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Aging and the time course of inhibition of return in a static environment

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Abstract. Age-related differences on the time course of inhibition of return (IOR), a phenomenon that refers to a slowed response time for targets appearing at a previously attended location, were examined in 30 young and 30 elderly adults. Stimulus onset asynchronies (SOAs) between peripheral cues and targets were systematically manipulated on a detection task with a double-cue procedure to capture the onset and offset of IOR. Results show that IOR in elderly people developed 50 ms later as compared to young adults, at an approximately 200 ms cue-target interval. The magnitude of IOR for elderly people was also weaker than that for young adults during short SOAs. Similar magnitude and dissipation of IOR at an approximately 3.5 s cue-target interval during long SOAs were observed for both young and elderly people. Possible reasons underlying the age effects on the time course of IOR and the involvement of temporal processing mechanisms are discussed.

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INTRODUCTION

Inhibition of return (IOR) is considered to be a phenomenon of spatial attention that biases attention from returning back to a previously inspected location, so as to facilitate the efficiency of visual searching activity (Posner and Cohen 1984, for a review see Klein 2000). Two types of cue-target paradigms are typically employed to investigate this phenomenon. One is a single-cue paradigm in which a peripheral cue is followed by a target stimulus appearing at either the previously cued location or an uncued location. The other is a double-cue paradigm in which a second cue is added to reorient subjects' attention from a previously cued location in the periphery to the central fixation point before the onset of a following target.

It has been demonstrated that attention can be drawn reflexively to a spatial location by the onset of a sudden peripheral cue even if the gaze remains unchanging and this covert shift of attention can subsequently facilitate the processing of target stimuli appearing at the cued location, i.e., response times (RTs) are faster for detecting targets at the cued location vs. the uncued location. However, this early facilitation only lasts for a short period of time and is substituted by a later inhibition if the stimulus onset asynchrony (SOA) between the peripheral cue and the target exceeds approximately 300 ms. This RT delay at the cued location relative to the uncued location is termed "inhibition of return", a phenomenon which enables visual search by discouraging attention from re-orienting back to the previously inspected locations and favoring novel spatial locations.

Since Posner and Cohen (1984) first described the IOR phenomenon in their seminal paper, an increasing amount of research has been dedicated to this field. Now it is known that IOR can be observed not only with a detection task (e.g., Tassinari et al. 1994) in which a speeded response is required at the appearance of a target, but also with a discrimination task (e.g., Lupiáñez et al. 1997, Pratt and Castel 2001) in which the discrimination of target features are necessary for making the response. However, the time course of IOR differs between these two tasks. While IOR occurs approximately 300 ms following the onset of the initial peripheral cue and lasts at least 1.5 second in detection tasks, IOR tends to develop more slowly and dissipates more quickly in discrimination tasks (Lupiáñez et al. 1997). It is also known that IOR is a robust phenomenon occurring not only in static stimulus displays but also in dynamic stimulus displays. In particular, when a cued object moves away from the location where it was cued, not only responses for detecting target stimuli appearing at the originally cued location are slowed but also responses to targets appearing in the cued object at its new location are prolonged. This indicates that IOR not only stays with the originally cued location but also stays with the cued object, thus showing both location-based and object-based IOR (McCrae and Abrams 2001, Tipper et al. 1994). Since in static stimulus displays the cued object and the cued location are bound together and difficult to separate, it has been suggested that IOR in a static environment has both location-based and object-based components and thus its magnitude is typically larger than the magnitude of IOR observed in a dynamic environment (Christ et al. 2002).

Although a large number of studies have been conducted toward understanding the different aspects of IOR, only a few studies to date explored the aging effect on IOR and results are somewhat conflicting. With a double-cue procedure, Hartley and Kieley (1995) reported that IOR effects were at least as large in elderly adults as in younger adults on both detection and discrimination tasks. Faust and Balota (1997) examined IOR in young adults, healthy elderly adults, and elderly adults with dementia of the Alzheimer type (DAT) on a detection task and also found equivalent IOR effects for all three groups. These studies seem to suggest that inhibition from peripheral cueing is relatively well preserved in healthy older adults.

However, two more recent studies did reveal some evidence on age-related effects of IOR. Besides the significant IOR effects for both young and elderly adults exhibited at the relatively short cue-target SOA (950 ms), Langley et al. (2001) also reported that the IOR effect for young adults declined significantly on a detection task at the long cue-target SOA (3 500 ms) and no such SOA-related reduction was found for the elderly, thus suggesting age-related differences in IOR. Unlike all previous studies exploring IOR in only static stimulus displays, McCrae and Abrams (2001) focused on examining the age effects of IOR in both a static and a dynamic environment. They found that both young and old adults demonstrated IOR effects in a static environment, as did the studies of Faust and Balota (1997) and Hartley and Kieley (1995). More importantly, they further observed in their studies that age did have a differential effect on IOR depending on the frame of reference of inhibition: object-based IOR broke down with age, whereas location-based IOR did not. This seems to indicate that age-related deterioration in inhibitory processing is task specific rather than general.

On the basis of all these studies with elderly people, it seems to us that the temporal characteristics of IOR play an important role in observing the age effect on IOR. As previous studies in normal young adults demonstrated, IOR is an extremely robust effect that can be consistently observed at a SOA of approximately 300 ms to at least 1.5 s (Posner and Cohen 1984) and it might last as long as about 3 s (Tassinari et al. 1989) or even 5 s when cueing several peripheral locations sequentially (Danziger et al. 1998). Focusing on the time course of IOR, we found that all previous studies that found age equivalence of IOR in a static environment or location-based IOR in a dynamic environment only examined the IOR effects in a relatively short time range of SOA, i.e., all SOAs between the peripheral cue and the target fell into the range of 350-1 250 ms, a typical SOA range for observing IOR. Although some researchers tried to find out the age effect in the time course of IOR (Hartley and Kieley 1995), the limited time range of their selected SOAs might have made it impossible to discover the age differences in their experiments. In contrast, the study conducted by Langley and her colleagues (2001), who suggested age-related differences in IOR, did benefit from examining the inhibitory effect at a long SOA of 3 500 ms. Moreover, following a discovery of the age-related breakdown in object-based IOR at a short SOA of 467 ms, McCrae and Abrams (2001) also turned their attention to the long SOAs of 1 167, 2 467 and 3 967 ms besides 467 ms in another experiment. Although they focused their attention on the time course of IOR, they did not find any further object-based IOR for both young and old adults at all longer SOAs. This failure could perhaps be attributed to a different time course of object-based IOR where inhibitory function might only last for a very short period.

Considering the importance of the SOA between cue and target for the IOR effect, the present study was aimed at finding out the possible age differences of onsets and offsets marking the temporal window of IOR. Two sections of experiments were conducted using the traditional double-cue procedure in a static environment: section A focused on the onset of IOR with all short SOAs varying from 150 to 350 ms with a 50-ms increment; section B focused on the offset of IOR with all long SOAs varying from 1 700 to 4 200 ms with a 500-ms increment. By systematically varying the short and long SOAs, we intended to explore the relationship between aging and the time course of IOR in greater detail.

METHOD

Subjects

Thirty young and 30 elderly volunteers participated in this study for a remuneration of 12 Euro. The young subjects ranged in age from 19 to 38 years (mean = 26.7 years, SD = 5.23 years) and the elderly subjects aged from 60 and 81 (mean = 68.6 years, SD = 6.41 years). All subjects reported normal or corrected-to-normal vision, and all were naive to the purpose of the experiment.

Apparatus and stimuli

The experiment took place in a dimly illuminated room. A Pentium III computer was used to present stimuli and collect responses. The stimulus display consisted of three boxes outlined in light grey and measuring $2.6° \times 1.0°$ of visual angle that were displayed on the horizontal meridian of the black screen. Inside the centre box, there was a white fixation cross "+" measuring $0.5° \times 0.5°$ of visual angle. The centre of the two peripheral boxes was 5° from the centre of the fixation point. Cueing of peripheral locations or the centre fixation was accomplished by brightening the outline of the peripheral or central boxes, i.e., changing their colour from light grey to white. The target was a light grey star sign measuring 0.7° in diameter, which appeared in the centre of the two peripheral boxes.

Procedure and design

The experiment included two sections: section A focused on short SOAs, while section B focused on long SOAs. Each subject participated in both sections. The order of the two sections was counterbalanced for both young and elderly groups. During each section, subjects were seated in front of the computer with their eyes approximately 60 cm from the screen. Each trial began with the presentation of three boxes with a cross serving as a fixation point inside the central one. This initial display remained visible throughout the trial. Following a delay of 1 000 ms, one of the two peripheral boxes was brightened (peripheral cue) for either 50 ms (section A) or 100 ms (section B). After a 50-ms (section A) or 100-ms (section B) interval, the central box was brightened (central cue) for either 50 ms (section A) or 100 ms (section B). Following another interval of either 0 / 50 / 100 / 150 / 200 ms (section A) or 1 400 / 1 900 / 2 400 / 2 900 / 3 400 / 3 900 ms (section B), the target appeared randomly at the center of either the left or the right peripheral box. On catch trials, no target was presented and the trial terminated 1 000 ms after the brightening of the central box. Subjects were instructed to keep their eyes fixed on the central cross throughout each trial and press the space bar with their dominant hand as quickly and as accurately as possible when they detected the target. The target remains on the screen until the subject responds. Figure 1 illustrates the procedure used in this experiment. Response time was measured in milliseconds as the time between the onset of the target and the onset of the response. No response should be made on catch trials. Whenever subjects made a mistake, a 300-Hz warning tone with the duration of 300 ms was presented. The inter-trial interval was 1 500 ms during which the screen was blank in both section A and section B.

At the beginning of each section, one practice block of 30 trials was performed. Then 240 experimental trials and 30 catch trials of the main test were presented randomly in 9 blocks with 30 trials in each block. Of the 240 experimental trials in section A, there were 48 trials for each of the five short SOAs between the peripheral cue and the target: 150, 200, 250, 300 and 350 ms. The target appeared at the cued location and the uncued location 24 times respectively. Of the 240 experimental trials in section B, there were 40 trials for each of the six long SOAs between the peripheral cue and the target: 1 700, 2 200, 2 700, 3 200, 3 700 and 4 200 ms. Of these 40 trials, the targets appeared 20 times at the cued location and 20 times at the uncued location. All blocks were initiated by the subjects pressing a space bar. A two-minute break interrupted the blocks in each section. Section A lasted approximately 30 minutes and section

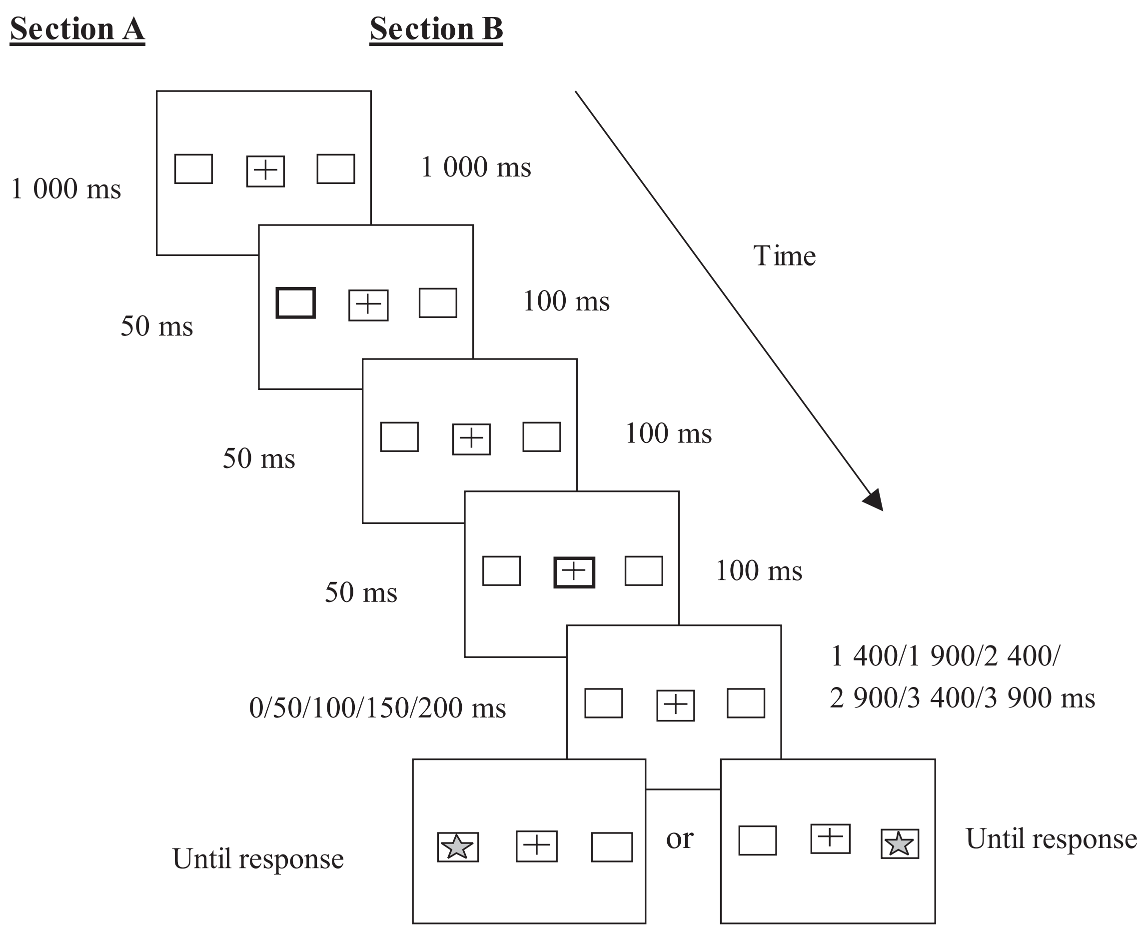

Fig. 1. Sequence of events for a sample trial in section A and B.

B 40 minutes. A ten-minute break was inserted between section A and section B.

Data analysis

The average error rates for both young and elderly subjects were very low (1.1% and 1.4%, respectively), thus only response times were submitted to further analyses. Since one elderly subject had an extreme error rate that was higher than 10%, his response time data was completely excluded from the experiment. For correct response times in each experimental condition, a 120-ms response lower limit was imposed to exclude anticipatory responses and an 800-ms response upper limit was imposed to remove delayed responses. Median RTs for each experimental condition were calculated from the remaining correct RTs for each subject. Separate ANOVA analyses on these medians in section A and section B were conducted to examine the possible age differences on the time course of IOR.

RESULTS

Inhibitory effects during short SOAs

Median RTs in section A were submitted to a 2 × 2 × 5 mixed ANOVA with age (young and elderly) as between-subjects variable and target location (cued and uncued) and SOA (150 ms, 200 ms, 250 ms, 300 ms and 350 ms) as within-subjects variables. The mean RTs of these medians for each age group and condition are illustrated in Figure 2.

There was a significant main effect of age ($F_{1,57}$=90.88, P<0.001), showing that elderly adults were generally slower (mean = 388 ms) than young adults (mean =2 96 ms). The main effects of target location ($F_{1,57}$=97.36, P<0.001) and SOA ($F_{3,185}$=101.14, P<0.001) were also significant. Overall, participants responded more slowly to targets presented at the cued location (mean = 355 ms) than to targets presented at the uncued location (mean = 329 ms), reflecting the IOR effect. RTs generally decreased as SOA increased. Moreover, these main effects are qualified by two significant two-way interactions. One is the age × target location interaction ($F_{1,57}$=7.85, P<0.01), which resulted from a stronger inhibitory effect for young adults (cued – uncued = 34 ms) as compared to the elderly (cued – uncued = 19 ms). The other is the age × SOA interaction ($F_{3,185}$=6.05, P<0.001). While the RTs for young adults stopped decreasing when SOA reached 250 ms, the RTs for elderly adults kept decreasing until SOA reached 300 ms. The remaining target location × SOA interaction was not significant ($F_{4,228}$=0.55, P>0.05). More importantly, the three-way interaction (age × target

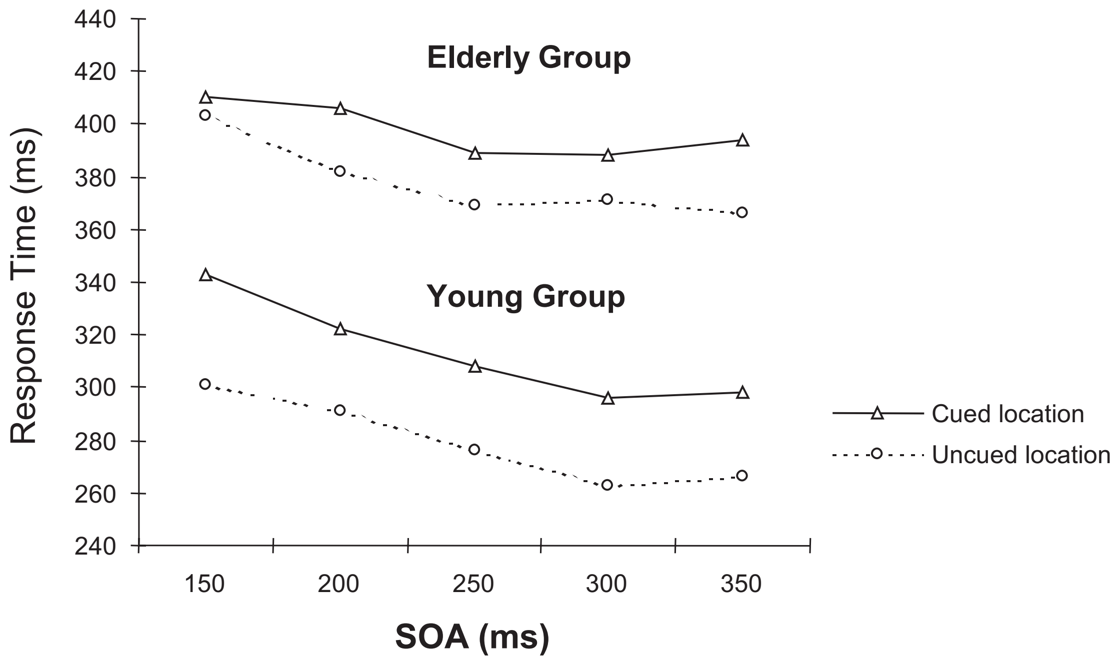

Fig. 2. Mean response times at the cued and uncued locations during short SOAs. The upper two lines represent the RT data for elderly adults, whereas the lower two lines represent the RT data for young adults.

location × SOA) was significant ($F_{4,228}$=5.00, P<0.01), indicating that young and elderly adults exhibited different time course of IOR.

To explore the three-way interaction of age × target location × SOA, separate ANOVAs with target location and SOA as within-subjects variables were conducted for each age group. For young subjects, there was a significant main effect of SOA ($F_{3,87}$=86.20, P<0.001), reflecting a general decrease of response times as SOA increased. The main effect of target location was also significant ($F_{1,29}$=134.72, P<0.001). Response times were significantly slower at the cued location (313 ms) than that at the uncued location (279 ms), showing the expected inhibitory effect. However, the interaction between target location and SOA was not significant ($F_{3,85}$=1.85, P>0.05). This indicated that the inhibitory effect did not change significantly across all short SOAs.

For elderly subjects, both the main effect of SOA ($F_{3,78}$=29.03, P<0.001) and the main effect of target location ($F_{1,28}$=17.43, P<0.001) were significant. However, unlike the result of young subjects, the interaction between target location and SOA was also significant ($F_{4,112}$=3.34, P<0.05). Further analysis of *t*-tests showed that response times were significantly slower at cued locations relative to uncued locations at all short SOAs (P<0.05) except the 150-ms SOA (P>0.05). This result indicated that IOR in elderly people did not emerge until the SOA reached approximately 200-ms.

Inhibitory effects during long SOAs

For median RTs in section B, a 2 × 2 × 6 mixed ANOVA with age (young and elderly) as between-subjects variable and target location (cued and uncued) and SOA (1 700 ms, 2 200 ms, 2 700 ms, 3 200 ms, 3 700 ms and 4 200 ms) as within-subjects variables was carried out. The mean RTs of these medians for each age group and condition are illustrated in Figure 3.

The main effects of age ($F_{1,57}$=49.84, P<0.001), target location ($F_{1,57}$=60.54, P<0.001) and SOA ($F_{4,231}$=60.36, P<0.001) were all significant. As expected, elderly adults were slower (mean = 413 ms) than young adults (mean = 320 ms). Participants responded more slowly to targets presented at the cued location (mean = 373 ms) than to targets presented at the uncued location (mean = 360 ms). RTs generally decreased as SOA increased. Unlike the results in section A, age only interacted with SOA ($F_{4,231}$=3.52, P<0.01), not with target location ($F_{1,57}$=0.25, P>0.05). The RTs for both young and elderly adults decreased as SOA increased from 1 700 ms to 2 200 ms, and no further decrease was observed between 2 200 ms to 3 200 ms SOA. As SOA increased from 3 200 ms to 3 700 ms, the RTs decreased

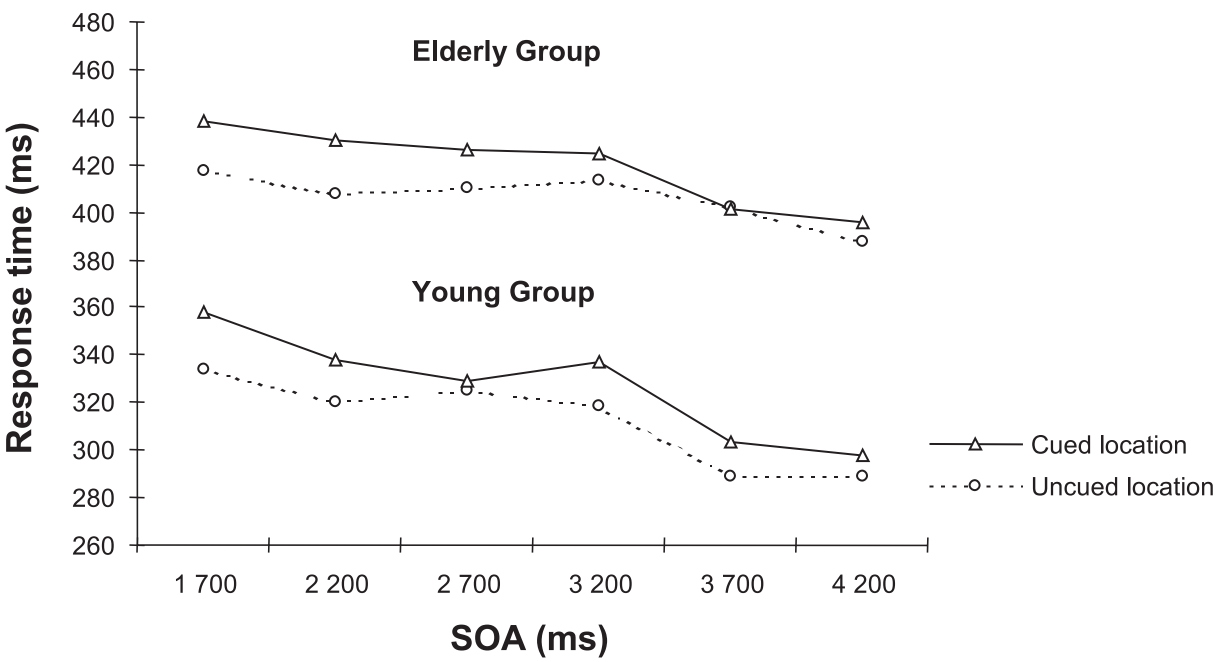

Fig. 3. Mean response times at the cued and uncued locations during long SOAs. The upper two lines represent the RT data for elderly adults, whereas the lower two lines represent the RT data for young adults.

again. However, only the RTs for elderly adults, not the young adults, continuously decreased after 3 700 ms SOA. Averaged across SOA, the magnitude of inhibitory effects did not differ between young (cued – uncued = 14 ms) and elderly adults (cued – uncued = 13 ms). The remaining two-way interaction (target location × SOA) was significant ($F_{4,244}$=3.27, P<0.05). Averaged across age, RTs were significantly longer to targets presented at the cued location than to targets at the uncued location at all long SOAs (P<0.05) except the 3 700-ms SOA (P>0.05), which indicated that the inhibitory effect once dissipated. Since the three-way interaction (age × target location × SOA) was not significant ($F_{4,244}$=1.79, P>0.05), the offset of IOR during long SOAs did not differ between young and elderly adults.

SUPPLEMENTARY EXPERIMENT

The above results demonstrated some characteristics on the time course of IOR in young and elderly people. However, several aspects still need to be addressed. First, IOR in young subjects already started at the shortest SOA (150 ms) in our experiment. Therefore, we do not know when it started to emerge. Second, since we examined the IOR effects during short and long SOAs in two separate sections, it is possible that the time course of IOR was affected by the possibly different processing strategies involved in the two sections. Finally, although a weaker IOR effect in elderly as compared to young adults was found during short SOAs, and no such age difference was found during long SOAs, the slightly different procedures used in the two sections, in particular, the different cueing time (50 ms in section A and 100 ms in section B), makes it difficult to discuss comparisons on the inhibitory magnitude between short and long SOAs.

To overcome the above problems, a supplementary experiment that included a 100-ms SOA and intermixed all short and long SOA trials randomly in one block with the same cueing procedure was carried out. Twenty-eight young adults aged from 18 to 25 (mean = 20.11, SD = 1.66) volunteered to participate in the supplementary experiment. In order to include a 100-ms SOA, the new procedure was arranged as the following: the peripheral cue was presented for 50 ms, then after an interval of 20 ms, the central cue was present for 30 ms, following a variable interval (0 / 50 / 100 / 150 / 200 / 250 / 1 600 / 2 100 / 2 600 / 3 100 / 3 600 / 4 100 ms), the target appeared at either the cued or the uncued location randomly. There were 576 trials with 24 repeated trials in each experimental condition. Another 96 catch trials were randomly mixed with the experimental trials. The

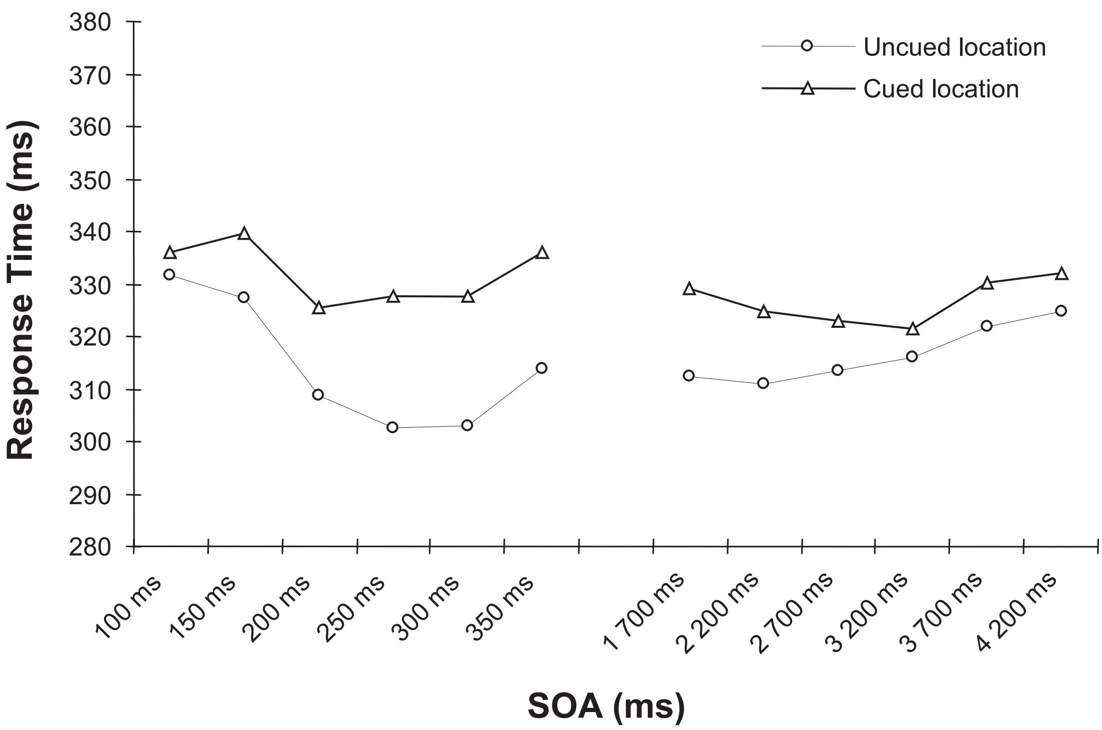

Fig. 4. Mean response times at the cued and uncued locations during different SOAs for the young adults.

experimental session included 12 blocks with 56 trials in each block. All other aspects in the supplementary experiment were similar to the previous main experiment. The results are illustrated in Figure 4.

A 2 × 12 repeated-measures ANOVA with target location and SOA as within-subjects variables showed that the main effects of target location ($F_{1,27}$=77.16, P<0.001), SOA ($F_{2,57}$=4.96, P<0.01), and the two-way interaction ($F_{11,297}$=4.42, P<0.001) were all significant. Further analysis showed that response times were significantly slowed at cued locations relative to uncued locations at all SOAs (P<0.05) except the 100-ms SOA (P>0.05) and the 3 200-ms SOA (P>0.05).

The results of the supplementary experiment demonstrate a unified picture of the time course of IOR for young adults. At a SOA as short as 100 ms, the inhibitory effect for young adults did not emerge. When the SOA was 150 ms, IOR appeared. The development of IOR showed a similar pattern as our main experiment when the SOA became longer, i.e., the inhibitory effect once disappeared (3 200-ms SOA) and then reoccurred again later.

To further investigate whether there was a general decrease in the magnitude of IOR for young subjects as the cue-target SOA increased, a paired *t*-test was conducted on the average inhibitory magnitude (average RT at cued location – average RT at uncued location) between short and long SOAs. Results showed that the inhibitory effect during long SOAs (1 700 to 4 200 ms) was significantly smaller than that during short SOAs (100 to 350 ms) (P<0.01), confirming a decreased inhibitory magnitude for young subjects across time.

DISCUSSION

The present study addressed the following questions and provided some new findings related to age effects on the time course of IOR.

Does IOR develop more slowly and dissipate later in elderly people as compared to younger people?

Hartley and Kieley (1995) tried to compare the time course of IOR for younger and older adults on a detection task with a double cue paradigm but found no age difference. They set up two levels of SOA: 150 ms and 350 ms. Since the SOA they manipulated was the time interval between the onset of the central cue and the target, the actual SOA between the peripheral cue and the target was 750 ms and 1050 ms. We showed in our present study that age differences appear at earlier SOA, i.e., at ca. 200 ms. Therefore, the SOAs used in Hartley and Kieley (1995) study are possibly in a time range not sensitive to age differences. Due to similar reasons, other studies (e.g., Faust and Balota 1997, who focused on SOAs ranged from 800 ms to 1 800 ms, McCrae and Abrams 2001, who focused on a short SOA of 366 ms in their first experiment with static displays) examining IOR in a static environment also failed to reveal the later onset of IOR in elderly people. When examining the possible age-related differences in the time course of IOR with moving stimuli, McCrae and Abrams (2001) found that elderly people failed to produce object-based IOR even when the amount of time between the presentation of the cue and the target was increased up to approximately 4 s, while young adults successfully developed it already at the shortest SOA (467 ms). Thus, no information was revealed about the onset of IOR. Regarding the offset of IOR, one recent study (Langley et al. 2001) did find an age-related difference, i.e., while IOR in young adults became non-significant at the 3 500-ms SOA, elderly people still exhibited a robust IOR effect. Since this study only concentrated on two SOAs (467 ms and 3 500 ms), it was not possible to find out more precisely the offset of IOR for both young and elderly adults.

By systematically examining IOR in a sufficiently long range of SOAs with a double-cue procedure in a static environment, the present study clearly demonstrated that age does affect the time course of IOR. While young people already started inhibition at a SOA as short as 150 ms, elderly people did not exhibit it until the cue-target SOA reached 200 ms. Results of the supplementary experiment further demonstrated that IOR for young people did not emerge until the SOA exceeded 150 ms. These results indicate for the first time a later onset of IOR (at least 50 ms later) for the elderly people as compared to young adults.

Although the present study did not observe any age difference on the offset of IOR, it did demonstrate a similar pattern of IOR during long SOAs for both young and elderly people. That is, the inhibitory effect once disappeared after 3 200 ms SOA and it reoccurred later once SOA approached 4 200 ms. The absence of IOR effect at approximately 3.5 s seems to indicate a clear offset of IOR, and the recurrence of IOR seems to suggest a cyclic processing of inhibition. The supplementary experiment with an intermixed SOA design for young adults also found a recurrence of IOR after its disappearance at 3 200 ms SOA, confirming a similar pattern observed in the main experiment except that the offset of IOR shifted 500 ms later, possibly due to the slightly different procedure. Taken together, the present study did not confirm a later offset of IOR for elderly people, but suggested a similar offset of IOR around 3.5 s for both young and elderly adults.

Several possible aspects might account for the age-related difference on the time course of IOR which was found in the present study. First, it has been suggested that IOR may begin when attention moves away from the cued location. So the sooner attention shifts away from the cued location, the earlier IOR appears. This was recently confirmed in a study conducted by Danziger and Kingstone (1999) where IOR did appear sooner when the subjects were motivated to remove their attention from the stimulated location when the cue predicted that a target would occur at another location. This influence of attentional dwell time on the time course of IOR may explain the later onset of IOR in elderly people, i.e. elderly people may need more time to disengage their attention from the cued location. Thus, their attentional dwell time on the peripheral cue is longer than that of younger adults, leading to a later onset of IOR. Second, from an ecological perspective, IOR is generally considered as an attentional bias that favors directing attentional resources towards uninspected novel locations so as to facilitate visual searching efficiency. Therefore, a quicker onset of IOR in young adults will lead to an immediately narrowed searching space, ensuring a prompt benefit to the visual searching activity. Third, as the inhibitory deficit theory of cognitive aging (Hasher and Zacks 1988) suggests, elderly people have a general deficit in their inhibitory processing, possibly leading to the observed smaller inhibitory magnitude in elderly people as compared to young adults during short SOAs. The generally weaker inhibitory function in elderly people might demand more time to develop so as to show a significant effect.

Besides our main interests on age-related differences in the time course of IOR, we also observed some unexpected results in the present study. Typically, facilitation occurs when the cue-target SOA is less than 250 ms, and inhibition of return, on the other hand, is observed at a longer SOA beyond 300 ms. Contrary to this general recognition, results of the present study demonstrated an earlier appearance of IOR for both young (150 ms) and elderly adults (200 ms). Since previous studies exploring IOR with a double-cue procedure only focus on SOAs longer than 300 ms and tend to take early facilitation for granted, it is actually not clear whether facilitation always precedes inhibition. In recent years some studies addressed this issue with a single-cue procedure and results tend to imply robust inhibition occurring at both short and long SOAs with little or no facilitation (e.g., Berlucchi et al. 1989, Tassinari et al. 1987, 1994). Our present study once again demonstrated similar results with a double-cue procedure. Therefore, it seems that no matter whether attention is shifted intrinsically or extrinsically to the central fixation location, a short cue-target SOA around 150-200 ms is already enough to generate evident inhibition of return.

Do elderly people exhibit equivalent IOR relative to young people? Does the magnitude of IOR decrease over time for both young and elderly adults?

Among previous studies on IOR and aging with a double-cue procedure on a detection task in a static environment, some reported equivalent IOR in both young and elderly adults (Faust and Balota 1997 (Experiment 2), Hartley and Kieley 1995 (Experiment 1)); others found a much stronger IOR effect in the elderly which seems to suggest an improved inhibitory function with aging (McCrae and Abrams 2001 (Experiment 1)). However, researchers tend to attribute the larger magnitude of IOR in elderly people to an overall slowness in their response times. By performing analyses on transformed response latencies (e.g., z-score), they found that the larger IOR effect in elderly people disappeared (McCrae and Abrams 2001 (Experiment 1)). With a similar method to these previous studies on a detection task, our present study demonstrated a clear age effect on inhibitory magnitude at short SOAs, but not at the long SOAs. To be specific, while equivalent magnitude of IOR at long SOAs was found for both young and elderly subjects (14 ms vs. 13 ms), the magnitude of IOR at short SOAs was significantly smaller in elderly people compared to that of young people (19 ms vs. 34 ms). This seems to indicate that inhibition in elderly people not only develops later, but also is weaker as measured with the IOR effect size in our study. Our current results are different from those that show either a reliable larger magnitude of IOR in elderly people on discrimination tasks in a static environment (Hartley and Kieley 1995 (Experiment 3 and 4)) or greater effects of object-based IOR for the elderly in a dynamic environment (Tipper et al. 1997 (Experiment 1 compared with Experiment 2)). Considering these different age effects on the magnitude of IOR, we believe that the absence of consistency is not only related to the specific tasks used in different experiments but also related to the different time intervals of SOA at which the magnitude is measured. Therefore, the possible change on the magnitude of IOR with increasing SOAs should be considered when comparing the magnitude of IOR between young and elderly people.

Hartley and Kieley (1995) in their first experiment with a detection task reported a significant decrease of IOR magnitude with increasing intervals between the cue and target for both young and elderly people. But a recent study with a detection task conducted by Langley and her colleagues (2001) only confirmed the decreasing magnitude of IOR in young subjects but not in the elderly. To focus on this issue, we compared the average magnitude of IOR at short SOAs (section A) with that at long SOAs (section B) for both young and elderly subjects. Results showed that the magnitude of IOR effect decreased across time significantly only for young people (P<0.01), not for the elderly. Since the cueing procedures in section A and section B were not exactly the same, results from the above comparison are doubtful. To further check whether similar results would be obtained in an experiment in which direct comparison is qualified, a supplementary experiment for young adults was conducted, and results from it revealed a similar decrease of the inhibitory magnitude between short and long SOAs (P<0.01). These results are consistent with the recent finding by Langley and her colleagues (2001). However, the present finding should be viewed with caution since only short and long SOAs were compared without checking the middle SOAs. Faust and Balota (1997) focused on three different SOAs (800 ms, 1 300 ms, and 1 800 ms) and they found that the magnitude of IOR is significantly larger at the middle SOA (1 300 ms) relative to the other two SOAs with no age effect. Considering the possible change on the magnitude of IOR, it is also reasonable to assume that elderly people may develop larger IOR effect at the middle range of SOA which was not measured in the present study. Therefore, a future study that examines the peak magnitude of IOR for both young and elderly people across time would be desirable.

Are temporal-integration processes of ca. 2 to 3 seconds involved in the apparent time course of IOR for both young and elderly people?

In our experiment, the offset of IOR (the disappearance of the inhibitory effect) in both young and elderly adults is measured at an interval of 3 700 ms in the main experiment and at an interval of 3 200 ms in the supplementary experiment. Interestingly, these transitions between inhibition and non-inhibition of the reaction appear on a time scale that has been identified as upper limit of a general temporal integration mechanism involved in cognitive processing. The temporal extent of this automatic and presemantic integration process is limited to approximately 2 to 3 s (e.g., Fraisse 1984, Pöppel 1997, 2004, Szelag et al. 1996, Wittmann 1999). Evidence from qualitatively different experimental paradigms suggests a categorical border with respect to the processing of time. If the duration of temporal intervals has to be reproduced, subjects estimate intervals up to approximately 3 s precisely, whereas they usually underestimate longer intervals substantially (Kagerer et al. 2002, Szelag et al. 2004). In sensorimotor synchronization, where sensory signals have to be precisely synchronized by finger movements, performance breaks down if the inter-stimulus interval is longer than approximately 2 to 3 s (Mates et al. 1994). Other examples come from the spontaneous rate of alterations of ambiguous figures or from binocular rivalry. It has been observed for instance that each perspective of the Necker cube, if allowed to switch spontaneously, only lasts ca. 3 s (Gómez et al. 1995). Therefore, some researchers talk about "time perception" for intervals within a range of ca. 3 s and use the term "time estimation" for longer intervals (Fraisse 1984). We tentatively suggest that our findings of a disappearance of IOR at SOAs of ca. 3 s indicate that attentional processes involved in inhibiting reactions are bound to temporal constraints of the neuronal system operating in the discussed time domain. Inhibition functions over a certain limited time period of 2 to 3 seconds. After this period, responses to the cued locations are hardly any slower as compared to the uncued locations. However, an interesting additional effect is registered in our experiment. After the disappearance of IOR at 3 700 ms SOA in the main experiment and 3 200 ms SOA in the supplementary experiment, IOR is measured again at longer SOAs. This finding seems to indicate a cyclic inhibitory function of visual attention for the first time and needs to be further investigated in the future. At least it is obvious that at some interval length IOR effects have to ultimately fade out.

CONCLUSIONS

Age-related differences on the time course of IOR were discovered at the onset of IOR, but not the offset of IOR. Compared to young adults, elderly people exhibited both a later onset and a weaker magnitude of IOR during short cue-target intervals. No such age effects were discovered during long cue-target intervals.

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