20	207.33	174.66	169.00
(SD)	(42.71)	(78.61)	(34.50)	(29.37)
Ten years after performance	161.60	170.42	162.39	158.73
(SD)	(36.17)	(71.10)	(30.49)	(32.73)
Mean decline ratio	0.05	0.11	0.06	0.04
(SD)	(0.10)	(0.18)	(0.09)	(0.06)

3. RESULTS

The performance decline ratio was calculated individually using the following formula: [(number of searched digits at the first year) – (number of searched digits at the ten years later)] / [(number of searched digits at the first year) + (number of searched digits at the ten years later)]. For example, participants' first year's performance in D-CAT1was 120, and 10 years later, it was 110, which indicated a declining ratio of 0.04, or a 4 % decline in 10 years. The first and 10^{th} year's performance and performance decline ratio during the ten years in D-CAT1 and D-CAT3 scores are shown in Table 2 as a function of the handedness group. It can be seen that neither the first year's mean performances in D-CAT1 and D-CAT3 between left- and right-handed groups (t = 1.81 and 1.47, df = 98, p > 0.05), nor third year's handedness group differences in mean D-CAT1 and D-CAT3 performances were significant (t = 1.94 and 1.31, df = 98, p > 0.05), suggesting no cognitive differences in the primary performance of left- and right-handed groups.

Mixed design analysis of variance (two-between factors: handedness /sex and one-within factor: D-CAT1/D-CAT3) was conducted on the data of the ratio of decline. Results indicated that handedness's main effect was significant, indicative of a more considerable decline during ten years in left-handed participants ($F_{1, 96}$ = 4.24, MSe = 0.01, p <0.05). Moreover, the interaction between sex and cognitive tests was significant ($F_{1, 96}$ = 24.67, MSe = 0.005, p <0.05), suggesting no difference between D-CAT 1 and D-CAT3 in women ($F_{1, 96}$ = 1.12, ns), whereas a larger ratio of decline in D-CAT3 compared to D-CAT1 was shown in men.

To summaries, these results indicate that the ratio of decline was higher in the left-handed than in the right-handed group. Moreover, men showed a larger decline ratio in the D-CAT3 than in the D-CAT1. Moreover, Figures 1 and 2 depict the handedness effect on the two cognitive tasks for men and women, respectively. It can be seen that the ratio of performance decline associated with aging differs according to the involvement of executive function between D-CAT1 and D-CAT3 and that the effect of aging is more pronounced in left than right-handed people. Moreover, the Figures show sex differences in performance. These results supported the hypothesis of handedness difference in the age-related cognitive decline curve for ten years based on the involvement of executive function component of cognitive tasks.

Figure 1: Mean decline ratios in the D-CAT1 and D-CAT3 performance for 10 years of men as a function of handedness.

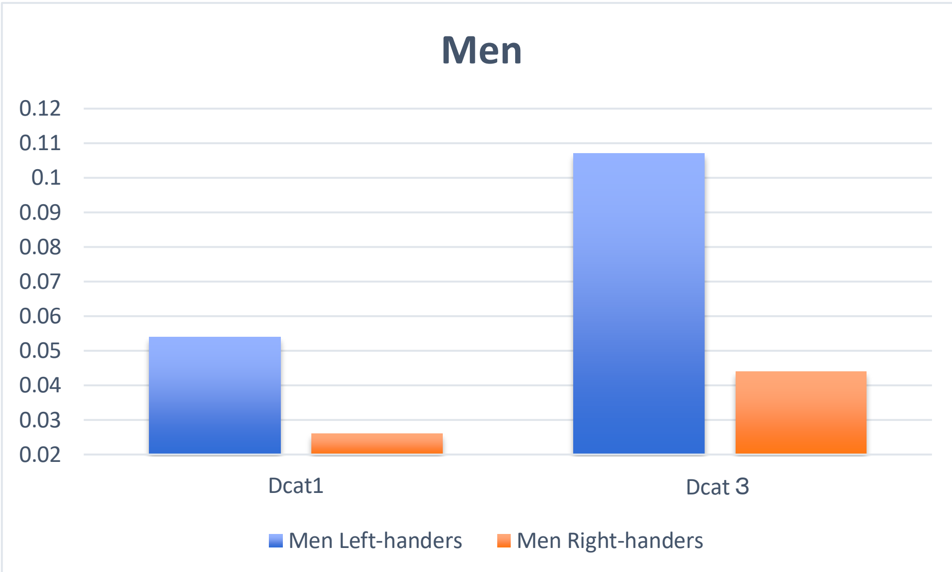
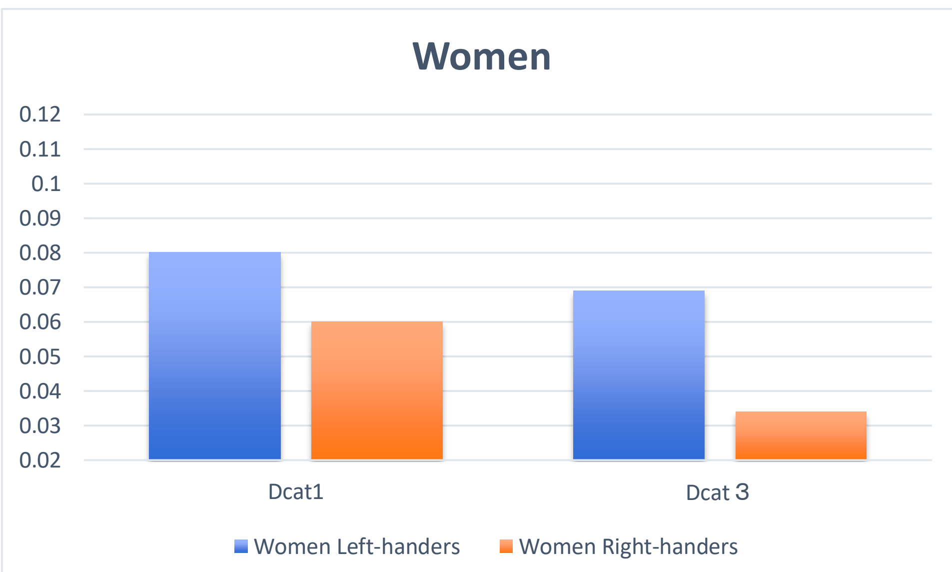


Figure 2: Mean decline ratios in the D-CAT1 and D-CAT3 performance for 10 years of women as a function of handedness.



4. DISCUSSION

The current study was designed to provide evidence supporting handedness differences in the effect of aging on executive function from the perspective of maintaining cognitive functions when aging after the upper-middle age. As indicated by Hatta,[15] a larger decline ratio in cognitive function can be expected in left-handed people than right-handed people during ten years.

As shown in Table 2 and Figures 1 and 2, the current study results supported the hypotheses that left-handed people's performance decline ratio is larger than that of right-handed people and a sex difference in the decline ratios between D-CAT1 and D-CAT3.

It can be seen that the performance of left- and right-handed people in the D-CAT1 and D-CAT3 was not significantly different in the first year of the study,however, left-handed people showed a more considerable decline in performance ratio during the ten years of upper-middle-age than right-handed people, suggesting that left-handed people are more vulnerable to cognitive function deterioration with age than right-handed people.

Furthermore, as expected, there was an interaction between handedness and sex on the decline of D-CAT1 and D-CAT3 performance ratios. D-CAT1 and D-CAT3 are behavioral measures assessing executive function, but they impose demonstrably different cognitive burdens. Hatta *et al* [15] compared longitudinal developmental changes in the two measures for 11 years (from 65 to 75 years) by individually calculating the coefficient of decline for right-handed middle-aged people. He reported that D-CAT3 declined more steeply than D-CAT1 performance, suggesting that cognitive load affected age-related cognitive decline and that cognitive decline due to aging can be detected more sensitively when the cognitive burden is large as in the D-CAT3 than in D-CAT1 when the burden is small.

As apparent in Table 2 and Figures 1 and 2, left-handed people's performance decline ratio was more extensive than in right-handed people. Moreover, comparison of performance decline ratios between D-CAT1 and D-CAT3 indicated sex differences, with men showing a larger performance decline ratio in D-CAT3 than in D-CAT1, whereas women showed a similar decline ratio in both tests.

To summaries, the results of this study suggested that left-handed people are more vulnerable to age-related decline in executive function after middle-aged than right-handed people. Moreover, the vulnerability to age-related cognitive decline in left-handed men was more extensive than in left-handed women based on the theory of sex-related brain functions and handedness,[28] which was more pronounced in tasks imposing a higher cognitive burden on executive function.

As described earlier, Van der Elst et al[9] examined handedness differences in trajectories of performance declined using the Stroop Test in a three-year longitudinal study and failed to show that left-handedness is associated with more pronounced cognitive decline. This might be because their study period was only three years, which might be too short to detect aging-related changes. The current study was ten years, which was considered sufficient to detect changes in the sustainability of executive function to age-related changes in middle-aged people.

Why were prior studies unable to demonstrate a consistent findings? It is known that the population of left-handed people is not large enough to be diverse. Studies conducted in the 1980s and 1990s have commonly included people that were left-handed by different causes. These causes included heredity, fetal environment, and birth status, among others. Moreover, left-handed people with different cultural backgrounds were also included in these studies. Furthermore, the definition of left-handedness used in these studies was diverse and included self-reports, tool use hand, and standardized handedness inventory scores, among others. Also, the participants in these studies were mostly college students.

It is hoped that future studies using a large sample size might compensate for these problems. A study with a large sample size based on the U.K. Biobank has been recently reported. The U.K. Biobank is a well-characterized, population-based cohort, which includes 501,730 participants with approximately 50,000 left-handed people, which allows multiple potential factors to be considered together.[29] The U.K. Biobank study analyzed a number of early life factors influencing adult hand preference and revealed that low birth weight rather than genetic factors are the largest contributor to left-handed births. Low birth weight can be caused by various reasons such as maternal malnutrition, maternal metabolic disorders caused by genetic factors, fetal growth failure due to the insufficiency of sex hormone secretion in the mother, and premature birth due to accidents, among others.[30] Immature brain development and brain network formation are common to all the causes of low birth weight mentioned above, which might influence later life's cognitive functions. Understandably, the left-handed people’s executive function is inferior to right-handed people because the control of brain networks for cognitive functions lies in the prefrontal cortex.[31] The immaturity of brain network formations could be another reason for the higher vulnerability to age-related functional decline in left-handed compared to right-handed people.

There is a consensus regarding human brain function characteristics; cognitive development is regulated by genetic code; the construction of neural networks is plastic, so patients with head injuries can regain a certain degree of cognitive function through training; and the brain's neural network system tends to produce the best performance and solutions. Therefore, inferior frontal cortex functions caused by low birth weight in left-handed people might not be apparent until rigorous tests are conducted to examine executive function components. It is plausible that among the three executive function components, *information updating*, and *shifting* is more sensitive to sex-related handedness effects than the *inhibition* component. On the whole, *shifting* is more exposed to the vulnerabilities of aging in left-handed people among the three components of executive function because its power begins to deplete with aging after middle age.

This study has several limitations, similar to all empirical studies. First, the size of the left-handed group, which had just 22 participants, was small. Our database originally consisted of 76 upper-middle-aged left-handed participants. However, the target population inevitably decreases as the study period increases in longitudinal studies that compare performance after a long period. The left-handed group of 22 participants are not insufficient for statistical analysis. Moreover, using "self-reported handedness" for categorizing the participants was also a limitation of this study because ambidextrous individuals' inclusion in the left-handed group might have influenced the results. Finally, this study's data were collected as a part of the cohort study in which handedness was not a primary concern. All researchers might not agree with including ambidextrous people in the left-handed group. However, this classification accords with the literature.[32, 33]

5. CONCLUSIONS

The performance decline ratios in D-CAT1 and the D-CAT3 were compared between left-handed and right-handed participants and the sexes. We conclude that

1. Performance decline ratios in the D-CAT1 and the D-CAT3 were significantly large in left-handed than right-handed people, suggesting that left-handed people's executive function has low aging tolerance.
2. The left-handed people are clearly more vulnerable to losing their cognitive functions with age compared to right-handed people.

3. *Information updating* and *shifting* components of the executive function are clearly vulnerable to aging effects in left-handed people.
4. The inferiority of the executive function in the left-handed people might be due to immature brain network formations resulting from low birth weight caused by maternal malnutrition, maternal metabolic disorders from genetic causes, fetal growth failure due to sex hormone insufficiency in the mother, and premature birth due to accidents.

Ethics

Ethical approval was obtained from the Ethical Committee of Nagoya University Medical School for Yakumo Study (2011 # 643) and written informed consent for participation and data publication was obtained from each participant.

Acknowledgements.

This research was a part of the Yakumo Study and a part of this study was supported by the GPSP KAKENHI grant (#23330219). Present author is much indebted to all participants, members of neuropsychology section (Drs. Kato Kimiko, Ito Emi, Nagahara Naoko, Ito Yasuhiro, & Hotta Chie) and staffs of the Health Care division of Yakumo Town.

REFERENCES

1. Carey DP, & Johnstone LT. Quantifying cerebral asymmetries for language in dextrals and adextrals with random-effects meta-analysis. *Frontiers in Psychology*. 2017; doi: 10.3389/fpsyg.2014.01128.
2. Hatta T. Handedness and brain: A review of brain-imaged techniques. *Magnetic Resonance in Medical Sciences.* 2007; 6: 99-112.
3. Monk CS. The development of emotion-related neural circuitry in health and psychopathology. *Development and Psychopathology.* 2008; 20: 1231-1250.
4. Omura K, Constable RD, & Canli T. Amygdala gray matter concentration is associated with extraversion and neuroticism. *Neuroreport.* 2005*;* 16: 1905-1908.
5. Baddeley AD. Working memory: theories, models, and controversies. *Annual Review of Psychol*ogy. 2012; 63: 1-29.
6. Jorgenson C, Davis J, Opella J, & Angerstein G. Hemispheric asymmetry in the processing of Stroop stimuli: An examination of gender, hand-preference, and language differences. *International Journal of Neuroscie*nce. 1980; 11: 165-169.
7. Simon JR, Paulline C, Overmyer SR, & Berbaum K. Reaction time to word meaning and ink color of laterally-presented Stroop stimuli: Effects of handedness and sex. *International Journal of Neuroscie*nce. 1985; 28: 21-33.
8. Hatta T. Handedness effects on the Stroop colour word test: Is left-handedness associated with a more inferior cognitive function? *Journal of Human Environmental Studies.* 2016; 14: 145-148.
9. Van der Elst W, Van Boxtel MPJ, Van Breukelen GJP & Jolles J. Is left-handedness associated with a more pronounced age-related cognitive decline? *Laterality.2008a;* 13: 234-254.
10. Van der Elst W, Van Boxtel MPJ, Van Breukelen GJ, & Jolles J. Detecting the significance of changes in performance on the Stroop Color-Word Test, Rey's Verbal Learning Test, and the Letter Digit Substitution Test: The regression-based change approach. *Journal of the International Neuropsychological Society*. 2008b; 14: 71–80.
11. Beratis IO, Rabavilas A, Kyprianou M, Papadimitriou GN & Parageorgiou C. Investigation of the link between higher order cognitive functions and handedness. *Journal of Clinical and Experimental Neuropsychology*. 2013; 35: 393-403.
12. Beratis IO, Rabavilas A, Papadimitriou GN, & Parageorgiou C. Effect of

handedness on the Stroop colour word task. *Laterality*. 2010; 15: 597-609.

13. Miyake A, Friedman NP, Emerson MJ, Witzki AH, Howerter A, & Wager TD. The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: a latent variable analysis. *Cognitive Psychol*ogy. 2000; 41: 49-100.
14. Morris N, & Jones DM. Memory updating in working memory: The role of the central executive. *British Journal of Psychology*. 1990; 81: 111-121.
15. Hatta T. Associations between handedness and executive function in upper-middle-aged people, *Laterality*. 2017; DOI: 10.1080/1357650X.2017.1358273
16. Schaie KW. Quasi-experimental design in the psychology of aging. In J. E. Birren & K.W. Schaie (Eds.). *Handbook of the psychology of aging* (pp.39-58). New York: Van Nordstrand Reinhold, 1997.
17. Uttl B, & Van Alstine CL. Rising verbal intelligence scores: implications for research and clinical practice. *Psychology and Aging*. 2003; 18: 616-621. doi: 10.1037/0882-7974.18.3.616
18. Hatta T. Which inventory should be used to assess Japanese handedness? : Comparison between Edinburgh and H. N. handedness inventories. *Journal of Human Environmental Studies.* 2008; 6: 45-48.
19. Hatta T. & Kawakami A. Patterns of handedness in modern Japanese: A cohort effect shown by re-administration of the H. N. Handedness Inventory after 20 years. *Canadian Journal of Experimental Psychology. 1996;* 49: 5050-512.33.
20. Coetzer R, & Balchin R. *Working with brain injury: A primer for psychologists in under-resourced setting*. London: Psychology Press, 2014.32.
21. Lezak MD, Howieson DB, Bigler ED, & Tranel D. *Neuropsychological Assessment*. New York, NY: Oxford University Press, 2012.
22. Hatta T, Yoshizaki K, Ito Y, Mase M, & Kabasawa H. Reliability and validity of the digit cancellation test: A brief screen of attention, *Psychologia*. 2012; 55: 246-256.
23. Solberg MM, & Mateer CA. Effectiveness of an attention-training program. *Journal of Clinical and Experimental Neuropsychology.* 1987; 9: 117-130.
24. Hatta T, Ito Y, & Yoshizaki K. *D-CAT: Screening test for attention*. Osaka: Union Press, 2001.
25. Hatta T, Yoshizaki K, & Ito Y. Development of screening test for attention by digit cancellation method.

In K. Yoshizaki & H. Ohnishi (Eds.) *Contemporary issues of brain, communication and education in psychology (pp. 3-19)*. Osaka: Union Press, 2009.

26. Hibino S, Mase M, Shirataki T, Nagano Y, Fukagawa K, Abe A, et. al. Oxyhemoglobin changes during cognitive rehabilitation of the traumatic brain injury using near Infrared Spectroscopy. *Neurolia Medico-Chirurgi.* 2013; **53**: 299-303.

27. Hatta T, Kato K, Hotta C, Higashikawa M, Iwahara A, Hatta T, et al. Visual search load effects on age-related cognitive decline : Evidence from the *Yakumo* longitudinal study. *American Journal of Psychology.* 2017; 130: 73-82.
28. Kimura D. *Sex and Cognition.* Cambridge: MIT Press, 1999.
29. De Kovel CF, Carrion-Castillo A, & Francks C. A large-scale population study of early life factors influencing left-handedness. *Scientific Reports.* 2019; 9: 584 Doi:10.1038/s41598-018-37423-8.
30. Geschwind N, & Galaburda AM. Cerebral lateralization. *Archives of Neurology.* 1985; 42: 428-459, 521-552, 634-654.
31. Burgess PW, & Stuss DT. Fifty-years of prefrontal cortex research: Impact of assessment. *Journal of the International Neuropsychological Society*. 2017; 23: 755-767.
32. Bryden MP, McManus IC, & Bultman-Fleming MB. Evaluating the empirical support for the Geschwind-Behan-Galaburda model of cerebral lateralization. *Brain and Cognition.* 1997; 26: 312-326.
33. Porac C, Friesen IC. Hand preference side and its relation to hand preference switch history among old and oldest-old adults. *Developmental Neuropsychology.* 2000; 17: 225-239.

Appendix a:

This study was undertaken as a part of the Neuropsychology Section of the *Yakumo* study, which is a large-scale Japanese cohort study that began in 1981, designed to investigate the health of people living in the *Yakumo* town located in Hokkaido. Department of preventive medicine of the Nagoya University of Medical School and the Yakumo town jointly conducted the project. The Investigations were conducted in the fields of epidemiology, internal medicine, orthopedics, urology, ophthalmology, otolaryngology, and neuropsychology. The participants in the study were engaged in a variety of jobs, not only white-collar positions, but also agriculture, fishery, and forestry. They had relatively homogeneous socioeconomic status, as typical of a normative sample of Japanese people living in the Yakumo town.

