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Developmental Changes of Prefrontal Cortex and Cerebro-Cerebellar Functioning in Older Adults: Evidence from Stabilometer and Cognitive Tests

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Abstract

The relation between cognitive and postural functioning was examined as developmental changes among healthy older adults. The 339 participants (207 women and 132 men) of four age groups (50’s, 60’s, 70’s, and 80’s) were given the Digit Cancellation Test (D-CAT) for the assessment of prefrontal cortex related cognitive functioning, and the Logical Memory Test for the assessment of fronto-parietal cortex related cognitive functioning. The postural functioning of the participants was measured by a stabilometer for the assessment of cerebro-cerebellar related motor functioning. The results showed that the developmental changes in performances for non-automatic intentional cognitive and automatic motor postural functioning were not parallel. Cognitive functioning did not show clear sex difference while motor postural functioning showed robust sex difference. Largely, cognitive functioning D-CAT and Logical Memory Test showed gradual performance decrease 23-48% for each age group from 50’s to 80’s while robust motor postural functioning performance decreased approximately 60% from 70’s to 80’s in men and approximately 65% from 60’s to 70’s in women. Based upon these findings, characteristics of age-related changes in cerebro-cerebellar brain systems in middle aged and older healthy people are discussed.

Keywords: Aging; Brain function; Stabilometer; Cognitive functioning; Postural functioning

Introduction

Studies using different research methods, a substantial inter-relationship between the prefrontal and cerebellar cortices have been reported. For example, fMRI studies showed that both the prefrontal cortex and cerebellum activated during tasks of sustained attention or working memory [1-11]. Strick et al. developed a new method of virus tracing and identified anatomical networks between the cerebellar cortex and the prefrontal cortex [12-15]. A recent comprehensive review by Boston and Strick (2011) [16] and Boston, Dum and Strick (2013) [17] show evidences that indicate more precise cerebro-cerebellar loops in primate and human brain.

By behavioral experimental methods, we demonstrated a relationship between cognitive and cerebro-cerebellar functions as well as fMRI studies [18]. In that study, we assessed the relationship between performance on a stabilometer, a measure of cerebello-thalamo-cortical circuit automatic functioning, and measures of attention and verbal cognitive non-automatic functioning that are representative of prefrontal cortex related function with healthy middle and upper-middle aged people. The results showed that the group scoring above the median on the stabilometer measurements had significantly better performance than the group scoring below the stabilometer median on the Digit Cancellation Test (D-CAT), whereas no group difference was found for the word fluency test. Although this previous study successfully demonstrated a group difference on a measure assessing cerebello-thalamo-cortical circuit functions, it was a limited study, such that age differences and sex differences were not examined.

The purpose of this present study was to investigate the relation between prefrontal cortex related and cerebro-cerebellar functions more precisely for the developmental change and the sex difference. To address this purpose, it is not realistic to administer data collection using fMRI or brain injury method, while it is possible when we use behavioral experimental method even if hundred participants participated.

In this study, we examined whether the developmental changes for cerebello-thalamo-cortical circuit automatic functioning are identical to those changes for prefrontal cortex and front-parietal cortex non-automatic cognitive functioning, as assessed by the D-CAT and Logical Memory Test from middle age to upper-middle age. We were also interested in determining whether there were any sex differences. Since in our previous study, verbal functioning (measured by a verbal fluency test) did not show a clear relation with postural functioning, in the present study we instead looked at memory function (measured by the Logical Memory Test).

Therefore, the following working hypotheses were examined in this study. First, age-related declining changes of postural maintenance performance (cerebello-thalamo-cortical circuit function) are not parallel with D-CAT performance (representing mainly prefrontal cortex function). Second, the age-related decline slopes for the Logical Memory Test are not similar to the slopes for the D-CAT, because the Logical Memory Test depends more upon front-parietal cortex functioning [19,20]. Third, there is a sex difference in developmental declining changes between both postural and cognitive functioning.

The first working hypothesis was induced from the cognitive aging proposal reflecting evolution proposed by Hatta [19], which are discussed later. The third working hypothesis was derived from a proposal about the relation between cognition and sex-related hormones from Kimura [21], which are discussed later.

Ethical Approval

Ethical approval was obtained from the Ethical Committee of the Nagoya University Medical School for the Yakumo Study (Genetic polymorphism study for health checkup examinees in Yakumo town, 2011 # 643). Written informed consent for participation and data publication were obtained from each participant. The data were collected in 2010 and 2011 as a part of the neuropsychology and orthopedics sections of the Yakumo Study designed to investigate the health of people living in the town of Yakumo on the island of Hokkaido in Japan (Hatta, 2007) [22]. The Department of Preventive Medicine of the Nagoya University Medical School and the town of Yakumo jointly conducted the study. The investigations were conducted by professionals in the fields of epidemiology, internal medicine, orthopedics, neuropsychology, ophthalmology, otolaryngology, and urology. Participants in the study had been engaged in a variety of jobs, not only white collar, but also agriculture, fishery and forestry.

Method

Participants

The participants were healthy rural-community dwellers over 50 years of age (N=339; 207 women, 132 men). All participants voluntarily participated in the health examination organized by local government of Yakumo Town and Nagoya University. All participants showed no sign of physical disorders or internal disease or dementia at the time of the initial examination. For signs of internal diseases, the participants were examined by physicians in accordance with the health examination program. For signs of dementia or other neurological disorders the participants were evaluated by neuropsychologists using the Mini Mental State Examination (MMSE) and the Quality of Life (QOL) questionnaire.

To examine developmental changes in a cross-sectional design, the participants were assigned into four groups based on the decade of their age: 50's (45 women, 17 men), 60's (76 women, 52 men), 70's (56 women, 39 men) and 80's (30 women, 24 men). The detail of the participants' information showed the Table 1. All participants were enrolled in the Yakumo Study in Japan.

Apparatus and procedures

Postural function: Postural function was measured by a stabilometer (Anima) in the same manner as in our previous study [23]. The manual and the standard norms for the stabilometer were developed by Tokita [24]. Two examiners, an orthopedic surgeon and an assistant, administered the postural examination to all participants. The stabilometer can provide indices such as distance and size of moving tracks for 60 s and the Ronberg ratios (eye-closed/eye-open conditions) in both the eye-open and eye-closed conditions. These reflect the cerebello-thalamo-cortical circuit functions more directly than the other index such as the velocity of moving [23]. These measures have been employed as a useful tool for the diagnosis of Parkinson's disease and equilibrium disorders and it relates to connectional profiles are involved in "automatic" motor functions [24-28].

Age	50's		60's		70's		80's	
Sex	Men	Women	Men	Women	Men	Women	Men	Women
Number of participants	17	45	52	76	39	56	24	30
M	54.18	55.49	63.81	64.45	74.18	73.1	83.58	82.7
SD	3.24	3.1	2.63	2.73	2.9	2.44	2.73	2.26
Years of Education								
M*	13.1	12.5	11.4	11.2	10.8	10.12	9	8.83
SD	2.23	1.73	1.93	1.51	2.02	1.69	1.48	2.18

Table 1: Participants' information. *M: Mean, SD: Standard Deviation

Cognitive function: Participants were given the Digit Cancellation Test (D-CAT) and the Logical Memory Test individually to measure prefrontal cortex function. These relate to different connectional profiles are involved in "non-automatic" intentional cognitive functions.

On the D-CAT, participants were requested to search for one, two or three target digits on a sheet of randomly arranged digit sequences and mark as many target digit(s) as they could for 60 s. The Total Performance score is the total number of digits that the participant cancelled correctly. It can be regarded as an assessment of information processing speed, focused attention, and sustained attention according

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to the hierarchal model of attention by Solberg and Mateer [29]. The D-CAT seems dependent on control of the frontal eye fields, a function of the dorsal attention network, consisting of frontal eye field and parietal lobe connections. Further, this task recruits the ventral attention network for object identification. Although these complex relationships are the underpinnings of performance on processing speed tasks and it certainly not restricted to the frontal-parietal networks, we refer to D-CAT as prefrontal cortex representing task to simplify description.

The D-CAT 3, with three targets, was used in the present study and is considered to reflect prefrontal cortex functioning [30]. In the D-CAT, errors such as missing targets and false alarms were recorded; however both missing targets and false alarms were not used in the statistical analyses in this study because they were so infrequent among our participants. The reliability and validity of the D-CAT have been reported elsewhere [23,31-33].

In the Logical Memory Test participants were given the Japanese version of the Wechsler Memory Scale-Revised (WMS-R). Twice the examiner read a short news story consisting of 25 segments, and each participant was asked to recall the story. Usually, the Logical Memory Test has both immediate and delayed recall conditions. In our present study, only immediate recall was used. Each segment that was correctly recalled by the participant was assigned a score of 1 point; therefore the total score ranged from 0 to 25 points. Memory is dependent on the medial temporal lobe system as measured by WMS-type subtests, however immediate memory related strongly to the frontal-parietal network. Therefore we refer to this task as fronto-parietal cortex representing one. In previous studies, the NIRS (Near-infrared Spectroscopy) identified robust activation of the prefrontal cortex during the D-CAT, and both frontal and temporal cortices activation during the Logical Memory Test [20,34,35].

Results

Performance scores for the stabilometer measures and the cognitive task items showed different distributions and ranges. Therefore, the raw scores were all transformed into z scores to compare the different measures. Table 2 shows the z scores for six measures from the stabilometer as a function of age group and sex. As can be observed in Table 2, the six stabilometer measures showed fairly similar patterns for the age groups and sex differences.

	50's		60's		70's		80's	
	Women	Men	Women	Men	Women	Men	Women	Men
Distance in open eye	0.44	-0.02	0.48	0.01	-0.04	-0.37	-0.16	-1.85
	-0.55	-0.64	-0.53	-0.78	-0.82	-0.87	-0.86	-1.68
Distance in closed eye	0.47	-0.1	0.47	-0.01	0.1	-0.43	-0.17	-1.87
	-0.41	-0.68	-0.53	-0.74	-0.64	-1.02	-0.81	-1.93
Ronberg ratio in distance	3.56	-0.15	0.32	0.03	0.22	-0.36	-0.12	-1.35
	-0.43	-0.76	-0.66	-0.93	-0.59	-1.21	-0.88	-2.04
Size in open eye	0.13	0.35	0.36	0.03	0.14	-0.15	-0.17	-1.02
	-0.92	-1.2	-0.92	-0.9	-0.86	-0.92	-0.92	-1.37
Size in closed eye	0.38	-0.09	0.33	0.06	0.13	-0.34	-0.13	-1.62
	-0.42	-0.77	-0.6	-0.65	-0.66	-1.02	-0.83	-2.29
Ronberg ratio in size	0.4	-0.11	0.19	0.06	0.08	-0.34	-0.06	-1.42
	-0.47	-1.11	-0.62	-0.77	-0.59	-1	-0.87	-2.3
D-CAT (3 digit cancellation)	0.78	0.65	0.27	-0.02	-0.43	-0.62	-0.78	-0.76
	-0.95	-1.02	-0.75	-0.88	-0.75	-0.78	-0.65	-0.76
Logical Memory	0.73	0.38	0.31	-0.15	-0.031	-0.025	-0.077	-0.51
	-0.76	-0.86	-0.88	-0.88	-1.08	-0.87	-0.85	-0.95

Table 2: Stabilometer measurements, D-CAT and Logical Memory performances as a function of age and sex (z scores). Numbers in the parentheses are standard deviations.

An analysis of variance (ANOVA: age by sex) was conducted for the six stabilometer measures. The results showed that the main effects of age group and sex and their interaction were all significant at 5 % level: for age group, F3, 331=14.49, 14.65, 6.21, 5.03, 8.77, and 4.66, Distance of moving tracks in open eye, Distance of moving tracks in closed eye, Ronberg ratio in distance, Size in open eye, Size in closed eye, and Ronberg ratio in size, respectively; for sex, F1, 331=55.35, 66.94, 35.20, 17.81, 38.69, and 23.70, Distance in open eye, Distance in closed eye, Ronberg ratio in distance, Size in open eye, Size in closed eye, and Ronberg ratio in size respectively; for the interaction of age group and sex, F3, 331=9.02, 7.55, 2.75, 2.9, 5.99, and 5.33, Distance in open eye,

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Distance in closed eye, Ronberg ratio in distance, Size in open eye, Size in closed eye, and Ronberg ratio in size.

All six stabilometer measures showed significant differences for age group and sex. To address the purpose of this study, the Distance of moving tracks in Eye Open(hereafter, Distance in Open Eye) measure was used as a representative of postural function in relation to age group differences and sex differences in elderly people (because all other indices showed similar statistical results). For the Distance in Open Eye, both main effects were significant, for age group (F3, 331=31.72, $p<0.001$, η^2=.279) and for sex (F1, 331=55.36, $p<0.001$, η^2=. 191). The interaction between age group and sex was also significant (F3, 331=9.01, $p<.001$, η^2=.497). Further analyses revealed that the significant interaction reflected the fact that men in their 50's, 60's and 80's showed poorer performance than women in those age groups ($p<0.048$, $p<0.002$, and $p<0.001$, respectively), while no sex difference was found for the performances of the 70's age groups (p 0.061). As can be seen from Figure 1, the results indicate that not only do men show poorer performance than women, but also men's performance shows a steep decline from their 70's to 80's while women's performance shows a gentle, gradual decline from their 60's to 80's. The statistical comparisons indicated that except for the absence of a significant difference between men and women in their 50's and 60's (p=0.097), there were significant sex difference for all the other age groups ($p<0.001$).

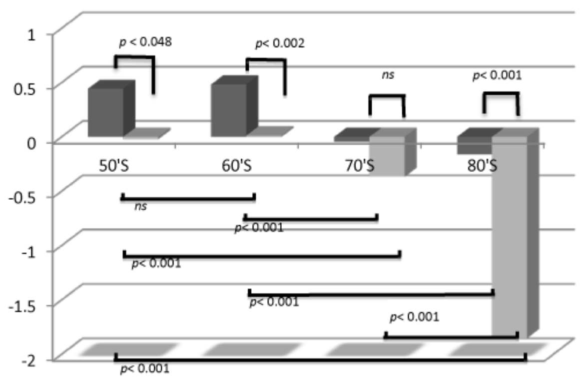

Figure 1: Postural performances (Distance in open eye) of men and women as a function of age groups after 50 years old (black column refers to women and gray column refers to men). Statistical results (p score) from age and sex interaction were shown in upper part of the figure whereas p scores in age group difference were shown in lower part of the figure. Statistical values (F score) were described in the text.

Table 2 shows z scores for the D-CAT 3 as a function of age group and sex. The ANOVA showed a significant effect for age group (F3, 331=40.21, $p<0.01$, η^2=.354). The sex difference was not significant (F1, 331=2.29, $p>0.05$), nor was the interaction between age group and sex (F3, 331=0.46, p=0.711). As seen from Figure 2, both women and men showed a gradual constant performance decline from the 50's to 80's. The D-CAT 3 performances for women and men show a decrease gradually from age 50's until 70's; all age group comparisons showed a significant sex difference at a confidence level of $p<0.001$, except the difference between the 70's and 80's was not significant, p=0.078. Sex differences were not significant for all age group comparisons (p=0.131).

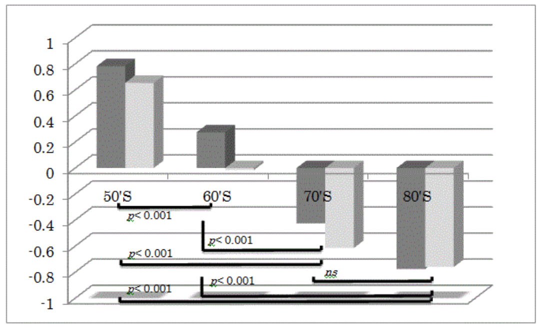

Figure 2: D-CAT 3 performances in men and women as a function of age groups after 50 years old (black column refers to women and gray column refers to men). Statistical results (p score) from age and sex interaction were shown in upper part of the figure whereas p scores in age group difference were shown in lower part of the figure. Statistical values (F score) were described in the text.

Table 2 also shows the z scores for the Logical Memory Test as a function of age group and sex. (F3, 331=17.45, $p<0.01$). A sex difference was not significant (F1, 331=1.26, $p>0.05$). The interaction between age group and sex was significant for the Logical Memory Test (F3, 331=2.70, $p<0.046$, η^2=.024). Further comparisons did not show significant sex difference for the 50's, 70's and 80's age groups (p=0.070, 0.756, and 0.222, respectively). For the 60's age group, women showed better performance than men ($p<0.005$). As seen from Figure 3, the significant interaction reflects the fact that men showed a steep performance decline from their 50's to 60's, while women showed a gradual constant decline from their 50's to 80's (all age group comparisons were significantly different at the $p<0.022$ or greater confidence level). Although women showed better performance at age 50's and 60's than men, at age 80's the men showed better performance than the women.

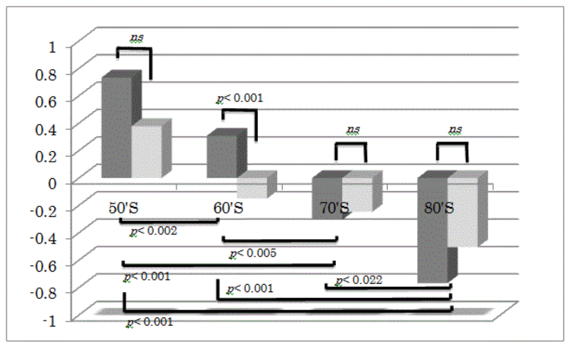

Figure 3: Logical Memory Test performances in men and women as a function of age groups after 50 years old (black column refers to women and gray column refers to men). Statistical results (p score) from age and sex interaction were shown in upper part of the figure whereas p scores in age group difference were shown in lower part of the figure. Statistical values (F score) were described in the text.

To summarize, the findings clearly showed that the developmental changes of postural functioning and cognitive functioning are not parallel, and a prominent sex difference was shown for postural functioning. The two cognitive measures, D-CAT 3 and Logical Memory Test, showed different changes, although both showed decline slopes and no sex differences.

Discussion

In our previous study [18], the adults scoring above the median on the stabilometer measurement showed better performance on the Digit Cancellation Test than those adults scoring below the median on the stabilometer measurement; no group difference was shown for the word fluency test. These results were regarded as a demonstration by using behavioral measures of the substantial relationship between the prefrontal cortex and cerebro-cerebellar functioning as described earlier in the introduction. Previous findings, however, did not offer further information, such as about any age or sex differences. Do both men and women show parallel developmental changes? Is there any possible serial-order relation, e.g., postural functioning declines earlier than cognitive functioning or is the reverse the case? How about the mutual developmental changes among cognitive tasks, such as attention and memory? In other words, the purposes of the present study were to address these questions that do development for cerebello-thalamo-cortical circuit of automatic postural functioning parallel with those for prefrontal cortex and fronto-parietal cortex of non-automatic cognitive functioning from middle age to upper-middle age?

In this study, the postural function measure that represents automatic motor function and two cognitive tasks (D-CAT and Logical Memory Test) representing unfamiliar non-automatic intentional function were employed. This is because that recent evidences by brain imaging and virus tracing methods in neuroanatomy suggest that cerebellar links vast range of neocortex areas including prefrontal and post-parietal cortex. Further, evidences elucidate that cerebellum involves not only automatic motor function associated with basal ganglia but also non-motor intentional cognitive functions mediated by the prefrontal and posterior parietal cortex [17,26]. Also striatum anatomy evidences indicate that motor related networks consisted of four types of neural network, sensori-motor loop, oculomotor loop, association loop, and limbic loop [25] and suggest therefore brain works as a system. Actually we demonstrated the findings that suggest brain works as a system where even memory recall of unilateral using tool (e.g., knife) picture invites related automatic motor imagery and recognition errors [36]. Therefore, it can be regarded that D-CAT represents processing speed that are dependent on the integrity of white matter tracts that connect many distal brain regions, including prefrontal cortex. Because, D-CAT seems dependent on control of the frontal eye fields, a function of the dorsal attention network, consisting of frontal eye field and parietal lobe connections; similarly, this task recruits the ventral attention network for object identification. And Logical Memory Test activates not only front-parietal neural network, medial temporal lobe related network, and association loop and limbic loops of striatum.

The results of the present study can be summarized as follows. First, for postural functioning, the results show that men's performance was inferior to women's for all age groups. A decline appeared at age 60's (a significant difference was shown between the 60's and 70's, but not between the 50's and 60's), and steep decline was shown from age 70's (the difference between 70's and 80's was significant). Second, men's performance was inferior to women's throughout the age groups from the 50's. Finally, an interaction between age and sex was seen that reflects a clear difference, which appeared between the age groups of the 70's and the 80's in men, while in women the decline of posture-sustaining functioning or "automatic" motor function in cerebro-cerebellar neural networks from age 50's was rather slow.

It is well known that men's motor kinetic abilities, such as arm/leg muscle power, are superior to those of women throughout the lifespan from adolescence. However our findings showed that this was not the case for posture-sustaining functioning [37-39]. The neural mechanisms to sustain human standing posture are complex and the precise mechanisms are still controversial. However, it is generally acknowledged that postural functioning depends mainly on the functioning in the somatic-sensory cortex, basal ganglia, and cerebellum (i.e., cerebro-cerebellar neural networks), and muscle power itself does not have a crucial role [40]. This means that postural functioning requires much more complex or integrated networks than simple arm/leg actions such as pick up or holding. The age-related decline in these integrated motor-kinetic abilities is not similar between men and women. Furthermore, the results for men in their 80's indicated a steep decline from their 70's, more than was found for women in their 80's, which suggests that robust functional decline appears in the "automatic" motor function in cerebro-cerebellar neural networks in older men.

Second, regarding cognitive functioning, both sexes showed similar age-related developmental changes. However, the age-related changes were not parallel between the D-CAT 3 and the Logical Memory Test. The performance decline on the D-CAT 3 was steeper than for the Logical Memory Test. According to previous studies, the D-CAT 3 reflects attention and information processing speed mainly related to prefrontal cortex functioning, whereas the Logical Memory Test reflects memory mainly related to fronto-parietal cortex network functioning [18,25,26,32,]. These findings have been supported by evidence of robust regional activation using the brain imaging technique of NIRS (Near-infrared Spectroscopy). The present findings of different declining slopes for the D-CAT 3 and the Logical Memory Test suggest that the prefrontal related functioning is more vulnerable than the fronto-parietal cortex network representing functioning in terms of age-related functional decline. The findings that prefrontal task showed greater decline than temporal tasks might be explained different way by the kind of processing, fluid or crystalline, involved.

Several previous studies have suggested developmental sex differences in cognitive functioning, e.g., women's performance is superior to men in memory-related tasks and information processing-speed tasks [21]. However, the present analyses did not yield a statistically significant sex difference. This discrepancy may reflect statistical limitations related to sampling age-range differences. In this present study the purpose was to focus on later stages of people's postural and cognitive function, so the youngest age group was the 50's, whereas in previous studies the youngest age groups were 30's or 40's. Kimura [21] proposed a sex-related hormonal mechanism that generates sex differences in cognitive functioning, which is supported by considerable evidence. Our research group as well as others also reported supportive evidence that age groups of pre-menopausal women showed better performance than men on information processing-speed tasks and memory tasks (e.g., D-CAT 1 and verbal memory test). In contrast, no differences were shown for older age groups of post-menopausal women [41,42]. Hatta and Nagaya (2009) [43] examined menstrual-cycle phase effects on memory and Stroop task performances, and found sex-related hormone modulation that selectively affected cognitive functions. The results showed a significant difference in Stroop task performance between low and high levels of estradiol and progesterone during the menstrual cycle, i.e., a low level of estradiol secretion contributed to reducing the attention level that is related to the prefrontal cortex. These findings suggest that a sex-related hormone effect is important for cognitive performance until menopause. Therefore, it seems reasonable that no sex difference was shown for the age groups of presumably post-menopausal participants in this present study, because the mean age for menopause in Japanese women is approximately 52 years old [44]. The sex differences in the declining trajectory difference for performance in this present study might also be interpreted as related to biopsychosocial influences. Very recent review by Miller and Halpern [45] suggested cultural effects on cognitive sex differences. Therefore, it seems reasonable that not only sex-related hormonal influence but also cultural factors such as economic prosperity and gender equity on cognitive development in men and women.

Comparison of postural and cognitive performances as a function of age groups clearly shows that postural performance declines rapidly in the later years, while cognitive performance declines gradually from an earlier time period of older age. Largely, cognitive functioning D-CAT and Logical Memory Test showed gradual performance decrease approximately 23-48% for every age group from 50's to 80's while motor postural functioning performance decreased approximately 60% from 70's to 80's in men and approximately 65% from 60's to 70's in women. Decline in postural performance appears from the 70's in both men and women, although this phenomenon was much clearer for men than for women. These findings suggest that prefrontal cortex related functioning that represents non-automatic intentional performance is more fragile than cerebro-cerebellar network functioning that represents automatic non-intentional performance differentially between men and women in elderly people [45]. We may be able to speculate that age-related functional decline appears in the opposite sequence from the evolution of brain functional areas, that is frontal cortex-related cognitive dysfunction occurs first, and then dysfunction follows relating to the cerebro-cerebellar network, including the limbic system and basal ganglia [34].

Several suggestions can be prepared for health care staffs from these empirical evidences. First, as non-automatic intentional frontal cortex-related cognitive dysfunction occurs earlier, age around 60's in both men and women, than automatic non-intentional performance, health care staffs of local government should develop exercise programs for ameliorating cognitive aging, such as exercise program to sustaining attention and information processing speed. Second, as a decline of cerebro-cerebellar network functioning that induces automatic performance appears robustly around the age of 70's years old, health care staffs should stress the importance of aerobic exercise from earlier age. Third, preparing exercise programs both for cognitive and motor functions should be considered sex differences in development. The importance of aerobic exercise should be stressed for men than for women, especially in winter season as our participants live in heavy snow accumulation area of Japan. Needless to say, as Greenwood and Parasuraman, [46] suggested, heath care staffs should develop proper programs for community-dwellers such that stress on the importance of not only aerobic exercise and cognitive tasks but also of diet as well as nutrition.

Finally, the findings of the present study demonstrated that the developmental changes in performances for non-automatic intentional cognitive and automatic motor postural functioning were not parallel using behavioral measures; however several limitations should be noted. The data are not longitudinal but cross-sectional (longitudinal data base for 15 years will be completed in 2016 in Yakumo Study) [47-49] and sample size of each age group is not enough large, therefore further examination should be continued.

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References

1. Awh E, Jonides J, Smith EE, Schumacher EH, Koeppe RA et al. (1996) Dissociation of storage and rehearsal in verbal working memory: Evidence from positron emission tomography. Psychological Science 7: 25-31.
2. Baldo JV, Shimamura AP (1998) Letter and category fluency in patients with frontal lobe lesions. Neuropsychology 12: 259-267.
3. Balsters JH, Cussans E, Diedrichsen J, Phillips KA, Preuss TM, et al. (2010) Evolution of the cerebellar cortex: the selective expansion of prefrontal-projecting cerebellar lobules. Neuroimage 49: 2045-2052.
4. Desmond JE, Fiez JA (1998) Neuroimaging studies of the cerebellum: language, learning and memory. Trends CognSci 2: 355-362.
5. Ide JS, Li CS (2011) A cerebellar thalamic cortical circuit for error-related cognitive control. Neuroimage 54: 455-464.
6. Ide JS, Li CS (2011) Error-related functional connectivity of the habenula in humans. Front Hum Neurosci 5: 25.
7. Mead LA, Mayer AR, Bobholz JA, Woodley SJ, Cunningham JM, et al. (2002) Neural basis of the Stroop interference task: response competition or selective attention? J IntNeuropsycholSoc 8: 735-742.
8. Rogers TD, Dickson PE, Heck DH, Goldowitz D, Mittleman G, et al. (2011) Connecting the dots of the cerebro-cerebellar role in cognitive function: neuronal pathways for cerebellar modulation of dopamine release in the prefrontal cortex. Synapse 65: 1204-1212.
9. Salmi J, Pallesen KJ, Neuvonen T, Brattico E, Korvenoja A, et al. (2010) Cognitive and motor loops of the human cerebro-cerebellar system. J CognNeurosci 22: 2663-2676.
10. Yeterian EH, Pandya DN, Tomaiuolo F, Petrides M (2012) The cortical connectivity of the prefrontal cortex in the monkey brain. Cortex 48: 58-81.
11. Takahashi H, Kato M, Takano H, Arakawa R, Okumura M, et al. (2008) Differential contributions of prefrontal and hippocampal dopamine D(1) and D(2) receptors in human cognitive functions. J Neurosci 28: 12032-12038.
12. Hoover JE, Strick PL (1999) The organization of cerebellar and basal ganglia outputs to primary motor cortex as revealed by retrograde transneuronal transport of herpes simplex virus type 1. J Neurosci 19: 1446-1463.
13. Ramnani N, Miall C (2001) Expanding cerebellar horizons. Trends CognSci 5: 135-136.
14. Middleton FA, Strick PL (1998) Cerebellar output: motor and cognitive channels. Trends CognSci 2: 348-354.
15. Middleton FA, Strick PL (2001) Cerebellar projections to the prefrontal cortex of the primate. J Neurosci 21: 700-712.
16. Bostan AC, Strick PL (2010) The cerebellum and basal ganglia are interconnected. Neuropsychol Rev 20: 261-270.
17. Bostan AC, Dum RP, Strick PL (2013) Cerebellar networks with the cerebral cortex and basal ganglia. Trends CognSci 17: 241-254.
18. Hatta T (2004) Development of a test battery for assessment of cognitive function. Human Environmental Studies 2: 15-20.

19. Hatta T, Kanari A, Mase M, Nagano Y, Shirataki T, et al. (2009) Strategy effects on word searching in Japanese letter fluency tests: Evidence from the NIRS findings. Reading and Writing 22: 1041-1052.
20. Hibino S, Mase M, Shirataki T, Nagano Y, Fukagawa K, et al. (2013) Oxyhemoglobin changes during cognitive rehabilitation of the traumatic brain injury using near Infrared Spectroscopy. Neurol Med Chir (Tokyo) 53: 299-303.
21. Kimura D (1996) Sex and cognition. Cambridge, MA: MIT Press.
22. Hatta T (2007) Report of the neuropsychological examination in middle and upper-middle people of Yakumo cohort. Nagoya University.
23. Hatta T, Masui T, Ito Y, Ito E, Hasegawa Y, et al. (2004) Relation between the prefrontal cortex and cerebro-cerebellar functions: evidence from the results of stabilometrical indexes. ApplNeuropsychol 11: 153-160.
24. Tokita T (1996) Thestabilometer test: Application and interpretation. Tokyo: Anima.
25. Higano S (2006) Knowledge of neuroimaging anatomy and neural network: Basal ganglia. 22nd work shop of Japan Radiological Society, 12th -13th, June.
26. Ito M (2008) Control of mental activities by internal models in the cerebellum. Nat Rev Neurosci 9: 304-313.
27. Mauritz KH, Schmitt C, Dichgans J (1981) Delayed and enhanced long latency reflexes as the possible cause of postural tremor in late cerebellar atrophy. Brain 104: 97-116.
28. Njiokiktjien C, De Rijke W, Dieker-Van Ophem A, Voorhoeve-Coebergh O (1978) A possible contribution of stabilography to the differential diagnosis of cerebellar processes. Agressologie 19: 87-88.
29. Sohlberg MM, Mateer CA (1987) Effectiveness of an attention-training program. J ClinExpNeuropsychol 9: 117-130.
30. Hatta T, Yoshizaki K, Ito Y (2009) 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: The science of mind, Osaka: Union Press 3-19.
31. Hatta T, Ito Y, Yoshizaki K (2006) Manuals of D-CAT (Digit Cancellation Test for Attention). Osaka: Union Press.
32. Ito E, Hatta T (2006) Reliability and validity of Japanese verbal fluency test. Japanese Journal of Neuropsychology 22: 146-152.
33. Hatta T, Kanari A, Mase M, Kabasawa H, Ogawa T, et al. (2008) Brain mechanism in Japanese verbal fluency test: Evidence from examination by NIRS (Near-Infrared Spectroscopy). Asia Pacific Journal of Speech, Language, and Hearing 11: 103-110.
34. Hatta T (2009) Memory, attention and verbal function in aging: How to sustain the function in elderly. In K. Karasawa& T. Hatta (Eds.) Happy life for elderly people (pp. 53-73). Kyoto: Nakanishiya,.
35. Hatta T, Yoshizaki K, Ito Y, Mase M, Kabasawa H (2012) Reliability and validity of the Digit Cancellation Test: A brief screen of attention. Psychologia 55: 246-256.
36. Hatta T, Kitagami S, Hotta C (2011) Handedness differences in memory recall and image generation: A neuropsychological supra-modal activation model. Journal of Mental Imagery 35: 33-46.
37. Billaut F, Bishop DJ (2012) Mechanical work accounts for sex differences in fatigue during repeated sprints. Eur J ApplPhysiol 112: 1429-1436.
38. Clark HM, Solomon NP (2012) Age and sex differences in orofacial strength. Dysphagia 27: 2-9.
39. Nagasawa Y, Demura S, Hamazaki H (2010) Age and sex differences of controlled force exertion measured by a computer-generated quasi-random target-pursuit system. J Musculoskelet Neuronal Interact 10: 237-244.
40. Fujiwara K (2011) Neural mechanisms in postural control. Tokyo: Kyorin-Shobo.
41. Hausmann M, Becker C, Gather U, Güntürkün O (2002) Functional cerebral asymmetries during the menstrual cycle: a cross-sectional and longitudinal analysis. Neuropsychologia 40: 808-816.
42. Miles C, Green R, Sanders G, Hines M (1998) Estrogen and memory in a transsexual population. HormBehav 34: 199-208.
43. Hatta T, Nagaya K (2009) Menstrual cycle phase effects on memory and Stroop task performance. Arch Sex Behav 38: 821-827.
44. Taketani Y, Maehara S (Eds.) (2001) Handbook of midwifery. Tokyo: Igakusyoin.
45. Miller DI, Halpern DF2 (2014) The new science of cognitive sex differences. Trends CognSci 18: 37-45.
46. Greenwood PM, Parasuraman R (2012) Nurturing the older brain and mind. Cambridge: MIT press.
47. Ito M (1998) Cerebellar learning in the vestibulo-ocular reflex. Trends CognSci 2: 313-321.
48. Marvel CL, Desmond JE (2010) The contributions of cerebro-cerebellar circuitry to executive verbal working memory. Cortex 46: 880-895.
49. Marvel CL, Desmond JE (2010) Functional topography of the cerebellum in verbal working memory. Neuropsychol Rev 20: 271-279.