Laterality: Asymmetries of Body, Brain and Cognition

Developmental trajectories of verbal and visuospatial abilities in healthy older adults: Comparison of the hemisphere asymmetry reduction in older adults model and the right hemi-ageing model

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Two models of cognitive ageing, the hemisphere asymmetry reduction in older adults (HAROLD) model and the right hemi-ageing model, were compared based upon the verbal memory and visuospatial task performance of 338 elderly participants. Comparison of the developmental trajectories for four age groups (50s, 60s, 70s and 80s) supported the HAROLD model, but not the right hemi-ageing model. Performance differences between the verbal memory and visuospatial tasks in the earlier age groups decreased in the later age groups. There was a sex difference in the cognitive-decline trajectories for verbal and visuospatial task performance after the 50s.

Keywords: Ageing; HAROLD model; Right hemi-ageing model; Verbal memory; Visuospatial function; Sex differences.

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Considerable evidence showing that the two hemispheres of the human brain are asymmetric not only in anatomical but also in functional characteristics has accumulated since the 1970s (Dimond, 1972; Hugdahl & Davidson, 2003). It is generally true to summarize the hemisphere differences as the left hemisphere engages more in verbal processing whereas the right hemisphere engages more in spatial processing. However, many factors such as levels of processing, strategy effects, cultural and sexual influences substantially affect the findings about hemisphere differences (see reviews: Bradshaw & Nettleton, 1983; Geschwind & Galaburda, 1981; Hatta, 1984, 2013; Hellige, 1993; Hugdahl & Davidson, 2003).

Compared to the large amount of research, which has aimed to find laterality differences in various kinds of cognitive functions, research studies investigating wide-range lifespan changes in laterality differences are few, probably due to the fact that conducting this research requires large numbers of participants. Still less is known about laterality differences in older adults because most experimental examinations of laterality differences were conducted using intact young adults. Developmental examination of hemisphere differences in the later stages of middle age seems to be a rather new topic, which can be done only with a large-size cohort study. The present study uses the data from a large cohort study in Japan, the Yakumo Study, which is described later.

Several models of hemisphere differences involving cognitive ageing have been proposed. The right hemi-ageing model hypothesizes that the right hemisphere is more vulnerable than the left hemisphere in ageing (Baltes & Lindenberger, 1997; Daselaar & Cabeza, 2005; Dolcos, Rice, & Cabeza, 2002; Salthouse, 1996). Supportive evidence for this model includes intelligence test scores where the scores on verbal subtests are largely invariant irrespective of increases in age, whereas the scores on visuospatial subtests show prominent age-dependent decline (Goldstein & Shelly, 1981). There is also evidence that visuospatial processes decline more precipitously than verbal processing with age (Jenkins, Myerson, Joerding, & Hale, 2000). Salthouse (1995) reported negative data for the right hemi-ageing model, where there were equivalent declines of visuospatial and verbal processing. In the Salthouse task, participants are asked to report digits (verbal processing) or cell locations (visuospatial processing) of stimuli where digits filled several cells in a matrix (e.g., 4 × 4). Both visuospatial and verbal processes can be evaluated with the identical stimuli and the task difficulty can be manipulated by changing the matrix size. Elias and Kinsbourne (1974) reported that when task complexity is controlled, elderly people showed similar levels of performance on verbal and spatial tasks.

Another model of cognitive ageing hypothesizes that hemisphere differences reduce with ageing, such as the model called HAROLD, an acronym for hemisphere asymmetry reduction in older adults (Cabeza, 2002). The HAROLD model states that neural activity during cognitive performance tends to be less lateralized in older adults than in younger adults. The HAROLD model is derived mainly from brain-imaging evidence and only a few studies using behavioural measures have been
conducted. For example, Park et al. (2002) compared well-matched visuospatial and verbal tasks in the domain of short-term memory, working memory and episodic memory across the lifespan (from the age groups of 20s to 80s). They found little differentiation between declines in visuospatial and verbal memory processes across the lifespan.

The main concern of the present study was to compare these two models of cognitive ageing, the right hemi-ageing model and HAROLD model, using behavioural measures. Dolcos et al. (2002) conducted a meta-analysis of articles concerning the right hemi-ageing model and the HAROLD model. They summarized that the right hemi-ageing model is supported by behavioural evidence in the domains of cognitive, affective and sensorimotor processing, whereas the HAROLD model is supported by brain-imaging evidence in the domains of episodic memory encoding and retrieval, semantic memory retrieval, working memory, perception and inhibitory control. Both models are not incompatible, but the HAROLD model is the most applicable to the prefrontal regions and the right hemi-ageing model is more applicable to the other brain regions.

In order to test validity of HAROLD model with behavioural measures, it is essential that performances representing left brain should be compared with that of the right brain, using common dependent measures, e.g., performance speed or correct recognition rates. It is also crucially important that behavioural performances, one for the left brain and the other for the right brain, involve common neural networks corresponding of each brain. However, as there is a laterality difference in the human brain, it is not possible to prepare behavioural tasks, one exclusively representing for the left brain and the other representing for the right brain, though it is possible that both partially share common neural networks and one task relates to the left brain and the other relates to the right brain neural networks.

In the present study, we compared the two models using visuospatial memory task (Money Road-Map Test) from Park et al. (2002) as the right brain task and verbal memory recall task [Wechsler Memory Scale (WMS)-type immediate recall] as the left brain task. Both tasks employed by the reasons that could be regarded as the reflection of common part mainly by the prefrontal regions and verbal memory recall task engaging corresponding neural network function of the left brain and visuospatial memory task engaging corresponding neural network function of the right brain. The reasons why we regard both employed tasks reflect common neural networks derive from neuroanatomical evidences using virus transneural tracer techniques. For example, Schmahmann and Pandya (1997, 2008) reported evidences that show projections to pons from association areas in anterior parietal cortex connected with spatial awareness, the supra modal areas of superior temporal gyrus relate to language, the posterior parahippocampal area concerned with spatial memory, the visual association area in parastriate cortices relevant for higher-order visual processing, and
multiple areas in the prefrontal cortex important for complex reasoning, judgement, attention and working memory (Schmahmann, 2010). Recent review of cerebellar networks with cerebral cortex and basal ganglia by Boston, Dum, and Strick (2013) also reported neuroanatomical evidences using virus trans-neural tracer that suggest cerebellar links vast range of neocortex areas including prefrontal and postparietal cortex. Further, evidences elucidate that cerebellum involves not only motor function associated with basal ganglia but also non-motor functions mediated by the prefrontal and posterior parietal cortex. Verbal 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 as such famous amnestic patient H. M. showed intact immediate memory recall, while he was unable to retain factual information. Money Road-Map Test has no direct brain-imaging evidences, however it seems reasonable to regard that this test performance needs to control the frontal eye fields, a function of the dorsal attention network, consisting of frontal eye field and parietal lobe connections by previous many findings of laterality studies for visuospatial tasks. Further, this task recruits the ventral attention network for target identification. Therefore, we may be able to regard that employed verbal memory recall and visuospatial memory tasks reflect neural networks, front-parietal cortex and cerebro-cerebellar functioning networks of the left and right brain. According to these anatomical evidences, it may be possible to assume that employed verbal task and spatial task involve homologous neural networks and primarily involve left and right hemispheres, respectively, though there is no direct evidence.

Although many studies have reported sex differences related to laterality differences (e.g., Kimura, 1999), Park et al. (2002) did not offer any information about sex differences in the cognitive ageing processes. Therefore, sex differences related to cognitive ageing were also examined in this study.

The working hypotheses were twofold. First, if the HAROLD model is valid, then the middle age groups (50s and 60s) should show differences between verbal and visuospatial task performance while these difference should diminish in the older age groups (70s and 80s). Second, if the right hemi-ageing model is valid, then visuospatial task performance should be better than memory task performance even in the older age groups (70s and 80s). We have no prediction about the influence of sex difference on these working hypotheses; to examine this issue was an exploratory interest of the present study.

Another concern of this cognitive developmental study was to look for information relevant to preparing health care programmes operated by the local government for community-dwelling elderly people, because this study is part of the Japanese Yakumo Study of this population. Typical men in this population begin a steep decline in their 60s in spatial functioning, whereas women show prominent decline in verbal functioning in their 60s. The findings from this present study could be used to improve scientific evidence-based health care activities for the elderly people provided by the local government.
METHOD

Ethical approval

Ethical approval was obtained from the Ethical Committee of Nagoya University Medical School for the Yakumo Study (genetic polymorphism study for health check-up examinees in Yakumo town, 2011 #643) and written informed consent for participation and data publication were obtained from each participant.

Participants

A total of 338 healthy rural community dwellers over 50 years of age participated in this research study; 206 were women and 132 were men. All participants were enrolled in the Yakumo Study in Japan. They showed no sign of physical disorders, internal disease or dementia at the initial phase of the study. All participants were examined by physicians in accordance with the health examination programme and signs of dementia or other neurological defects were evaluated by neuropsychologists using the Mini Mental State Examination (MMSE score greater than 23) and the QOL (Quality of Life) questionnaire (Folstein, Folstein, & McHugh, 1975).

To examine developmental changes by using a cross-sectional design, participants were assigned into four groups based on their age decade of 50s ($n = 62; 17$ men, $45$ women), 60s ($n = 128; 52$ men, $76$ women), 70s ($n = 95; 39$ men, $56$ women) and 80s ($n = 53; 24$ men, $29$ women).

Procedures

Participants completed the Nagoya University Cognitive Assessment Battery (NU-CAB) that assessed individual cognitive functions, such as attention, language, memory and executive functions (Hatta, 2004). In the NU-CAB, the logical memory scale score was used to indicate left hemisphere function and the Money Road-Map Test score was used to indicate right hemisphere function. The reliability and validity of the NU-CAB, including comparison to brain-imaging methods, have been reported elsewhere (Hatta, Ito, & Yoshizaki, 2006; Hatta et al., 2008, 2009; Hatta, Yoshizaki, Ito, Mase, & Kabasawa, 2012; Hibino et al., 2013). The same examiner administered both the logical memory scale and the Money Road-Map Test individually. The data were collected in 2010 and 2011 as a part of the neuropsychology 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). The Department of Preventive Medicine of the Nagoya University Medical School and the town of Yakumo jointly conducted the study since 1981. Investigations were conducted in the fields of epidemiology, internal medicine, orthopaedics, neuropsychology, ophthalmology, otolaryngology and urology. Participants in the study were or had been engaged in
a variety of jobs, not only in white collar, but also in agriculture, fishery and forestry.

Logical memory function was evaluated using the Japanese version of the WMS-Revised, where short news items consisting of 25 segments were read twice by the examiner, and each participant was asked to recall the story. Usually, this logical memory scale takes into consideration both immediate and delayed conditions, but in this study, only immediate recall was considered since a previous examination (Hatta, Nagahara, Iwahara, & Ito, 2005) of the correlation coefficient between the scores for the immediate and delayed recall conditions was high ($r = .92$). 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. This test performance was regarded as reflecting left brain verbal ability and we refer to it as a *verbal task* hereafter.

The Money Road-Map Test, developed by Money and Walker (1976), can be regarded as reflecting right brain visuospatial ability and we refer to it as a *spatial task* hereafter. The test consisted of figures of a 2-cm wide road with 12 turns of various angles. After two practice trials using the road figure with four turns, the test trial was administered. The participants were asked whether the turn should be to the right or to the left at each turning point on the presented road picture located in front of the participants. The participants had to do this task without any head or body movements, but only using mental imagery rotation. Scoring assigned 1 point for a correct answer at each turn, therefore the total score ranged from 0 to 12 points.

**RESULTS**

To prepare ideal experimental design to address our purpose, both verbal and spatial tasks should have equal cognitive burden for all age groups, however it is substantially not possible in preparing behavioural experiment. One possible way is to transform into standardized scores when we try to compare performances derived from different task performance even though it decreases confidence in interpretation of the findings and possess scientific confidential weakness. The performance scores on the verbal and spatial tasks showed different means and distributions, so they were transformed into standard scores (Z-score) for the statistical analyses (PASW Statistics 18). Table 1 shows the Z-transformed performance scores on both tasks as a function of age and sex.

To compare whether the developmental changes on both tasks show different declining trajectories, a multivariate analysis of variance (MANOVAs; two between and one within mixed design) were conducted. The results showed that the within effect of task was not significant, $F(1, 330) = .010, p = .583$. The effect of age group was significant, $F(3, 330) = 26.229, p = .000, \eta^2 = .193$, and the interaction between age group and sex was also significant, $F(3, 330) = 3.536$,
This significant interaction indicates that men and women showed different developmental trajectories from the age groups of 50s to 80s.

To examine sex differences, further analyses were conducted. Paired comparisons showed that task differences were significant for the age groups of 60s (\(p = .020\)) and 80s (\(p = .019\)). These reflect that women showed better performance than men in the age group of 60s, while men showed better performance than women in the age group of 80s.

More precise examination showed that for women, there was no significant decline between the age groups of 50s and 60s (\(p = .188\)) but there were significant declines between 60s and 70s (\(p = .000\)) and between 70s and 80s (\(p = .00\)). These suggest that for women, performance of both verbal and spatial tasks declines gradually as age increase, but remain stable from 50s to 60s and then declines linearly from 60s to 80s. Examination showed that for men, there were no significant declines between the age groups of 50s and 60s (\(p = .091\)), between 60s and 70s (\(p = .207\)) and between 70s and 80s (\(p = 1.00\)). These suggest that for men, performance of both verbal and spatial tasks declines gradually as age increases and there was no turning point of prominent cognitive decline. Furthermore, these results suggest that prominent cognitive decline begins earlier in men than in women.

Although the interaction between task and sex remained a tendency, and did not reach a significance confidential level of 5%, \(F(1, 330) = 2.014\), further analyses were conducted for future reference. Figures 1 and 2 were prepared to visually represent these tendencies.

Examinations of the relation between age group and task for men revealed that the confidence probability scores for spatial task functioning were .157 (50s–60s), .014 (60s–70s) and .342 (70s–80s), whereas the confidence probability scores for verbal task functioning were .037 (50s–60s), .614 (60s–70s) and .272 (70s–80s). These indicate that for men, performance of both verbal and spatial tasks declined gradually; spatial ability showed a steep decline from the age groups of 50s to 60s while verbal ability declined more prominently from

\[\eta^2 = 0.031\]
60s to 70s. On the one hand, the relation between age group and task for women showed a different pattern. Confidence probability scores for spatial ability were .476 (50s–60s), .049 (60s–70s) and .050 (70s–80s), whereas confidence probability scores for verbal ability were .013 (50s–60s), .000 (60s–70s) and .026 (70s–80s). These suggest that for women, performance of both verbal and spatial tasks declined gradually as age increased; spatial ability remained stable from the age groups of 50s to 60s but showed steep decline from 60s to 80s, while verbal ability declined linearly from 50s to 80s. On the other hand, for men both abilities declined gradually as age increased, spatial ability showed a steep decline from the age groups of 60s to 70s while verbal ability showed prominent decline from 50s to 60s. Figures 1 and 2 show the developmental trajectories of the verbal and spatial task performance for men and women. Performance

Figure 1. Developmental trajectories of the memory (logical memory) and spatial (Money Road-Map) task performances (z-score transformed) in men as a function of age groups.

Figure 2. Developmental trajectories of the memory (logical memory) and spatial (Money Road-Map) task performances (z-score transformed) in women as a function of age groups.
differences between the verbal and spatial tasks were not significant for most age groups, except the difference was significant for women at age 50s ($t = 2.01$, $df = 1$, $p < .05$).

In summary, the present analyses showed a sex difference in the process of performance decline with increasing age. However, there was no evidence for a superiority of spatial ability over verbal ability; instead, both abilities declined gradually as age increased. These findings suggest that both right and left brain functions decline as age increases. A slight difference could be detected in the trajectory patterns, which supports the view of the HAROLD model rather than the right hemic-aging model of cognitive ageing.

**DISCUSSION**

The purpose of this study was to examine two representative models of cognitive ageing related to hemisphere differences or laterality in the brain. Roughly speaking, the right hemi-ageing model has been derived from behavioural experimental evidence and the HAROLD model has been developed mainly from evidence using brain-imaging techniques, as reported in Cabeza et al. (1997, 2004) and Dolcos et al. (2002). We aimed to compare these two models using similar research data, to avoid the confounding effects related to the use of radically different research methodologies. In this study, behavioural data were used to compare the right hemi-ageing and HAROLD models.

The findings in this study showed no evidence of a significant interaction between tasks (verbal and visuospatial) and age groups. This indicates that the right brain function (visuospatial task performance) did not show a steeper decline pattern as age increased than the decline pattern of the left brain function (verbal task performance). These findings are similar to the findings of Park et al. (2002), which involved verbal and visuospatial memory. The evidence that there was no difference of right brain functioning throughout the 50s to 80s supports the HAROLD model but not the right hemic-aging model of cognitive ageing.

These findings may support the view that age-related hemispheric asymmetry reduces as a compensatory function or there may be differentiation processes as Cabeza (2002) proposed. Reuter-Lorenz et al. (2000) examined verbal and spatial short-term storage using positron emission tomography (PET) with two groups (older and younger adult women). They found age differences in laterality, i.e., younger women showed activation predominantly left laterality for verbal and right laterality for spatial working memory, whereas older women showed a global pattern of anterior bilateral activation for both verbal and spatial tasks. They considered that this age difference reflected increasing bilateral activation to compensate for the neural decline of developmental changes of brain function. The increase of inter-hemispheric interaction or integration might be evidence for the proposal that the brain works dynamically as a system.
Another finding in our study was that there was a significant interaction between sex and age groups. This means that cognitive-decline trajectories related to ageing in women and men are not parallel but do differ. Women’s prominent cognitive decline begins from ages in 60s not in 50s, while men’s decline begins from their 50s. This later beginning of cognitive decline in women might be an effect of sex-related hormonal secretion. This interpretation may be supported by the present evidence that only women showed significantly better verbal than visuospatial performance scores in their 50s because the mean age of menopause of Japanese women is around 52-year-old (Taketani & Maehara, 2001). Based upon an intensive review of cognition and sex differences, Kimura (1999) concluded that women’s better verbal cognitive performance, such as verbal memory, reading and verbal fluency, can be interpreted as influenced by sex-related hormones. Hatta and Nagaya (2009) examined the effects of gonadal steroid hormones during menstrual cycles on attention and memory performance in women. They found that sex-related hormones, especially estradiol, influenced cognitive performance in young women. The sex differences in the declining trajectory difference for performance in this present study might be interpreted as related to biopsychosocial influences. Very recent review by Miller and Halpern (2014) 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.

Though it was ancillary, as the interaction did not reach the confidence level but remained a tendency, we examined the developmental trajectories of verbal and visuospatial functioning as a function of sex difference. The results indicated that men showed a steep decline in their 50s to 60s in spatial and during their 60s to 70s in verbal functioning. On the other hand, women showed verbal function decline gradually with no turning point, whereas there was a turning point of decline for spatial functioning at around 60 years of age.

Examination of the cognitive-decline trajectories suggests that a steep decline or turning point is a reflection of the difficulty of sustaining the previous level of cognitive functioning. In developing evidence-based health maintenance programmes, the present findings suggest that it is important for health care staffs in local government to prepare different health-keeping programmes taking into consideration these sex differences and types of function, i.e., right brain-related function or left brain-related function.

This study used a cross-sectional developmental approach to obtain an overview of the phenomena. However, we realize this limitation and we are pursuing further analyses in a longitudinal study.

In conclusion, the findings of the present study concerning cognitive ageing did not give support to the right hemi-ageing model and show sex-related
differences in the developmental trajectories. It must be careful to say that HAROLD model is supported by our findings, as we do not show hemispheres asymmetry is reduced across ageing. In this study, we could show evidences that support the right hemi-ageing model should be rejected. The HAROLD model is seen to have some support only because as the rejection of right hemi-ageing hypothesis. It should be stressed that this does not automatically indicate that HAROLD model hypothesis is supported.

Finding the turning points of steep age-dependent decline can offer cues for health care department staffs to prepare health care activities in the most beneficial and cost-effective manner.

REFERENCES


