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# Age-related change of location-based visual selectivity depending on conflict frequency

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**Abstract:** Age-related change in cognitive control for visual selectivity was examined using a conflict adaptation effect (CAE). The CAE reflects an increased stimulus compatibility effect for low levels of conflict frequency within blocks of trials. Younger ($n = 20$) and elderly ($n = 20$) adults received an Eriksen-type flanker task involving compatible (e.g., "44444") or incompatible (e.g., "44644") arrays presented to either the left or right visual field (VF). The participants identified the central digit of an array. Relative frequency of conflict (incompatible) trials varied as a function of the VF. Also manipulated was the presentation order of more-conflict VF and less-conflict VF conditions over trial blocks. The results showed that a location-based CAE appeared for both age groups in the first set of trial blocks, whereas in the final set of trial blocks the location-based CAE appeared only for the younger adults. These results suggested that cognitive flexibility related to context-dependent cognitive control diminishes with age.

**Key words:** cognitive control, visual selectivity, aging, executive function.

Executive functions including cognitive/attentional control, planning, set shifting, and cognitive flexibility appear to be mediated primarily by frontal lobes (Miller & Cohen, 2001; Stuss & Benson, 1986; West, 1996). Furthermore, recent neurophysiological and neuroimaging studies suggested that Brodmann area 10, which is situated at the rostral of the frontal cortex, plays a crucial role in executive functions (Burgess, Dumontheil, & Gilbert, 2007; Tsujimoto, Genovesio, & Wise, 2011). There are also data that demonstrate a relation between aging and changes in abilities that are mediated by the executive functions (Hasher & Zacks, 1988; Phillips & Henry, 2008; Raz, 2000; West, 1996), but the specific nature of this relation remains to be clarified. The present study investigated age-related changes in executive functions. In this research, cognitive control refers to the ability to adapt to circumstances that change from moment to moment. It represents a critical executive function that operates throughout our lives. Yet it is noteworthy that very little data speaks to ways in which cognitive control in corresponding tasks might vary with age and task context. To these ends, we examined the effects of task context on the cognitive control of visual attention in elderly and younger adults.

In the field of visual attention, goal-directed behavior, which consists of selecting task-relevant information and choosing the

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appropriate response, is assessed by comparing the trials in which task-irrelevant information indicates an incorrect response with those in which task-irrelevant information indicates a correct response, such as the Stroop task (Stroop, 1935), the Simon task (Simon, 1969) and the Eriksen flanker task (Eriksen & Eriksen, 1974). These classic tasks, in which stimulus-based or response-based conflict is resolved with respect to the task requirements, are prevalent in investigations of the cognitive control of visual selectivity, which refers to the ability to discriminate information corresponding to task demands among visually presented stimuli. For example, the typical Stroop task provides a robust and replicated phenomenon in which it takes longer for an individual to name the color of the ink when a different color-word is printed (i.e., the word "BLUE" printed in red), namely an incompatible condition, than to name the color of the ink when the same color-word is printed (i.e., the word "BLUE" printed in blue), namely a compatible condition. In the compatible condition, task-relevant information (i.e., the color of the ink) and task-irrelevant information (i.e., the name of the word) are both associated with the same response, resulting in converging response activation. In contrast, in the incompatible condition, they are associated with different responses, resulting in a response conflict. The longer latency to respond in the incompatible relative to the compatible condition (i.e., the Stroop effect) is derived from the resolution of the conflict. Thus, the magnitude of interference effect (i.e., the Stroop effect) gauges the extent of visual selectivity: a larger Stroop effect corresponds to poorer visual selectivity.

Modulation in the magnitude of the Stroop effect has been used as an index of cognitive control; it has also served as an index of attentional ability of the elderly and clinical population (MacLeod, 1991; Rabin, Barr, & Burton, 2005; Verhaeghen, Cerella, Bopp, & Basak, 2005). For example, a manipulation of the proportion of compatible to incompatible trials occurring in a block of trials, referred to as list-wide proportion conflict manipulation, has revealed that the magnitude of the Stroop effect is attenuated when a trial block comprises mostly incompatible trials (Logan & Zbrodoff, 1979; West & Baylis, 1998). This modulation of the compatibility effect depends on the proportion of conflicting (incompatible) conditions. The modulation of the compatibility effect in the current trial depending on the conflict in the previous trial was originally called the *conflict adaptation effect (CAE)* or *Gratton effect* (Gratton, Coles, & Donchin, 1992, Experiment 1). In the current study, however, the modulation of the compatibility effect depending on the block-wise conflict frequency is termed the *block-wise conflict adaptation effect (block-wise CAE)*. That is because Verguts and Notebaert (2009) argued that the block-wise effect is assumed to have the same origin as the Gratton effect, although this argument is still controversial (Funes, Lupiáñez, & Humphreys, 2010). Thus, the block-wise CAE is attributed to global cognitive control strategies that are implemented based on expectancies arising from the likelihood of conflict (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Egner, 2007; van Veen & Carter, 2006).

A conflict-monitoring model (Botvinick et al., 2001) proposes the existence of a so-called conflict monitoring module, localized in the anterior cingulate cortex (ACC). This module constantly registers the level of representational conflict in the system. Once conflict is detected, this detection automatically triggers the recruitment of attentional control activities, which are usually associated with lateral prefrontal cortex (LPFC).

The goals of the present study were twofold. The first goal was to examine whether or not the block-wise CAE, which has been observed for younger adults, also appears in elderly adults (Corballis & Gratton, 2003; Egner, 2007). Following the conflict-monitoring model mediated by the prefrontal cortex, the block-wise CAE would not appear in elderly adults because of age-related decline of the prefrontal cortex. When dealing with the block-wise CAE, which is assumed to derive from experience with conflict detection and resolution, it is noteworthy that, as the relative probability of compatible to incompatible trials within a trial block increases, participants, particularly the elderly, are likely to make mistakes due to losing track of the goal of the task, that is, they fail to name the ink color of a color-word (Bélanger, Belleville, & Gauthier, 2010; Kane & Engle, 2003). When compatible trials were very likely in a given block, participants tend to rely on over-learned stimulus-response mappings (i.e., naming the meaning of a color-word); however, in these cases, they also tend to miss the primary task (i.e., naming the ink color of a color-word). In addition, the change in difficulty of task-goal maintenance caused by manipulating the compatibility ratio (conflict frequency) may have an influence on task performance. Taken together, it is plausible that the block-wise CAE, which depends on frequency of the conflict within a trial block, is caused not only by the experience of conflict detection and resolution, but also by an inability to maintain the task goal over time.

In order to examine the block-wise CAE in the present experiment, we sought to strengthen the maintenance of a task goal in two ways. First, we used the Eriksen flanker task (Eriksen & Eriksen, 1974), instead of the Stroop task, to measure the compatibility effects. In the Eriksen flanker task, the identification of a target stimulus (e.g., "S" or "H") in a letter string (e.g., "HHHSHHH" or "HHHHHHH") is required, while flanker stimuli (e.g., "HHH") which are simultaneously presented with the target must be ignored. The flankers can be either compatible or incompatible with the target. In this example, compatible flankers are associated with the same letter-response category as that of the target, while incompatible flankers are associated with the opposite letter-response relative to the target. Typically, the performance with incompatible flankers is impaired relative to that with compatible flankers. Note that, unlike the Stroop task with an overlearned, dominant S-R mapping (i.e., naming the meaning of a word) and an inferior S-R mapping (i.e., naming the ink-color of a word), a typical flanker task has two symmetrical S-R mappings (e.g., each specified letter corresponding to each response finger). Thus, viewers are unlikely to lose track of the task goal even when compatible trials are very frequent in a given block. Furthermore, it is important to note that numerous studies which have investigated the adjustment of visual selectivity with the Eriksen-type flanker task have demonstrated block-wise conflict adaptation (Corballis & Gratton, 2003; Gratton et al., 1992, Experiment 2; Kuratomi & Yoshizaki, 2010; Purmann, Badde, Luna-Rodriguez, & Wendt, 2011; Vietze & Wendt, 2009; Wendt, Kluwe, & Vietze, 2008; Wendt, Luna-Rodriguez, & Jacobsen, 2012; Żurawska vel Grajewska, Sim, Hoenig, Herrnberger, & Kiefer, 2011) as well as trial-by-trial conflict adaptation, that is, the Gratton effect (Akçay & Hazeltine, 2011; Gratton et al., 1992, Experiment 1; Mayr, Awh, & Laurey, 2003; Wendt et al., 2012).

Second, the present experiment held the overall proportion of compatible trials equal to that of incompatible ones (i.e., 50%) within a trial block by presenting letter strings at two spatial locations (left visual field (LVF) and right visual field (RVF)). In each block, one VF in which the compatible trials are more frequent (e.g., 75%) is paired with the opposite VF in which compatible trials are less frequent (e.g., 25%). Previous studies (Corballis & Gratton, 2003; Kuratomi & Yoshizaki, 2010; Wendt et al., 2008) that investigated the relation between CAE and stimulus location have shown that the compatibility effect is larger in the location where compatible trials appear frequently (i.e., the less-conflict VF) than in the location where they appear less frequently (i.e., the more-conflict VF). Moreover, viewers failed to notice the unbalanced proportion of compatible trials between the two locations (Kuratomi, Kimura, & Yoshizaki, 2011).

In sum, the present experiment was designed to observe the block-wise CAE in two possible locations, the LVF and the RVF, where the ratio of compatible to incompatible trials was manipulated while holding constant the total frequency of compatible/incompatible trials in each experimental block. Four types of a five-numeral array ("44644," "44444," "66466," and "66666") were presented to either the LVF or the RVF. The experimental block of 32 trials consisted of the more-conflict VF, in which compatible trials appear with a frequency of

25%, and the less-conflict VF, in which compatible trials appear with a frequency of 75%. Following the previous findings, which demonstrated the block-wise CAE independently for two locations (Corballis & Gratton, 2003; Vietze & Wendt, 2009; Wendt et al., 2008), we hypothesized that the compatibility effect would be larger in the less-conflict VF than in the more-conflict VF. More importantly, we also hypothesized that this block-wise CAE should be smaller in the elderly than in the younger adults because of age-related decline in the function of the frontal lobes.

The second goal of this study was to examine an age-related change in perseverative behavior that has been attributed to the lack of cognitive flexibility. We aim to use the block-wise CAE independently for the LVF and the RVF to accomplish this. In the field of clinical and cognitive neuropsychology, the Wisconsin Card Sorting Test (WCST; Grant & Berg, 1948) is used as an effective tool by which to examine cognitive flexibility. Typically, compared with younger adults, older adults tend to perseverate; that is, they maintain the attentional set used in prior task (task set) when, in fact, the subsequent task calls for a shift to a new task set (Fristoe, Salthouse, & Woodard, 1997; Rhodes, 2004). This increased perseveration observed in normal older adults resembles that observed in the WCST performance of frontal-lobe patients (West, 1996). Taking into consideration that an fMRI study demonstrated that the performance-monitoring component of WCST performance is involved by the prefrontal cortex (Konishi, Kawazu, Uchida, Kikyo, Asakura, & Miyashita, 1999), the increased perseveration in normal older adults is due to the degradation of monitoring function derived from age-related decline of the prefrontal cortex (West, 1996). However, the WCST is a complex multidimensional task that engages many different cognitive functions, including task switching, working memory, and inhibition, and its use does not shed light on specific aspects of age-related changes in cognitive control governed by executive functions. On the contrary, as described previously, the mechanism associated with a manifestation of the block-wise CAE is relatively well explained by the conflict-monitoring model of Botvinick et al. (2001). A number of brain imaging studies based on this conflict-monitoring model have demonstrated that the trial-by-trial conflict adaptation can be attributed to the detection of conflict, which is mediated in the ACC, and to the recruitment of attentional control, which is mediated in the LPFC (Botvinick, Cohen, & Carter, 2004; Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Kerns, Cohen, MacDonald, Cho, Stenger, & Carter, 2004). Recently, Żurawska vel Grajewska et al. (2011, Experiment 2) demonstrated that block-wise conflict adaptation is mediated by brain regions including the ACC and the LPFC. Therefore, it is worthwhile to investigate whether or not the phenomenon resembling *stuck-in-set perseveration*, which is an inappropriate maintenance of a framework for responding when a shift in task occurs (Sandson & Albert, 1984), is observed in elderly adults.

Furthermore, it is possible that the inhibitory deficit with aging leads to the phenomenon resembling stuck-in-set perseveration, which is an inappropriate maintenance of an attentional set for responding. Taking into account that a number of previous studies have suggested the age-related decline of inhibition of task-irrelevant information (Gazzaley, Cooney, Rissman, & D'Esposito, 2005; Hasher & Zacks, 1988; Lustig, Hasher, & Zacks, 2007; Mitchell, Johnson, Higgins, & Johnson, 2010), it is also difficult for elderly adults to inhibit the trend for visual selectivity according to conflict frequency, which is acquired in a given location when the conflict frequency is drastically changed in that location.

In order to address this issue, we gave participants eight experimental blocks of trials. The more- or less-conflict VF was reversed across the first four blocks of trials and the final four blocks of trials. That is, after the completion of the fourth block, the less-conflict VF shifts to the more-conflict VF, and vice versa. Taking into account that aging decreases cognitive flexibility and increases signs of perseveration, we predicted that, whereas the block-wise CAE would appear in both the first and the last four trial blocks of the younger adult group, a reduced or reversed block-wise CAE would appear in the second set of four trial blocks in the elderly.

## Method

### Participants

Twenty right-handed graduate and undergraduate students (the younger adult group: 15 women and 5 men, mean age = 22.7 years, *SD* = 3.6 years) and 20 right-handed healthy elderly adults (the elderly group: 9 women and 11 men, mean age = 70.4 years, *SD* = 5.6 years) participated in the experiment. Their handedness was evaluated using the H.N. handedness inventory (Hatta & Nakatsuka, 1975). No elderly participants revealed cognitive impairment; all participants' scores met or exceeded the criterion of 24 points (of 30) in the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975), a common screening criterion for dementia. All the participants gave informed consent, were paid for their participation, and reported normal or corrected-to-normal vision.

### Stimuli

All stimuli were drawn in black on a white background. The Arabic numerals "4" and "6" were employed as targets and flankers. Each numeral subtended 0.9 deg by 0.6 deg of the visual angle. The target numeral ("4" or "6") was presented together with two identical flanker numerals ("44" or "66") on each side. One of the critical variables in the experiment was compatibility between a target and its flankers (compatible condition "44444" and "66666," incompatible condition "66466," and "44644"). Each of the four types of a five-numeral-array was arranged vertically and presented to either the LVF or the RVF. The distance between the meridian through to the fixation point and each numeral of the five-numeral-array was 2.2 deg of the visual angle. These arrays were 6.8 deg in height and 0.9 deg in width, and the center-to-center distance between the numerals was 1.5 deg.

Each experimental block contained 32 trials. The less-conflict VF condition, in which 12 (75%) compatible trials and 4 (25%) incompatible trials appeared, was paired with the more-conflict VF condition, in which 4 (25%) compatible trials and 12 (75%) incompatible trials appeared. Therefore, the overall proportion of compatible to incompatible trials in the experimental block was 50%. Two types of the experimental blocks were created by changing the correspondence between the two spatial locations (LVF/RVF) and the conflict frequency in the VF (more-/less-conflict VF). The frequency of appearance for these arrays was equal in each experimental block.

### Apparatus

An IBM-compatible personal computer equipped with a 17-in. CRT color monitor (Sony, CPD-E230) with a refresh rate of 70 Hz was used to present the stimuli. Trial presentation and recording of response choices and response times were controlled using SuperLab Pro for Windows Version 4.07b software (Cedrus Company, San Pedro, CA, USA). The participants' responses were recorded using a response box (Cedrus RB-530), which obtained responses accurate to within 1 ms.

### Experimental design

The experimental design was a 2 × 2 × 2 × 2 mixed factorial with age group (the younger adults vs. the elderly adults) as the only between-participants factor. The remaining three within-participants factors were: compatibility between a target and its flankers (compatible vs. incompatible), conflict VF (less-conflict VF vs. more-conflict VF), and the time course of the experimental blocks (the first half vs. the second half of the blocks of trials).

### Procedure

Participants received explicit instructions indicating that they were to maintain central fixation at all times during the task. These instructions were repeated at the beginning of each block. The viewing distance from the participants' eyes to the monitor was 37 cm and was maintained with a chin-rest. Prior to the experimental

**Table 1** Mean reaction times (ms) and *SD*s (in parentheses) for correct responses of each experimental condition in the two age groups

| | Younger adults | | | | Elderly adults | | | |
|---|---|---|---|---|---|---|---|---|
| | First half blocks | | Second half blocks | | First half blocks | | Second half blocks | |
| | Less conflict | More conflict | Less conflict | More conflict | Less conflict | More conflict | Less conflict | More conflict |
| Compatible | 419 (66) | 420 (80) | 411 (62) | 417 (59) | 627 (147) | 628 (147) | 616 (120) | 609 (112) |
| Incompatible | 474 (83) | 458 (73) | 468 (71) | 455 (67) | 690 (135) | 657 (122) | 654 (70) | 670 (93) |

session, the participants also received a practice block that consisted of eight compatible and eight incompatible trials in each VF.

The sequence of events for each trial was as follows. First there was a warning tone, and a 500-ms central fixation point ("+", 0.5 deg × 0.5 deg) was presented. Second, the five-numeral-array was presented for 100 ms. The participants were required to discriminate a target ("4" or "6") that was presented at the center of the array as quickly and as accurately as possible. They were asked to make their choice via a button press made with their index finger of their left and right hand. The two buttons were arranged one above the other in order to reduce the influence caused by the correspondence or the competition between the stimulus presentation location (the LVF or the RVF) and the button locations on the performance. The correspondence between the hand and the target was counterbalanced across the participants. All reaction times were measured from a stimulus onset to a response. The viewers had 1.5 s to respond. The intertrial interval was 1500 ms.

The participants repeated one of the two types of experimental blocks for the first four trial blocks (128 trials), and then they did the other type of experimental block for the last four trial blocks (a total of 256 trials over all blocks). The order of these two blocks was counterbalanced across the participants in each age group. A rest of 30 s separated all blocks. The critical variable was the time course of the experimental blocks, which consisted of the first four blocks of trials and the second four blocks of trials.

After the completion of the experiment, an experimenter asked the participants to report whether or not they had noticed that the proportion of compatible to incompatible trials varied depending on the presentation location (i.e., LVF or RVF); if so, they had to indicate the nature of any observed change. None of the participants reported the correct relation between the presentation location, the ratio of compatible to incompatible trials in a given block, or the time course of the experimental blocks.

## Results

The mean individual reaction times (RTs) of the correct responses were calculated for each participant. Trials with RTs of 200 ms or less were considered to be errors and eliminated from the analyses (less than 0.01% in both age groups). Table 1 gives the means and standard deviations of the RTs for correct responses in each experimental condition. Also, Table 2 shows the means and standard deviations of the error rates. The correlation between the reaction times and the error rates in the 16 experimental conditions was high, $r(14) = .80$, suggesting that the speed-accuracy trade-off was not observed.

### *Reaction times*

We conducted a four-way mixed factorial ANOVA in accordance with the experimental design. As predicted, main effects of both age group and compatibility demonstrated that the RTs were much faster in the younger adults

**Table 2** Mean error rates and *SD*s (in parentheses) of each experimental condition in the two age groups

| | Younger adults | | | | Elderly adults | | | |
|---|---|---|---|---|---|---|---|---|
| | First half blocks | | Second half blocks | | First half blocks | | Second half blocks | |
| | Less conflict | More conflict | Less conflict | More conflict | Less conflict | More conflict | Less conflict | More conflict |
| Compatible | .031 (.030) | .041 (.050) | .024 (.021) | .028 (.046) | .114 (.115) | .125 (.131) | .090 (.077) | .106 (.112) |
| Incompatible | .100 (.103) | .064 (.060) | .072 (.087) | .071 (.053) | .188 (.170) | .122 (.095) | .072 (.082) | .086 (.074) |

(440 ms) than in the elderly participants (644 ms), $F(1, 38) = 47.14$, $p < .001$, partial eta squared ($\eta_p^2$) = .55, and a robust compatibility effect (47 ms) appeared, $F(1, 38) = 56.13$, $p < .001$, $\eta_p^2 = .60$. Importantly, a four-way interaction was significant, $F(1, 38) = 6.97$, $p < .05$, $\eta_p^2 = .16$. Given that we verified an effect of compatibility and we need to investigate this interaction, we subsequently simplified the analysis in a three-way mixed ANOVA with the variables of age group (the between-participants factor), the conflict VF, and the time course of experimental blocks as within-participants factors, and used the compatibility effect as a dependent variable (this registered the difference between the compatible and incompatible conditions).

The three-way mixed ANOVA showed a significant main effect of conflict VF condition, $F(1,38) = 6.93$, $p < .05$, $\eta_p^2 = .15$, suggesting that the compatibility effect was greater in the less-conflict VF condition (53 ms) than in the more-conflict VF (42 ms). That is, the block-wise CAE (11 ms) appeared. Also, an interaction between the time course of the experimental blocks and the conflict VF was significant, $F(1, 38) = 5.60$, $p < .05$, $\eta_p^2 = .13$. This interaction was fluctuated by the age group variable, $F(1, 38) = 6.97$, $p < .05$, $\eta_p^2 = .16$. Therefore further analyses were conducted in each age group.

The simple interaction between the time course of the experimental blocks and the conflict VF condition in the younger adults was not significant, $F(1, 38) = 0.04$, suggesting that the extent of the block-wise CAE was invariant across the first (16 ms) and the second half blocks (19 ms). In contrast, this interaction was significant in the elderly adults, $F(1,38) = 12.53$, $p < .005$, suggesting that, as shown in Figure 1, the block-wise CAE (33 ms) appeared in the first half block, whereas the reversed block-wise CAE (–23 ms) was observed in the second half block.

### *Error rates*

As with the RT data, we conducted a four-way mixed factorial ANOVA in accordance with the experimental design. Although the four-way interaction was not significant, $F(1, 38) = .41$, $p = .52$, the resulting pattern of error rates was similar to that from the reaction times.

The main effects of the age group, the compatibility, and the time course of the experimental blocks demonstrated that the error rates were lower in the younger adult group (5.4%) than in the elderly group (11.3%), $F(1, 38) = 10.22$, $p < .01$, $\eta_p^2 = .21$, that the compatibility effect (2.7%) appeared, $F(1, 38) = 3.69$, $p = .062$, $\eta_p^2 = .09$, and that the error rates were higher in the first half (9.8%) than in the second half (6.9%), $F(1, 38) = 19.96$, $p < .001$, $\eta_p^2 = .34$. Importantly, although an interaction between the conflict VF and the compatibility was significant, $F(1, 38) = 5.48$, $p < .05$, $\eta_p^2 = .13$, this interaction did not significantly fluctuate by the age group, $F(1, 38) = .41$, suggesting that the block-wise CAE appeared in both age groups and that the extent of the block-wise CAE was invariant across the age groups. Furthermore, the three-way interaction between the conflict VF, the compatibility, and the time course of the experimental blocks was significant, $F(1, 38) = 4.68$, $p < .05$, $\eta_p^2 = .11$. This indicates that the block-wise CAE was much larger in the first half (6.2%) than in the second half (0.3%) of the eight-block session. This interaction might be caused by the floor effect in the second half ($M = 6.9\%$). Other interactions did not reach significance.

## Discussion

Two major findings emerged from the RT data. First, we provided evidence that both younger adults and the elderly adapt their visual selectivity depending on the conflict frequency associated with a given stimulus location. In other words, the compatibility effect was greater in the less-conflict location than in the more-conflict location, and this modulation of the effect was observed irrespective of the two age groups. Furthermore, in order to investigate the modulation of visual selectivity without the experience of the preceding blocks, we reanalyzed the age-related change in the block-wise CAE only in the first half blocks. The result of this analysis showed that the block-wise CAE was very similar in the two age groups: age group × conflict VF; $F(1, 38) = 1.39$. These results are consistent with previous findings with younger adults (Corballis & Gratton, 2003; Vietze & Wendt, 2009; Wendt et al., 2008) in which visual selectivity was modulated by varying conflict frequency on each stimulus location within a block of trials. To our knowledge, our results are the first demonstration that the location-based modulation of visual selectivity depending on conflict frequency appears even in the elderly, and that it does not change with age. These results suggest that the cognitive control for visual selectivity might work normally in elderly adults.

Second, our results provide evidence of an age-related impairment of cognitive flexibility, as this is manifest in cognitive control that depends on conflict frequency. In the elderly, if the correspondence between the stimulus location (the LVF or the RVF) and conflict frequency is switched, the original selectivity of visual processing in each location persists, revealing a failure in these participants to adapt to a task switch. By contrast, younger adults promptly adapt visual selectivity depending on the latest conflict frequency. As described above, according to the conflict-monitoring model (Botvinick et al., 2001), the modulation of visual selectivity (i.e., the block-wise CAE) in response to relative frequency has been decomposed into two main processes: conflict monitoring mediated in the ACC, and control recruitment (on incompatible trials) mediated in the LPFC. The present results suggest that the loop between these two processes works well in elderly adults in the sense that the block-wise CAE was observed. However, our data also raise the possibility that elderly

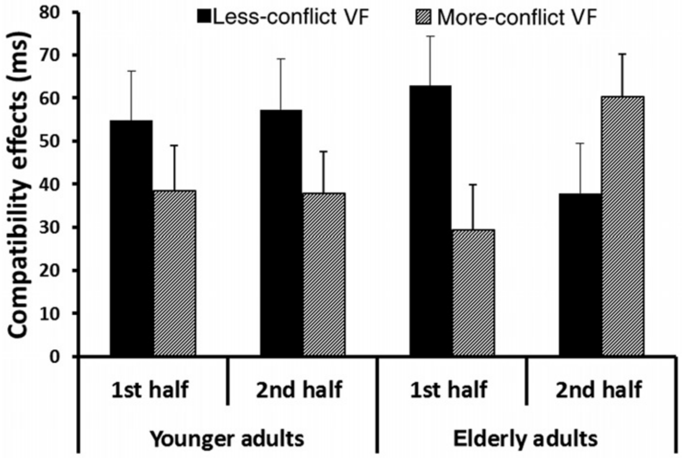

**Figure 1** Mean compatibility effects (ms) for the time course of experimental blocks in each age group. Bars indicate standard errors. VF = visual field.

observers carry over the trend of cognitive control, that is, the task set, acquired in previous blocks into subsequent blocks of trials that require a different task set. This observation seems to be in line with the stuck-in-set perseveration obtained using the WCST (Rhodes, 2004).

Interestingly, although the present results showed that the normal older adults did not have a deficit in inhibition of task-irrelevant information compared with the young adults, we suggested that the elderly would have difficulty in inhibiting the trend of cognitive control acquired during the previous blocks in a given stimulus location. As several studies with the Eriksen-type flanker task have demonstrated that the performance in the compatible trials is equal with that in the neutral condition (Develaar & Stevens, 2009; Fan, Flombaum, McCandliss, Thomas, & Posner, 2003; Hazeltine, Bunge, Scanlon, & Gabrieli, 2003), it is assumed that the difference between the compatible/neutral and the incompatible trials, that is, the compatibility effect, reflects the degree of interference from task-irrelevant information. The present results showed that the compatibility effect in the elderly (47.6 ms) was comparable with that in the younger adults (47.1 ms), $F(1, 38) = .002$. Thus, the inhibitory deficit for task-irrelevant information was not observed in the elderly in our study, whereas the perseveration-like phenomenon observed in our study, in which the trend of cognitive control acquired in previous blocks was preserved even when the conflict frequency was changed, suggests that normal older adults may have difficulty in inhibiting the acquired trend of cognitive control.

Taking into account recent findings in brain imaging (Cappell, Gmeindl, & Reuter-Lorenz, 2010; Carp, Gmeindl, & Reuter-Lorenz, 2010; Duverne, Motamedinia, & Rugg, 2009; Li, Lindenberger, & Sikström, 2001), it is possible that this perseveration-like phenomenon observed only in the elderly is due to an age-related difference shown in the pattern and magnitude of brain activation during the present flanker task. According to the Compensation-Related Utilization of Neural Circuits Hypothesis (CRUNCH) model (Reuter-Lorenz & Cappell, 2008), age differences in neural engagement vary with the level of task demands. At low levels of task demands, declining neural efficiency leads older adults to recruit more neural resources than younger adults, whereas as task demands increase, older adults reach a resource recruitment ceiling and this leads to underactivation in relevant brain regions relative to younger adults. The present result of the error rate (total $M = 11.3\%$) in the elderly, as well as the result that the degree of interference from the task-irrelevant information in the elderly was comparable with the younger adults imply that the demands of the present task were not so high for the elderly adults. In the first half blocks of the present experiment, the extent of the block-wise CAE observed in the elderly was comparable to that in the younger adults. Following the CRUNCH, it is plausible that the elderly adults would recruit more neural resources than the younger adults during the first half blocks, resulting in over-activity in the brains of the elderly participants. Overactivation, in turn, may lead to a lack of location-based visual selectivity, which depends on the conflict frequency presented in the trial blocks following a task switch. In this case, following the task switch the relation between the presentation location and conflict frequency is reversed.

In addition to the view that the overactivation in the brain of elderly adults is associated with the perseveration-like phenomenon in cognitive control, the presentation configuration (the LVF or the RVF) of task-relevant stimuli in the present experiment may lead to the impairment of cognitive flexibility. Recently, studies of local visuospatial interaction (Nishimura & Yoshizaki, 2010; Torralbo & Beck, 2008), visual short-term memory (Delvenne, 2005), visual tracking (Alvarez & Cavanagh, 2005), as well as various neuroimaging studies (Pollmann, Zaidel, & von Cramon, 2003) have supported the view that each hemisphere has a separate attentional resource pool. Evidence to date suggests that parallel processing taking place in each hemisphere leads to the most efficient processing of visual information. In light of these findings, it is suggested that each overactivated hemisphere which experienced the detection and resolution of the conflict could have the long-lasting tendency of visual selectivity acquired in the first half blocks.

In summary, the present study provides new evidence that the performance of the elderly is similar to that of younger adults in a task requiring cognitive control, in that both age groups could adapt visual selectivity depending on the conflict frequency of the presentation location. However, we also demonstrated an age difference in terms of the cognitive flexibility in location-based visual selectivity. Whereas the younger adults could promptly switch visual selectivity in each presentation location corresponding to conflict frequency, it was difficult for the elderly to modulate visual selectivity in each location depending on a new conflict situation.

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