Brain and Cognition 75 (2011) 205–210

Contents lists available at ScienceDirect

Brain and Cognition

journal homepage: www.elsevier.com/locate/b&c

Age-related differences in attentional networks of alerting and executive control in young, middle-aged, and older Chinese adults

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ARTICLE INFO

Article history:
Accepted 3 December 2010
Available online 19 January 2011

Keywords:
Attention network
Cognition
Alerting network
Orienting network
Executive control network

ABSTRACT

Previous studies suggest that aging is associated with impairment of attention. However, it is not known whether this represents a global attentional deficit or relates to a specific attentional network. We used the attention network test to examine three groups of younger, middle-aged, and older participants with respect to the efficiency of three anatomically defined attentional networks: alerting network, orienting network, and executive control network. Age-related change was found to have the greatest effect on the executive network and the least effect on the alerting network as well as on overall mean response time. Impairment of the orienting network was found to be insignificant. Age-related deterioration of the prefrontal lobe, the dopaminergic system, and function of specific genes may explain the age-related changes in executive attention, which occur after the fourth decade of life.

1. Introduction

Few domains of human cognition remain uninfluenced by the effects of aging. Numerous studies on the process of healthy aging suggest that older adults display deficits in various cognitive domains, including slowed mental processing, disturbances of attention and concentration, executive disabilities that include an impaired ability to manipulate concepts or generate strategies, visuospatial abnormalities, and a memory disorder that primarily affects retrieval rather than learning (Gunning-Dixon & Raz, 2003; Head, Kennedy, Rodrigue, & Raz, 2009; Hedden & Gabrieli, 2004). Aging has been associated with both preservation and impairment of attention (McDowd & Shaw, 2000). Older individuals tend to have reduced visual acuity and contrast sensitivity (Spear, 1993) and are more vulnerable to attentional capture by irrelevant singleton distractors that occur with an abrupt onset (Pratt & Bellomo, 1999). These observations may be indicators of an age-related decline in the ability to maintain an inhibitory set (Colcombe et al., 2003; Kramer, Hahn, Irwin, & Theeuwes, 2000; Kramer & Strayer, 2001). An age-related decline in top-down attentional guidance would be expected on the basis of the age-related deficits that have been noted generally in executive control processes (Kramer, Hahn, & Gopher, 1999; Mayr & Liebscher, 2001). The age-associated decline in attention is thought to be due to changes in the functioning of neural systems that support these attention processes.

Healthy adult aging is associated with deterioration of the frontal lobes of the brain, which occurs earlier and more severely than the deterioration of other areas of the brain (Haug et al., 1983; Lamar, Yousem, & Resnick, 2004). Prefrontal regions seem to be particularly vulnerable to the effects of aging (Raz, 2000), and autopsy studies have shown that there is a significant decrease in brain weight, cortical thickness, and quantities of large neurons in the prefrontal cortex (Terry, DeTeresa, & Hansen, 1987). Cross-sectional and longitudinal neuroimaging data obtained from older adults without dementia suggests that areas within the prefrontal cortex (PFC) show greater vulnerability to structural change with age (Resnick et al., 2000; Resnick, Pham, Kraut, Zonderman, & Davatzikos, 2003). Frontal dysfunction has been linked to age-related impairments in memory, attention and executive control processes (Chao & Knight, 1997) and is hypothesized to represent the source of various cognitive deficits identified in older adults (Moscovitch & Winocur, 1995; West, 1996). Imaging studies have indicated that dopaminergic degeneration is associated with normal aging, and previous reports have suggested that dopamine may be important for cognitive functions, especially for executive functions (Brozoski, Brown, Rosvold, & Goldman, 1979; Williams & Goldman-Rakic, 1995). The prefrontal areas are the most important regions and neurotransmitter pathways/projections for executive control of behaviors, and their activities tend to decrease with increasing age (MacPherson, Phillips, & Della Sala, 2002; Williams & Goldman-Rakic, 1995).

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doi:10.1016/j.bandc.2010.12.003

Attention can be defined as an internal cognitive process that preferentially directs a person's focus on objects or locations that are salient or important to current goals, including management of distractions. Posner and Petersen proposed that sources of attention could be further broken down into three networks (Posner & Petersen, 1990). These networks carry out the functions of alerting, orienting, and executive control. The attentional component of alerting involves the ability to tonically maintain the alert state and involves the phasic response to a warning signal. Neuroimaging evidence reveals that the alerting network consists of specific frontal and parietal areas and involves the cortical projection of the norepinephrine system (Marrocco & Davidson, 1998). The orienting network involves the selection of information from numerous sensory inputs. The temporal parietal junction, superior parietal lobe, and frontal eye fields are involved (Corbetta & Shulman, 2002). Blockage of cholinergic input to the superior parietal lobe influences the ability to shift attention to cues (Davidson & Marrocco, 2000). Executive control of attention is involved in self-regulation of cognition and emotion. The executive network involves the anterior cingulate cortex and lateral prefrontal cortical regions and is modulated by dopamine (Benes, 2000; Diamond, Briand, Fossella, & Gehlbach, 2004; Fan, Fossella, Sommer, Wu, & Posner, 2003; Fossella et al., 2002).

The attention network test (ANT) is a combination of the cued reaction time (RT) and the flanker task (Posner, 1980). The ANT provides a measure of the efficiency of the alerting, orienting, and executive attention networks (Fan, McCandliss, Sommer, Raz, & Posner, 2002). The ANT task has been deliberately kept brief, with straightforward instructions and test results can be obtained within 30 min. The ANT has been widely used as a behavioral test to assess the performance of normal children and those with disorders (Mezzacappa, 2004; Rueda et al., 2004; Sobin et al., 2004), as well as adults with borderline personality disorders relative to temperamentally-matched controls and patients with schizophrenia and Alzheimer's disease (Fernandez-Duque & Black, 2006; Gu et al., 2008; Klein, 2003; Posner et al., 2002; Wang et al., 2005).

Although the ANT has been used to study attentional functions in a wide range of populations, relatively mixed data have been reported with respect to age differences in the three attention networks. Jennings et al. found that older adults showed significantly less alerting than young adults, although there were no age differences with respect to orientation and the executive effect (Jennings, Dagenbach, Engle, & Funke, 2007). However, additional research using the ANT has been found to be inconsistent with this claim and has indicated the existence of a significantly greater alerting effect in older adults with no difference in the orienting and executive networks (Fernandez-Duque & Black, 2006). Our present study aimed to explore age effects with respect to the three attention systems that had been defined functionally or anatomically, and to determine whether age has an influence on all three attentional networks or specifically affects the alerting and executive attention networks. On the basis of the reviewed literature, we predicted that age differences might be observed in the attention networks, especially in the alerting network and/or the executive control network. ANT was used to compare the effect of networks among young, middle-aged, and older adults in the present study.

2. Method

2.1. Participants

Table 1
Participants' descriptive and demographic data.

	Young	Middle-aged	Older
Age in years	27.8 (5.63)	51.2 (5.82)	70.9 (5.86)
Range (in years)	19–38	40–58	61–83
Education in years	12.8 (3.14)	11.2 (2.98)	10.5 (4.88)
Range (in years)	8–17	6–16	0–16
Sex (M/F)	15:15	15:15	15:15
SDS	33.2 (5.39)	32.8 (5.09)	35.1 (5.45)
MMSE total	29.2 (0.95)	29.1 (0.84)	28.8 (0.99)

Note. MMSE = Mini-Mental State Examination.
SDS = Zung's Self-rating Depression Scale.

The study group included 90 men and women from three age ranges: 20–38, 40–59, and 61–80 (Table 1). The participants were recruited from Hefei Senior Center and Anhui Medial University located in Anhui Province, China. All participants had no history of significant health problems such as hypertension, diabetes, and atherosclerotic cardiovascular disease. In addition, the participants had no history of alcohol or drug abuse, and no history of psychiatric or neurological disorders. Magnetic resonance imaging was used to investigate the brain images in the elderly participants before the experiment. The T2-weighted structural brain images of each participant in the group of elderly participants were examined and judged to be free of significant abnormalities beyond the expected age-related incidence of atrophy, ventricular dilation, and white matter hyperintensities. Written informed consent was obtained from each participant before the experiment was conducted. This research was performed according to the ethical standards of the 1964 Declaration of Helsinki.

2.2. Materials and stimuli

2.2.1. Attention network test

The revised attention network test was created using E-Prime (Version 1.1, Psychology Software Tools, Pittsburgh, PA). Stimuli were presented on a 17-in. color monitor controlled by a personal computer with a Pentium 4 processor. Participants viewed the stimuli shown on a computer screen, and responses were collected via two response buttons. Stimuli consisted of a row of five visually presented horizontal black lines, with arrowheads pointing leftward or rightward, against a white background where the target was a leftward or rightward arrowhead at the center. This target was flanked on either side by two arrows in the same direction (congruent condition), or in the opposite direction (incongruent condition), or by nothing (neutral condition) (Fig. 1). Participants were instructed to focus on a centrally located stationary cross throughout the task, and to respond as quickly and accurately as possible. The task was to identify the direction of the center arrow by pressing one button for the left direction with the index finger of the left hand and a second button for the right direction with the index finger of the right hand. The target stimulus remained on the screen until the participant responded or until a maximum of 2700 ms had elapsed. Cues consisted of the appearance of an asterisk for 100 ms that was presented 400 ms before the presentation of the target. There were four cue-related conditions: (1) no cue, wherein participants were shown a cross at the same location as the first stationary cross for 100 ms; (2) a central cue, wherein an asterisk was presented at the central point; (3) a double cue, in which an asterisk was presented at two target locations simultaneously above and below the central point; and (4) a spatial cue, in which an asterisk was presented at a target location either above or below the central point. The ANT consisted of a 24-trial practice block and three experimental blocks of trials. Each experimental block consisted of 96 trials with 48 different conditions: 4 cue types × 2 target locations × 2 target directions × 3 congruencies, with two repetitions). The presentation of trials was in a random order.

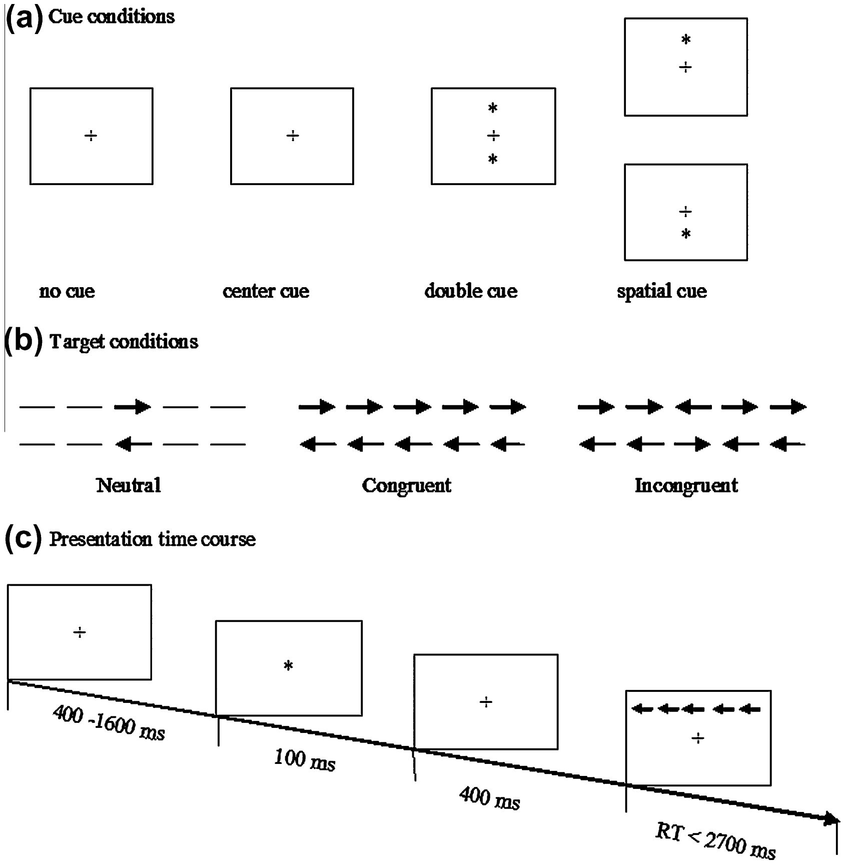

Fig. 1. Experimental paradigm of the attention network test (ANT). (a) The four cue conditions; (b) The six stimuli used in the present experiment; and (c) an example of the procedure.

2.2.2. Calculation of attention network efficiencies

The ANT uses differences in reaction times (RT) derived from the different experimental conditions to measure the alerting, orienting, and executive control networks (Fan et al., 2002).

2.2.3. Alerting network

The alerting effect was calculated by subtracting the mean RTs of the conditions with double cues from the mean RTs of the conditions with no cue.

2.2.4. Orienting network

The orienting effect was calculated by subtracting the mean RTs of the conditions with spatial cues from the mean RTs of the conditions with center cues.

2.2.5. Executive control network

The executive effect was calculated by subtracting the mean RTs of the conditions with congruent flankers from the mean RTs of the conditions with incongruent flankers. For details of the ANT, see Fan et al. (2002).

3. Result

3.1. Demographic and background data

Participants had normal vision and scored a minimum of 27 points on the Mini-Mental State Examination (MMSE). The three groups did not significantly differ in extent of education, gender, handiness, the Zung Self-Rating Depression Scale (SDS), and MMSE (Table 1).

3.2. The efficiencies of three networks

Mean RTs and error rates for each condition of the three groups are summarized in Table 2. We carried out a 4 (cue condition: center cue, double cue, none cue, spatial cue) × 3 (flanker type: congruent, incongruent, neutral) one-way analysis of variance (ANOVA) of the RT data listed in Table 2. There were significant differences in the main effects with respect to cue conditions and flanker types among the different groups. For the young group, there were significant main effects with respect to cue conditions ($F(3, 87) = 216.15$, $p < 0.001$) and flanker type ($F(2, 58) = 265.39$, $p < 0.001$). For the middle-aged group, there were also significant main effects with respect to cue conditions ($F(3, 87) = 52.41$, $p < 0.001$) and flanker type ($F(2, 58) = 94.74$, $p < 0.001$). There were also significant main effects of cue conditions ($F(3, 87) = 191.08$, $p < 0.001$) and flanker type ($F(2, 58) = 941.73$, $p < 0.001$) for the elderly group. Error data were analyzed using the same approach used to analyze the RT data. The analysis of the raw error data yielded a similar pattern of results, unless otherwise specified below.

3.2.1. Effects of normal aging

The results of ANT are summarized in Table 3. ANOVA was used to evaluate age-related differences. To determine differences between individual groups, a Student–Newman–Keuls (SNK) test was also used for analyses.

3.2.2. Alerting effect

A one-way ANOVA with respect to the alerting network, with age as a factor, demonstrated an age effect ($F(2, 87) = 6.135$,

Table 2
Mean reaction times and error rates (%) under each condition in young, middle-aged, and older groups.

Group	Center		Double		None		Spatial	
	Congruent	Incongruent	Congruent	Incongruent	Congruent	Incongruent	Congruent	Incongruent
Mean RTs (ms) and standard deviations								
Young	663 (103)	729 (115)	658 (101)	735 (132)	719 (115)	782 (131)	619 (114)	678 (133)
Middle-aged	781 (140)	858 (127)	781 (133)	884 (139)	847 (132)	939 (143)	737 (138)	803 (146)
Older	936 (117)	1068 (162)	948 (137)	1073 (165)	975 (119)	1102 (154)	890 (121)	1006 (161)
Error rates (%) and standard deviations								
Young	4.2 (0.3)	8.3 (1.8)	4.2 (0.4)	8.3 (1.8)	4.2 (0.4)	16.7 (2.8)	0.0 (0)	8.3 (1.3)
Middle-aged	0.4 (1.3)	1.1 (2.2)	0.6 (1.8)	2.6 (3.2)	0.4 (1.3)	1.7 (2.3)	0.6 (1.8)	0.4 (1.3)
Older	0.6 (1.4)	1.9 (3.4)	0.8 (1.7)	1.5 (2.8)	0.6 (1.4)	1.5 (2.6)	0.4 (1.3)	1.8 (3.0)

Table 3
Attention network scores (in RT and ratio score) of the young, middle-aged, and older groups.

	Young		Middle-aged		Older	
	M	*SE*	*M*	*SE*	*M*	*SE*
Alerting	55.98	5.69	55.94	5.75	31.68	6.68
Ratio	0.99	0.10	1.16	0.11	0.61	0.13
Orienting	46.08	3.77	45.34	5.79	55.77	9.09
Ratio	0.95	0.07	0.92	0.12	1.13	0.18
Conflict RT	66.78	5.90	84.16	5.45	124.30	11.86
Ratio	0.68	0.05	0.94	0.06	1.38	0.13
Mean RT	690.11	19.27	809.04	22.81	977.68	23.16

$p < 0.01$). The finding demonstrated that the older participants were significantly less alert than the young and middle-aged participants in terms of maintaining the alert state by responding to a warning signal (SNK, $p < 0.05$). The group comparison between the young and middle-aged groups did not show a significant difference (SNK, $p > 0.05$).

3.2.3. Orienting network

The orienting effect comparison yielded a non-significant age difference ($F(2, 87) = 0.759$, $p > 0.05$).

3.2.4. Executive effect

Scores of the executive network were analyzed using a one-way ANOVA. Under this analysis, there was a significant main effect of age ($F(2, 87) = 16.357$, $p < 0.001$) on the executive effect. It is notable that this executive effect increased with age. This finding suggests that the older participants had greater difficulties in resolving conflict than the younger and middle-aged groups (SNK, $p < 0.05$). The data also shows that the middle-aged group responded slower than the young group with respect to the executive network (SNK, $p < 0.05$). This interpretation, however, is qualified by the overall group differences in executive scores (Table 3). Fig. 2 demonstrates the performance of young, middle-aged, and older participants with respect to the executive attention network.

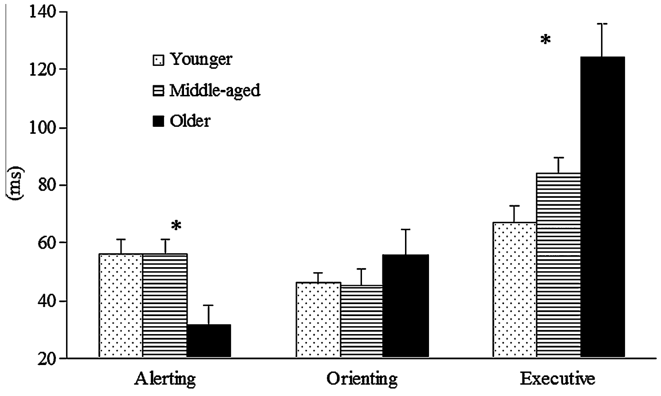

Fig. 2. Age-related changes in three attention networks. Asterisks indicate statistically significant differences and bars are standard errors.

Although overall mean RTs ($F(2, 87) = 43.863$, $p > 0.05$) were reduced during the process of healthy aging, the alerting effect became worse only with age, the executive effect became more pronounced only with aging, and the orienting effect remained unchanged (Fig. 2).

3.2.5. Correlation between the attention networks and aging

We examined the relationship of age with the scores for the three networks. Fig. 2 demonstrates the ANT scores of mean RT and three attentional networks for the young, middle-aged, and older participants. Since RTs were generally longer for the older adults, it is useful to use the ratio to examine specific effects that are not influenced by overall reaction time. Ratio score transformations have proven effective in uncovering age effects in processes in a manner that is independent of global slowing. Consequently, we calculated a ratio score transformation for each participant by dividing the mean RT determined under each condition by the participant's overall RT. (Faust & Balota, 1997). Table 3 also shows the ratio scores. On the basis of the ratio scores, significant correlations were identified between the executive network effect and age ($r = 0.54$, $p < 0.001$, Spearman) and between alerting and age ($r = -0.282$, $p < 0.001$). The correlation based on the ratio score of the orienting effect was found to be non-significant ($r = 0.058$, $p = 0.470$).

4. Discussion

The objective of the present study was to compare the three attentional networks in young, middle-aged, and older participants by using the ANT. There is a clear age effect on the executive network and on the alerting network. No evidence of abnormalities was found in the orienting network. The results suggest that the effects of aging on attention are selective for the executive and alerting networks but not for the orienting network.

4.1. Alerting effect and aging

In line with the studies, our research showed that the alerting effect decreased with age, especially for the elderly participants. Previous studies have investigated the effects of aging on performance in the ANT task. Additional studies have identified an age-related decline (Festa-Martino, Ott, & Heindel, 2004; Jennings et al., 2007). Jennings et al. found that older adults show significantly less alerting than young adults in response to a warning cue, and it was suggested that age-related differences in alerting may depend, in part, upon the duration of the warning cue presentation (Jennings et al., 2007). Similarly, Festa-Martino et al.

presented their alerting cues for 100 ms and identified an age-related decline in alerting (Festa-Martino et al., 2004). However, Fernandez-Duque used a modified version of the ANT task and reported that the alerting effect increases with age (Fernandez-Duque & Black, 2006). This study found that the older adults had difficulty sustaining attention and therefore benefited from an external cue. Consistent with previous studies, there is an age effect on the alerting network for responding efficiently to warning signals. The present findings replicated the results from two previous studies, which reported that older adults show significantly less alerting than younger adults in response to a warning cue. A possible interpretation of this finding is that the discrepancy in the literature is caused by differences in methodology. For instance, Festa-Martino and Jennings presented cues for 100 ms (as performed in the present study) whereas Fernandez-Duque and Black presented their alertness cue for 500 ms. The persistence of cue presentation may allow older adults to sustain their attention and longer cue durations may result in increasing alerting effects in older adults that can reduce or even reverse the age-related declines (Jennings et al., 2007).

A possible interpretation of the decreased alerting effect is that decreased cortical levels of noradrenaline are a common occurrence during aging (Lohr & Jeste, 1988). This system has been previously associated with alerting (Marrocco & Davidson, 1998). Experimental evidence indicates that reduced levels of noradrenaline in the brain causes lowering of the magnitude of the alerting effect (Oberlin, Alford, & Marrocco, 2005). Indeed, noradrenergic deficits may cause a decline of the alerting effect.

4.2. Orienting effect and aging

Unlike alertness, the process of orienting was found to be unaffected in the older participants. This result is similar to findings from previous studies that suggest that older adults benefit as much as younger adults from physical or symbolic cues that direct attention to the likely location or identity of upcoming target information (Greenwood & Parasuraman, 1994; Kramer & Strayer, 2001). Hartley et al. found that orienting of attention remained intact with aging by using a central cue (Hartley, 1993). Fernandez-Duque and Black (2006) also suggested that there was no age difference in orienting function. Moreover, Jennings et al. (2007) reported that elderly participants had the same orienting performance as young participants. Consistent with these results, the orienting network may not be affected by age-related changes. On the basis of ratio scores, there was no significant correlation between the orienting effect and age.

4.3. Executive effect and aging

As we expected, the executive effect was significantly decreased with age. This result offers evidence for general age-related slowing of information processing. Many studies involving different tasks have indicated that aging exerts a major effect on cognitive response speed (Cerella, 1985; Salthouse, Fristoe, & Hyun Rhee, 1996). A similar result was observed which indicated that the executive effect significantly decreases with age, based on the analyses of ratio scores. In other words, normal aging affects the capacity for conflict resolution. However, certain experiments have indicated that executive function is not affected by age (Fernandez-Duque & Black, 2006; Jennings et al., 2007). Jennings et al. (2007) reported that executive function indexed by the flanker paradigm used here appear to be unaffected by age. The results reported by Fernandez-Duque et al. also did not provide evidence that the executive control effect increased with age. The results of the current project, together with results from research on non-human animals and on neurobiological variables, suggest that age-related cognitive decline, especially for the executive effect, begins relatively early in adulthood (Finch, 2009; Salthouse, 2009). Salthouse has established that early adult age-related decreases in cognitive performance can be distinguished from the confusions of cohort differences in cross-sectional studies and from the retest effects of longitudinal studies (Salthouse, 2009). Multi-tasking of cognitive and motor functions (such as the "walking-while-memorizing" paradigm) also undergoes a decline during middle-age (Li, Lindenberger, Freund, & Baltes, 2001).

Compelling neurological evidence indicates that the neural substrates underlying the PFC, the putative seat of executive function, deteriorate more rapidly with age than other cortical regions (Lamar et al., 2004; Raz, 2000; Resnick et al., 2000, 2003). There is also extensive behavioral evidence indicating that older adults perform more poorly than young adult controls on a number of tasks that are thought to rely on executive functioning and that are sensitive to frontal lobe lesions. For instance, older adults show a greater extent of interference in incongruent trials of the Stroop task (Houx, Jolles, & Vreeling, 1993), produce fewer words on tests of verbal and semantic fluency (Troyer, Moscovitch, & Winocur, 1997), have greater difficulties with tasks that require planning (Daigneault & Braun, 1993), and show impairments in source memory (Glisky, Polster, & Routhieaux, 1995). Another study reported that older adults committed significantly more perseverative errors and completed fewer categories than young adults on the portion of the Wisconsin Card Sorting Test (WSCT), which is labeled "executive functions" (Daigneault, Braun, & Whitaker, 1992). Meanwhile, it was suggested that under appropriate control, the processing speed accounts for most of the age-related differences in executive deficits (Verhaeghen & Cerella, 2002). However, ratio scores of execution effect that involve transforming the data to correct for age differences in speed provide evidence for a deficit in conflict resolution. Thus, the present data may indicate that an inhibitory deficit occurs with advancing age, as in the Stroop task, WSCT, and other executive function. Further research is needed to better explain this difficulty.

In summary, the results of the current study support the existence of selective cognitive differences in the alerting and executive attentional networks with advanced age, rather than a global decline in attention. Furthermore, the present results suggest that age-related cognitive decline, especially for the executive effect, begins relatively early during middle-age. Age-related deterioration of the prefrontal lobe and the dopaminergic system may explain the age-related differences in executive attention that occur after the fourth decade of life. Additional experiments that manipulate potentially key variables are required. Further studies combining ANT with functional magnetic resonance imaging are required to explore age-related differences in alerting, orienting, and executive function by localizing age differences in the neural basis of each network.

Acknowledgments

We thank the participants in this study for their involvement and support. This work was supported by National Natural Science Foundation of China (30670706, 30870766) to Kai Wang.

References

Benes, F. M. (2000). Emerging principles of altered neural circuitry in schizophrenia. *Brain Research Review, 31*(2–3), 251–269.

Brozoski, T. J., Brown, R. M., Rosvold, H. E., & Goldman, P. S. (1979). Cognitive deficit caused by regional depletion of dopamine in prefrontal cortex of rhesus monkey. *Science, 205*(4409), 929–932.

Cerella, J. (1985). Information processing rates in the elderly. *Psychological Bulletin, 98*(1), 67–83.

Chao, L. L., & Knight, R. T. (1997). Prefrontal deficits in attention and inhibitory control with aging. *Cerebral Cortex, 7*(1), 63–69.

Colcombe, A. M., Kramer, A. F., Irwin, D. E., Peterson, M. S., Colcombe, S., & Hahn, S. (2003). Age-related effects of attentional and oculomotor capture by onsets and color singletons as a function of experience. *Acta Psychologica (Amst), 113*(2), 205–225.

Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience, 3*(3), 201–215.

Daigneault, S., & Braun, C. M. (1993). Working memory and the Self-Ordered Pointing Task: Further evidence of early prefrontal decline in normal aging. *Journal of Clinical and Experimental Neuropsychology, 15*(6), 881–895.

Daigneault, S., Braun, C. M., & Whitaker, H. A. (1992). Early effects of normal aging on preservative errors. *Developmental Neuropsychology, 8*, 99–114.

Davidson, M. C., & Marrocco, R. T. (2000). Local infusion of scopolamine into intraparietal cortex slows covert orienting in rhesus monkeys. *Journal of Neurophysiology, 83*(3), 1536–1549.

Diamond, A., Briand, L., Fossella, J., & Gehlbach, L. (2004). Genetic and neurochemical modulation of prefrontal cognitive functions in children. *American Journal of Psychiatry, 161*(1), 125–132.

Fan, J., Fossella, J., Sommer, T., Wu, Y., & Posner, M. I. (2003). Mapping the genetic variation of executive attention onto brain activity. *Proceedings of the National Academy of Sciences USA, 100*(12), 7406–7411.

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience, 14*(3), 340–347.

Faust, M. E., & Balota, D. A. (1997). Inhibition of return and visuospatial attention in healthy older adults and individuals with dementia of the Alzheimer type. *Neuropsychology, 11*(1), 13–29.

Fernandez-Duque, D., & Black, S. E. (2006). Attentional networks in normal aging and Alzheimer's disease. *Neuropsychology, 20*(2), 133–143.

Festa-Martino, E., Ott, B. R., & Heindel, W. C. (2004). Interactions between phasic alerting and spatial orienting: Effects of normal aging and Alzheimer's disease. *Neuropsychology, 18*(2), 258–268.

Finch, C. E. (2009). The neurobiology of middle-age has arrived. *Neurobiology of Aging, 30*(4), 515–520 [discussion 530–533].

Fossella, J., Sommer, T., Fan, J., Wu, Y., Swanson, J. M., Pfaff, D. W., et al. (2002). Assessing the molecular genetics of attention networks. *BMC Neuroscience, 3*, 14.

Glisky, E. L., Polster, M. R., & Routhieaux, B. C. (1995). Double dissociation between item and source memory. *Neuropsychology, 9*, 229–235.

Greenwood, P. M., & Parasuraman, R. (1994). Attentional disengagement deficit in nondemented elderly over 75 years of age. *Aging, Neuropsychology and Cognition, 1*(3), 188–202.

Gu, X., Liu, X., Guise, K. G., Fossella, J., Wang, K., & Fan, J. (2008). Alexithymic trait and voluntary control in healthy adults. *PLoS One, 3*(11), e3702.

Gunning-Dixon, F. M., & Raz, N. (2003). Neuroanatomical correlates of selected executive functions in middle-aged and older adults: A prospective MRI study. *Neuropsychologia, 41*(14), 1929–1941.

Hartley, A. A. (1993). Evidence for the selective preservation of spatial selective attention in old age. *Psychology and Aging, 8*(3), 371–379.

Haug, H., Barmwater, U., Eggers, R., Fischer, D., Kuhl, S., & Sass, N. L. (1983). Anatomical changes in aging brain: Morphometric analysis of the human prosencephalon. In J. Cervos-Navarro & H. I. Sarkander (Eds.), *Brain aging: Neuropathology and neuropharmacology* (pp. 1–12). New York: Raven Press.

Head, D., Kennedy, K. M., Rodrigue, K. M., & Raz, N. (2009). Age differences in perseveration: Cognitive and neuroanatomical mediators of performance on the Wisconsin Card Sorting Test. *Neuropsychologia, 47*(4), 1200–1203.

Hedden, T., & Gabrieli, J. D. (2004). Insights into the ageing mind: A view from cognitive neuroscience. *Nature Reviews Neuroscience, 5*(2), 87–96.

Houx, P. J., Jolles, J., & Vreeling, F. W. (1993). Stroop interference: Aging effects assessed with the Stroop Color-Word Test. *Experimental Aging Research, 19*(3), 209–224.

Jennings, J. M., Dagenbach, D., Engle, C. M., & Funke, L. J. (2007). Age-related changes and the attention network task: An examination of alerting, orienting, and executive function. *Aging Neuropsychology and Cognition, 14*(4), 353–369.

Klein, R. M. (2003). Chronometric explorations of disordered minds. *Trends in Cognitive Sciences, 7*(5), 190–192.

Kramer, A. F., Hahn, S., & Gopher, D. (1999). Task coordination and aging: Explorations of executive control processes in the task switching paradigm. *Acta Psychologica (Amst), 101*(2–3), 339–378.

Kramer, A. F., Hahn, S., Irwin, D. E., & Theeuwes, J. (2000). Age differences in the control of looking behavior: Do you know where your eyes have been? *Psychological Science, 11*(3), 210–217.

Kramer, A. F., & Strayer, D. L. (2001). Influence of stimulus repetition on negative priming. *Psychological Aging, 16*(4), 580–587.

Lamar, M., Yousem, D. M., & Resnick, S. M. (2004). Age differences in orbitofrontal activation: An fMRI investigation of delayed match and nonmatch to sample. *Neuroimage, 21*(4), 1368–1376.

Li, K. Z., Lindenberger, U., Freund, A. M., & Baltes, P. B. (2001). Walking while memorizing: Age-related differences in compensatory behavior. *Psychological Science, 12*(3), 230–237.

Lohr, J. B., & Jeste, D. V. (1988). Locus ceruleus morphometry in aging and schizophrenia. *Acta Psychiatrica Scandinavica, 77*(6), 689–697.

MacPherson, S. E., Phillips, L. H., & Della Sala, S. (2002). Age, executive function, and social decision making: A dorsolateral prefrontal theory of cognitive aging. *Psychology and Aging, 17*(4), 598–609.

Marrocco, R. T., & Davidson, M. C. (1998). Neurochemistry of attention. In R. Parasuraman (Ed.), *The attentive brain* (pp. 35–50). Cambridge: MIT Press.

Mayr, U., & Liebscher, T. (2001). Is there an age deficit in the selection of mental sets? *European Journal of Cognitive Psychology, 13*(1), 47–69.

McDowd, J. M., & Shaw, R. J. (2000). Attention and aging: A functional perspective. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 221–292). Mahwah, NJ: Lawrence Erlbaum Associates.

Mezzacappa, E. (2004). Alerting, orienting, and executive attention: Developmental properties and sociodemographic correlates in an epidemiological sample of young, urban children. *Child Development, 75*(5), 1373–1386.

Moscovitch, M., & Winocur, G. (1995). Frontal lobes, memory, and aging. *Annals of the New York Academy of Sciences, 769*, 119–150.

Oberlin, B. G., Alford, J. L., & Marrocco, R. T. (2005). Normal attention orienting but abnormal stimulus alerting and conflict effect in combined subtype of ADHD. *Behavioral Brain Research, 165*(1), 1–11.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*(1), 3–25.

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience, 13*, 25–42.

Posner, M. I., Rothbart, M. K., Vizueta, N., Levy, K. N., Evans, D. E., Thomas, K. M., et al. (2002). Attentional mechanisms of borderline personality disorder. *Proceedings of the National Academy of Sciences USA, 99*(25), 16366–16370.

Pratt, J., & Bellomo, C. N. (1999). Attentional capture in younger and older adults: Aging. *Neuropsychology and Cognition, 6*(1), 19–31.

Raz, N. (2000). Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 1–90). Mahwah, NJ: Lawrence Erlbaum Associates.

Resnick, S. M., Goldszal, A. F., Davatzikos, C., Golski, S., Kraut, M. A., Metter, E. J., et al. (2000). One-year age changes in MRI brain volumes in older adults. *Cerebral Cortex, 10*(5), 464–472.

Resnick, S. M., Pham, D. L., Kraut, M. A., Zonderman, A. B., & Davatzikos, C. (2003). Longitudinal magnetic resonance imaging studies of older adults: A shrinking brain. *Journal of Neuroscience, 23*(8), 3295–3301.

Rueda, M. R., Fan, J., McCandliss, B. D., Halparin, J. D., Gruber, D. B., Lercari, L. P., et al. (2004). Development of attentional networks in childhood. *Neuropsychologia, 42*(8), 1029–1040.

Salthouse, T. A. (2009). When does age-related cognitive decline begin? *Neurobiology of Aging, 30*(4), 507–514.

Salthouse, T. A., Fristoe, N., & Hyun Rhee, S. (1996). How localized are age-related effects on neuropsychological measures? *Neuropsychology, 10*, 272–285.

Sobin, C., Kiley-Brabeck, K., Daniels, S., Blundell, M., Anyane-Yeboa, K., & Karayiorgou, M. (2004). Networks of attention in children with the 22q11 deletion syndrome. *Developmental Neuropsychology, 26*(2), 611–626.

Spear, P. D. (1993). Neural bases of visual deficits during aging. *Vision Research, 33*(18), 2589–2609.

Terry, R. D., DeTeresa, R., & Hansen, L. A. (1987). Neocortical cell counts in normal human adult aging. *Annals of Neurology, 21*(6), 530–539.

Troyer, A. K., Moscovitch, M., & Winocur, G. (1997). Clustering and switching as two components of verbal fluency: Evidence from younger and older healthy adults. *Neuropsychology, 11*(1), 138–146.

Verhaeghen, P., & Cerella, J. (2002). Aging, executive control, and attention: a review of meta-analyses. *Neuroscience & Biobehavioral Reviews, 26*(7), 849–857.

Wang, K., Fan, J., Dong, Y., Wang, C. Q., Lee, T. M., & Posner, M. I. (2005). Selective impairment of attentional networks of orienting and executive control in schizophrenia. *Schizophrenia Research, 78*(2–3), 235–241.

West, R. L. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychological Bulletin, 120*(2), 272–292.

Williams, G. V., & Goldman-Rakic, P. S. (1995). Modulation of memory fields by dopamine D1 receptors in prefrontal cortex. *Nature, 376*(6541), 572–575.