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On the time course of attentional focusing in older adults

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Abstract Many sensory and cognitive changes accompany normal ageing, including changes to visual attention. Several studies have investigated age-related changes in the control of attention to specific locations (spatial orienting), but it is unknown whether control over the distribution or breadth of attention (spatial focus) also changes with age. In the present study, we employed a dual-stream attentional blink task and assessed changes to the spatial distribution of attention through the joint consequences of temporal lag and spatial separation on second-target accuracy. Experiment 1 compared the rate at which attention narrows in younger (mean age 22.6, SD 4.25) and older (mean age 66.8, SD 4.36) adults. The results showed that whereas young adults can narrow attention to one stream within 133 ms, older adults were unable to do the same within this time period. Experiment 2 showed that older adults can narrow their attention to one stream when given more time (266 ms). Experiment 3 confirmed that age-related changes in retinal illuminance did not account for delayed attentional narrowing in older adults. Considered together, these experiments demonstrate that older adults can narrow their attentional focus, but that they are delayed in initiating this process compared to younger adults. This finding adds to previously reported reductions in attentional dynamics, deficits in inhibitory processes, and reductions in posterior parietal cortex function that accompany normal ageing.

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Assessing the time course of attentional focusing in older adults

In everyday life, individuals are exposed to a stream of incoming visual information that changes continuously over space and time. To extract task-relevant information, the stream must be organized and structured. Selective attention serves this function by guiding visual processing to the most relevant information in a scene. To guide visual processing efficiently, the focus of attention can be shifted from one location to another (a process referred to as orienting) and adjusted in spatial extent to accommodate a smaller or larger portion of the visual field (here referred to as focusing; Eriksen & Yeh, 1985; Eriksen & St. James, 1986; Maringelli & Umiltà, 1998; Turatto et al., 2000). Visual attention is known to change with normal ageing (see review by Craik & Salthouse, 2008). Older adults, for example, are less able to selectively focus on a stimulus while filtering out distractors (Carlson, Hasher, Connelly, & Zacks, 1995; Luck, 1998; Plude, Enns, & Brodeur, 1994; Wascher, Schneider, Hoffman, Beste, & Sänger, 2012) and are often impaired in shifting focused attention from one object or location to another (e.g., Atchley & Kramer,

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1998; Greenwood, Parasuraman, & Haxby, 1993; Lincourt, Folk, & Hoyer, 1997; Nissen & Corkin, 1985; Robinson & Kerttzman, 1990; Tales, Muir, Bayer, & Snowden, 2002; Yamaguchi, Tsuchiya, & Kobayashi, 1995).

Studies have also examined whether older adults deploy the focus of attention broadly or narrowly in a variety of attention-demanding tasks such as visual search (e.g., Greenwood & Parasuraman, 1999; Greenwood, Parasuraman, & Alexander, 1997; Hartley, Kieley, & McKenzie, 1992; Madden, 1992). Of particular interest are reported differences in the breadth (spatial extent) of the attentional focus between younger and older adults (e.g., McCalley, Bouwhuis, & Juola, 1995) and reduced sensitivity among older adults to the nature and difficulty of the task (e.g., Quigley, Andersen, & Müller, 2012; Russell, Malhorta, Deidda, & Husain, 2013). We note that these studies provide a static snapshot of the distribution of attention. They do not measure the important dynamic aspect that involves actively expanding and contracting the attentional focus in response to task demands. Although studies have examined the temporal dynamics of attentional focusing in young adults (Benso, Turatto, Mascetti, & Umiltà, 1998; Jefferies & Di Lollo, 2009), only one to date has examined the temporal dynamics of attention in older adults (Russell, Malhorta, Deidda, & Husain, 2013). However, in that study, the temporal range was only sampled beginning at 250 ms, which might be too late to detect an age-related difference, and accuracy for the younger group was often near ceiling. The present study was intended to fill this gap in the literature by tracking the dynamics of attentional narrowing in older adults over periods shorter than 250 ms.

Control over the focus of attention is thought to be implemented by a network of brain areas. Posner and colleagues have identified key brain regions correlated with three steps in the changing of attentional focus: disengage, move or shift, and re-engage (Posner & Cohen, 1984; Posner & Petersen, 1989; Posner & Raichle, 1994). There is neurological evidence to suggest that several of these key brain regions change as a function of ageing. In particular, the frontal and posterior parietal regions, which are intimately involved in initiating and governing changes in the spatial distribution of attention (Posner & Petersen, 1990; Posner, 1980; Yantis et al., 2002), are strongly affected by the ageing process. Frontal brain regions exhibit marked cell loss (e.g., Shefer, 1973; Creasey & Rapoport, 1985) and reduced dendritic and synaptic counts (Bartzokis et al., 2003; Head et al., 2004; Jacobs & Scheidbel, 1993; Peter, 1979; Masliah, Mallory, Hansen, DeTeresa, & Terry, 1993). Posterior parietal regions exhibit pronounced age-related decreases in cerebral blood flow and grey matter volume (e.g., Bentourkia et al., 2000; Good et al., 2001; Kalpouzos et al., 2009; Martin, Friston, Colebatch, & Frackowiak, 1991). These age-related changes suggest that one or more of the steps involved in attentional focusing may change with ageing. In particular, it seems likely that either the process of disengaging or the process of focusing itself may be substantially altered as a function of ageing. The goal of the present study is to determine whether the *time course* of attentional focusing varies between younger and older adults.

Dual-stream paradigm

To investigate this issue, we employed the dual-stream paradigm described by Jefferies and Di Lollo (2009), which uses two well-known phenomena—the attentional blink (AB) and Lag-1 sparing—to determine the rate at which focal attention contracts. In a typical AB paradigm, two target letters are inserted in a stream of digit distractors presented in rapid serial visual presentation (RSVP). The first target is usually reported correctly, but identification of the second target is impaired if it appears within about 500 ms of the first (Raymond, Shapiro, & Arnell, 1992). Jefferies and Di Lollo employed a dual-stream paradigm in which two streams of distractor digits were presented, one on either side of fixation. The two letter targets appeared unpredictably in either the left- or the right-hand stream, and could appear in either the same or opposite streams. The paradigm employed by Jefferies and Di Lollo, and also employed in the present study, is illustrated in Fig. 1.

Jefferies and Di Lollo's (2009) paradigm also utilized an aspect of the AB known as Lag-1 sparing, which refers to the finding that the magnitude of the AB is reduced significantly if the second target is presented immediately after the first, in the temporal position known as Lag 1 (Chun & Potter, 1995; Potter, Chun, Banks, & Muckenhoupt, 1998). Specifically, Lag-1 sparing is in evidence when second-target accuracy is higher at Lag 1 than at

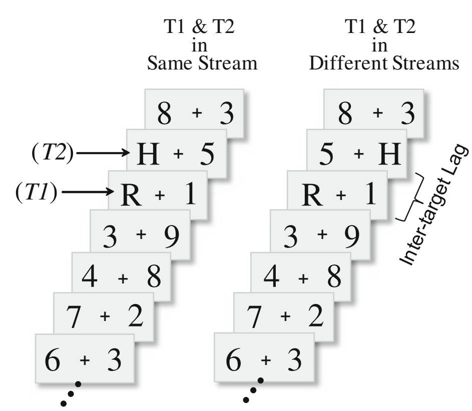

Fig. 1 Schematic representation of the sequence of events within a trial in Experiment 1. The first and the second targets (*T1* and *T2*) could appear in either the left or the right RSVP stream and in either the same or opposite streams

Lags 2 or 3. Although Lag-1 sparing typically occurs when the two targets are presented in the same spatial location (Visser, Bischof, & Di Lollo, 1999), it also occurs when the targets appear in different spatial locations, provided that the second target falls within the focus of attention (Jefferies, Ghorashi, Kawahara & Di Lollo, 2007; Shih, 2000). In light of this finding, Lag-1 sparing can be used to assess whether, and to what extent, the second target's location falls within the focus of attention (Jefferies & Di Lollo, 2009; Jefferies et al., 2007; Jefferies, Enns, & Di Lollo, 2013; Kawahara & Yamada, 2006; Lunau & Olivers, 2010; Yamada & Kawahara, 2007). As explained below, changes in the magnitude of Lag-1 sparing also can be used to assess changes in the spatial extent of the focus of attention over time.

In a dual-stream paradigm, focal attention is assumed to initially encompass both streams but to contract rapidly and reflexively to the stream in which the first target (T1) appears. Evidence of such narrowing has been reported numerous times (Jefferies & Di Lollo, 2009; Jefferies et al., 2007; Visser, Bischof, & Di Lollo, 2004). It has also been shown that the narrowing of attention to T1 begins prior to its identification (Ghorashi, Jefferies, Kawahara, & Wantanabe, 2008; Ghorashi, Enns, Klein, & Di Lollo, 2010). The advantages of such an automatic narrowing process include faster and more accurate letter identification (Barriopedro & Botella, 1998; Castiello & Umiltà, 1990; Eriksen & Yeh, 1985; Eriksen & St. James, 1986; Maringelli & Umiltà, 1998).

But there is also a consequence of this reflexive narrowing of attention to the first-target stream, in that the focus of attention no longer encompasses the opposite stream. If the second target (T2) then appears in the Same-stream as T1, it may still fall within the same focus if too little time has elapsed, or it will fall outside the focus if the reflexive narrowing has already occurred. The critical factor is the stimulus-onset asynchrony (SOA) between the two targets. This reasoning is illustrated in Fig. 2a, b, which illustrates changes in the spatial extent of the focus of attention when the SOA is short (66 ms), medium (100 ms) or long (133 ms). For clarity and convenience, Fig. 2 does not portray the entire RSVP stream (which can be seen in Fig. 1); rather, two sequential RSVP frames are shown at each SOA: the frame containing T1 and a distractor (D), and that containing T2 and another distractor. In each case, T2 is shown as appearing at Lag 1 and in the RSVP stream opposite to the one containing T1.

Consider first Fig. 2a, headed "Fast". The spatial extent of the focus of attention is illustrated by the red segmented boxes. Because the first target appears unpredictably in either stream, we assume that the focus of attention is deployed broadly so as to encompass both streams, regardless of the SOA. We hypothesize that, when T2

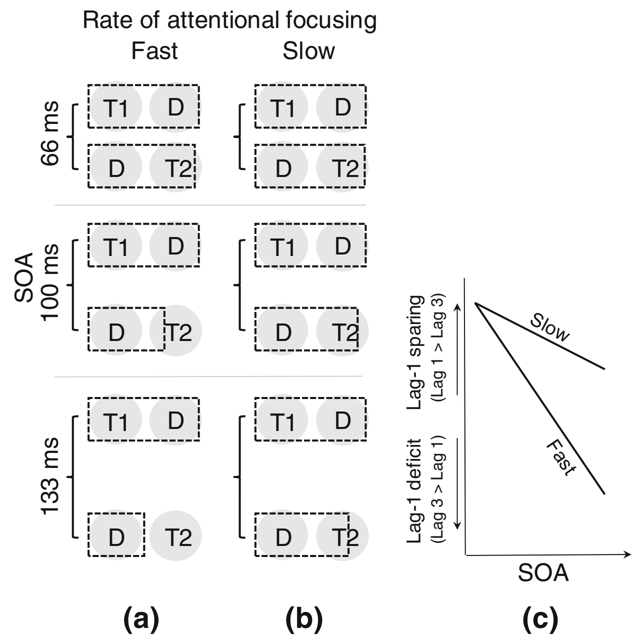

Fig. 2 Schematic illustration of the progressive changes in the spatial extent of the focus of attention (*segmented rectangles*) as a function of SOA and Lag. See text for explanation

appears only 66 ms after T1, there has not been sufficient time for attention to focus narrowly on the T1 stream and withdraw from the distractor presented in the opposite stream. When T2 appears, it will therefore still fall within the focus of attention, and Lag-1 sparing will occur. In contrast, at the longest SOA (133 ms), sufficient time has elapsed for the focus of attention to contract completely to the T1 stream. In this case, T2 will not fall within the focus of attention, and Lag-1 deficit (i.e., when accuracy at Lag 1 is *worse* than at Lags 2 or 3, which is opposite to Lag-1 sparing) will occur.

In the preceding descriptions it was assumed that changes in the spatial extent of the focus of attention are relatively fast, as illustrated in Fig. 2a. Figure 2b illustrates the case in which the changes take place more slowly. The most notable difference between fast and slow rates of focusing is seen at the longest SOA (133 ms). When focusing occurs quickly (Fig. 2a), T2 appears outside the focus of attention, and Lag-1 sparing will not occur (indeed, its converse, *Lag-1 deficit* will be in evidence). In contrast, when focusing occurs slowly (Fig. 2b), T2 appears within the focus of attention, and Lag-1 sparing will occur. Hence, the time at which the focus of attention has narrowed to the location of T1 can be inferred from the SOA at which Lag-1 sparing turns into Lag-1 deficit.

Changes in the magnitude of Lag-1 sparing and Lag-1 deficit as a function of SOA are summarized in Fig. 2c. The functions labelled "Fast" and "Slow" reflect the corresponding changes in the spatial extent of attentional focus illustrated in Fig. 2a,b, respectively. The two functions coincide at the shortest SOA (66 ms), because there has not been sufficient time for the attentional focus to begin to narrow, as illustrated at the top of Fig. 2a,b. The two functions diverge progressively, however, as the SOA is increased, showing that the narrowing of the spatial extent of attention progresses at different rates. This reasoning was employed in Experiment 1 to determine whether the rate at which the focus of attention contracts changes with age.

Experiment 1

Experiment 1 employed the logic illustrated in Fig. 2 to examine the rate of attentional focusing in older adults. The experiment was modelled on that of Jefferies and Di Lollo (2009), who systematically varied the SOA between successive items in the RSVP streams. The design of the present experiment involved the manipulation of three factors in each of two age groups (young and older adults): the SOA between successive items in the RSVP stream (66, 100, or 133 ms), the inter-target lag (1, 3, or 9, indicating that either 0, 2, or 8 distractors intervened between the two targets), and the RSVP stream in which the two targets appeared (Same-stream or Different-streams).

Not all levels of these factors were equally relevant to the main objective of the experiment, which was to assess the incidence of Lag-1 sparing with targets appearing in Different-streams, as a function of SOA in young and older observers. Given that Lag-1 sparing is measured as the difference in T2 accuracy between Lags 1 and 3, Lag 9 was included for only two purposes, neither directly relevant to the objective of the experiment: (a) to show that second-target accuracy does recover at longer lags (i.e., that an AB has occurred); and (b) to ensure the temporal unpredictability of the second target. Similarly, the narrowing of the attentional focus can be tracked only when the two targets are presented in Different-streams. The Same-stream condition was included for two reasons: (a) to ensure the spatial unpredictability of T2; and (b) to verify the prediction that when the two targets are presented in the Same-stream, T2 will necessarily fall within the focus of attention and Lag-1 sparing will always occur. For these reasons, the data of interest are those for Lags 1 and 3 in the Different-Streams condition, across SOA and age group.

Method

Participants

Eighteen young adults (mean age 22.6, SD 4.25) and 23 older adults (mean age 66.8, SD 4.4), all with normal or corrected-to-normal visual acuity and naïve as to the purpose of the study, participated in the experiment. The young adults were recruited from the undergraduate population at McMaster University and participated for course credit. The older adults were recruited by newspaper advertisements from the Hamilton, Ontario area and were paid $10 per hour for their participation. All participants completed visual and general health questionnaires to screen for visual pathology, such as cataract, macular degeneration, and amblyopia. Near and far decimal logMAR (logarithm of the minimum angle of resolution) acuities were measured for all participants with CSV-1000EDTRS eye charts (Precision Vision, LaSalle, IL, USA). When measuring visual acuity, participants wore their normal optical correction for each distance. Older participants were also screened for dementia and scored within the normal range of the Mini Mental State Examination (Folstein, Folstein, & McHugh, 1975)

Stimuli and apparatus

Observers were seated in a dark room approximately 57 cm from a computer monitor, with a small lamp illuminating the computer keyboard. The luminance of all stimuli was 34.3 cd/m^2, and the luminance of the black background was 2.3 cd/m^2. A white fixation cross (.25° by .25°) was displayed in the centre of the screen for the duration of each trial. The stimuli consisted of white digits (0–9) and capital letters (excluding the letters I, O, Q, and Z), each subtending approximately .9° vertically. The screen refresh rate varied depending on the SOA between successive items in the display sequence. To obtain the three SOAs of 66, 100, and 133 ms, the screen refresh rate was set at 75, 60, and 75 Hz, respectively.

Procedure

Observers initiated a trial by pressing the spacebar. At the beginning of the trial, two synchronized RSVP streams of items were presented 1.75° to the left and right of fixation. It should be noted that since the streams were displayed within an area with less than a 4° diameter, reductions in the Useful Field of View for older adults (Ball, Beard, Roenker, Miller, & Griggs, 1988; Ball & Owsley, 1993) were not a limiting factor. Each stream contained 8–14 distractor digits prior to the onset of the targets. The digits were chosen randomly with the restriction that the same digit not be displayed concurrently in the two streams and that each digit not be the same as the preceding two digits in that stream. Two different letter targets were presented on each trial. The two targets appeared randomly but with equal probability in either the left or the right stream and could appear in either the Same-stream or in Different-streams. Each RSVP stream ended with one digit-distractor. The display sequence on any given trial is illustrated in Fig. 1. The observers' task was to identify the two target letters by entering them in the keyboard in either order at the end of the trial.

The SOA between successive items in the RSVP stream was 66, 100, or 133 ms. The three SOAs were presented in separate blocks of trials, which were ordered randomly across participants. In every case, the SOA consisted of two parts: first, the item itself (whether distractor or target) was displayed for approximately two-thirds of the SOA. Second, a blank inter-stimulus interval (ISI) was inserted for the remaining one-third of the SOA. The actual duration of the two parts depended on the SOA. On trials in which the SOA was 66 ms, the stimulus (letter or digit) was displayed for 40 ms, followed by a blank ISI of 26 ms. When the SOA was 100 ms, exposure duration of the stimulus was 70 ms, followed by a blank ISI of 30 ms. Finally, when the SOA was 133 ms, the stimulus duration was 80 ms while the blank ISI was 53 ms.[1]

The second target was presented at one of three inter-target lags: 1, 3, or 9. At Lag 1, T2 was presented immediately following T1. At Lag 3, two distractors were inserted between the two targets. At Lag 9, eight distractors were inserted between the two targets. The three inter-target lags occurred in random order and with equal frequency across trials. Each block contained 120 trials; participants completed a total of 360 trials.

Results and discussion

The main finding of Experiment 1 was that the young adults showed evidence of narrowing their attentional focus during the 133 ms SOA interval, replicating the findings of Jefferies and Di Lollo (2009), but the older participants showed no evidence of narrowing their attentional focus over this time span. In all experiments reported in the present study, only those trials in which the first target was identified correctly were included for analysis. This procedure is commonly adopted in AB experiments on the grounds that, on trials in which T1 is identified incorrectly, the source of the error is unknown, and thus its effect on T2 processing cannot be estimated.

First-target accuracy for the young adults, averaged across observers, lag, and Same/Different streams, was 72.5, 91.3, and 90.6 % for SOAs of 66, 100, and 133 ms, respectively. The corresponding first-target accuracies for the older adults were 54.1, 71.5, and 73.1 %. It is clear that first-target identification accuracy is worse for the older adults than for the young adults—this reduction could be due to several different factors. First, it could stem either from the general decline in processing speed that has been proposed to accompany ageing (e.g., Salthouse, 1996) or to the slower rate at which older adults accumulate information about stimulus identity (e.g., Gottlob & Madden, 1998). Second, the first-target identification accuracy reduction is likely due, at least in part, to visual masking. It is well known that the strength of masking is inversely related to the period of time that elapses from the onset of a target to the onset of the trailing mask (Breitmeyer & Ogmen, 2006; Purcell & Stewart, 1970), which, in the current paradigm, would be the SOA between the onset of the first target and the onset of the next item in the stream. Consistent with this, the current results show that first-target accuracy is worst at the shortest SOA (66 ms), improving as the SOA increases to 100 and 133 ms; this is true both for the younger and older adults. There is also evidence in the literature that visual masking is stronger in older adults and that the effects of masking persist with longer periods of time between the stimulus and the mask (Di Lollo, Arnett, & Kruk, 1982; Kline & Birren, 1975; Kline & Szafran, 1975; Walsh, 1982). This increase in the strength and duration of masking may underlie the reduced first-target identification accuracy observed for the older adults. Finally, it is possible that the reduction in first-target identification accuracy for older adults results from age-related changes in the sensory organs; this option is tested in Experiment 3.

Figure 3 illustrates the percentage of correct T2 responses as a function of Same-stream/Different-streams conditions and Lag, separately for each SOA and for young and older participants.

The data were analyzed in a 3 (SOA: 66, 100, and 133 ms) × 3 (Lag: 1, 3, 9) × 2 (Stream: Same, Different) × 2 (Group: Young adults, Older adults) ANOVA, with Group as a between-subjects factor. The analysis revealed significant main effects of Lag, $F(2,78) = 34.25$, $p < .001$, $\eta_p^2 = .468$, Stream, $F(1,39) = 79.42$, $p < .001$, $\eta_p^2 = .671$, Group, $F(1,39) = 56.15$, $p < .001$, $\eta_p^2 = .590$, and SOA, $F(2,78) = 95.35$, $p < .001$, $\eta_p^2 = .710$. The following interactions were also significant: Stream × Group, $F(1,39) = 25.7$, $p < .001$, $\eta_p^2 = .397$, Lag × Group, $F(2,78) = 7.96$, $p = .001$, $\eta_p^2 = .169$, Stream × Lag, $F(2,78) = 37.10$, $p < .001$, $\eta_p^2 = .488$, SOA × Lag, $F(4,156) = 7.36$, $p < .001$, $\eta_p^2 = .159$, SOA × Lag × Group, $F(4,156) = 11.15$, $p < .001$, $\eta_p^2 = .22$, and SOA × Stream × Lag, $F(4,156) = 10.949$, $p < .001$, $\eta_p^2 = .219$. The interpretation of these interactions was constrained by the significant four-way interaction among Lag, Stream, Group, and SOA, $F(4,156) = 7.52$, $p < .001$,

[1] Jefferies and Di Lollo (2009, Experiment 3) compared a condition in which the duration of the stimulus and the blank ISI was proportional, as in the present experiment, with a condition in which stimulus duration was fixed and the blank ISI was varied, depending on the SOA. No differences were found in the patterns of results obtained in the two conditions.

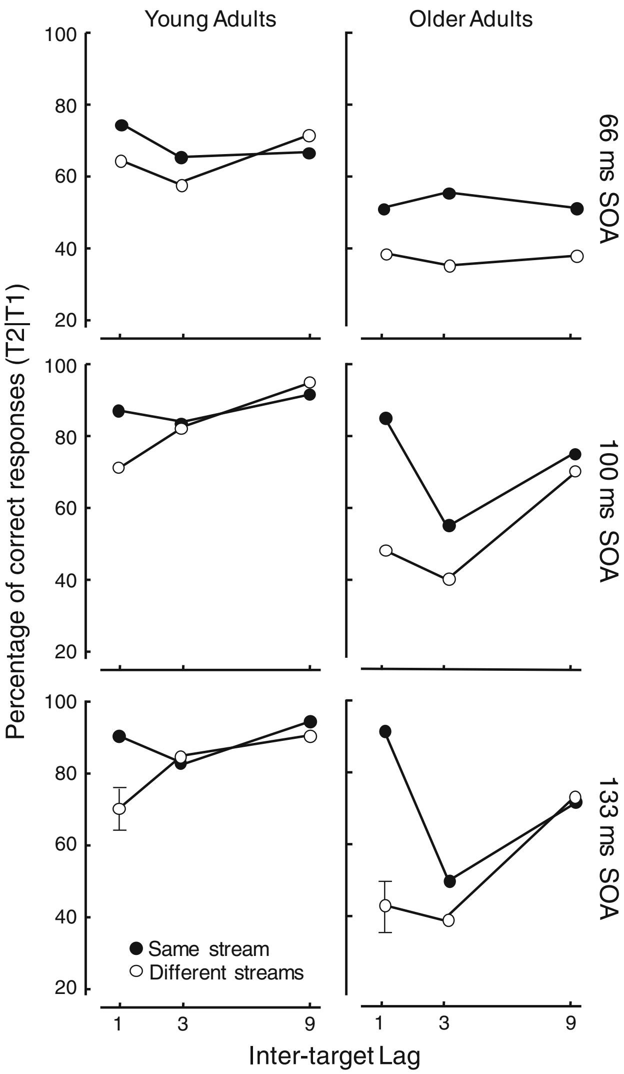

Fig. 3 Mean percentages of correct identifications of the second target in Experiment 1. Data are plotted separately for the Young and Older adults at each SOA. The *filled circles* represent data from trials in which the targets were presented in the Same-stream; *open circles* represent data from trials in which the targets were presented in Different-streams. The *error bars* represents the average standard error of the mean for the Young and Older adults, respectively

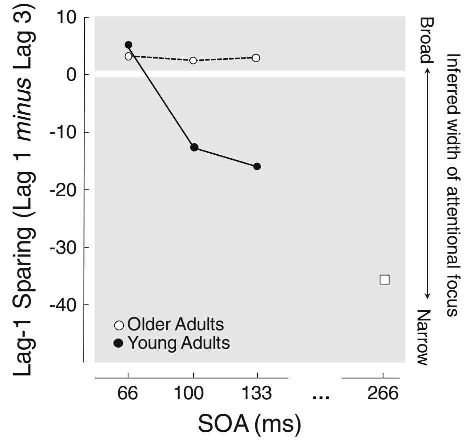

Fig. 4 Variation in the magnitude of Lag-1 sparing (*positive values*) and Lag-1 deficit (*negative values*) as a function of SOA. The *filled symbols* represent data from the young adults; the *open symbols* represent data from the older adults. The *square symbol* represents the results of Experiment 2

$\eta_p^2 = .163$. It is worth noting that accuracy is not a linear scale and that the young adults and the older adults differ in overall level of accuracy. As confirmation of the effects reported in the overall repeated-measures ANOVA, therefore, we repeated the analysis with arcsine-transformed data. All the significant results were confirmed, with two additional interactions now being significant: SOA × Group, $F(2,78) = 3.82$, $p = .026$, $\eta_p^2 = .089$, and SOA × Stream, $F(2,78) = 3.122$, $p = .05$, $\eta_p^2 = .074$.

Interpretation of the significant four-way interaction is complicated and requires further analyses. As noted in the introduction of Experiment 1, not all levels of the four factors included in the overall ANOVA are relevant to the objective of the present experiment. The relevant data are those for Lags 1 and 3 in the Different-Stream condition at each SOA. Before proceeding to analyze only the data for Lags 1 and 3, we repeated the overall ANOVA just described while excluding the data for Lag 9. That is, the data were analyzed in a 3 (SOA: 66, 100, and 133 ms) × 2 (Lag: 1, 3) × 2 (Stream: Same, Different) × 2 (Group: Young adults, Older adults) ANOVA, with Group as a between-subjects factor. The analysis revealed significant main effects of SOA, $F(2,78) = 44.72$, $p < .001$, $\eta_p^2 = .534$, Stream, $F(1,39) = 107.03$, $p < .001$, $\eta_p^2 = .733$, Lag, $F(1,39) = 14.33$, $p = .001$, $\eta_p^2 = .269$, and Group, $F(1,39) = 58.91$, $p < .001$, $\eta_p^2 = .602$. The following interactions were also significant: Stream × Group, $F(1,39) = 26.19$, $p < .001$, $\eta_p^2 = .40$, Lag × Group, $F(1,39) = 15.08$, $p < .001$, $\eta_p^2 = .279$, SOA × Stream, $F(2,78) = 3.95$, $p = .023$, $\eta_p^2 = .092$, Stream × Lag, $F(1,39) = 36.75$, $p < .001$, $\eta_p^2 = .485$, SOA × Stream × Group, $F(2,78) = 5.0$, $p < .01$, $\eta_p^2 = .114$, SOA × Lag × Group, $F(2,78) = 18.85$, $p < .001$, $\eta_p^2 = .326$, and SOA × Stream × Lag, $F(2,78) = 15.29$, $p < .001$, $\eta_p^2 = .282$. The four-way interaction among Lag, Stream, Group, and SOA was marginally significant, $F(2,78) = 2.86$, $p = .064$, $\eta_p^2 = .068$. On the grounds that the results of the omnibus analyses with and without Lag 9 were quite comparable, we proceeded to analyze performance only at Lags 1 and 3.

Differences between Lags 1 and 3 are difficult to compare across SOAs in Fig. 3; to simplify the comparisons, we calculated the difference between T2 accuracy at Lag 1 and Lag 3: a positive difference indexes the magnitude of Lag-1 sparing and a negative difference indexes the magnitude of Lag-1 deficit. Those values are illustrated in

Fig. 4, and were analyzed in a 2 (Group: Young Adults, Older Adults) × 3 (SOA: 66, 100, 133 ms) ANOVA. The analysis revealed a significant effect of Group, $F(1, 39) = 8.52$, $p < .01$, $\eta_p^2 = .179$. Critically, the Group × SOA interaction was significant, $F(2, 78) = 3.86$, $p = .025$, $\eta_p^2 = .09$, indicating that the progression from Lag-1 sparing to Lag-1 deficit across SOAs differed for young and older adults.

Figure 4 plots the magnitude of Lag-1 sparing (positive values) and Lag-1 deficit (negative values) for the two age groups. At a first approximation, the pattern resembles that in Fig. 2c. This is especially the case for the younger observers for whom the Lag-1 sparing at an SOA of 66 ms turns into Lag-1 deficit at the two longer SOAs. This result is consistent with a relatively rapid narrowing of the focus of attention which is well underway by 100 ms after the presentation of the first target. The rapid narrowing and corresponding withdrawal of attention from the opposite stream is illustrated in Fig. 2a, c: at the shortest SOA the focus of attention is still broad, T2 is attended, and Lag-1 sparing ensues; in contrast, at the longest SOA, the focus of attention has contracted to the T1 stream, T2 is unattended, and Lag-1 deficit ensues. These results closely match those reported by Jefferies and Di Lollo (2009), and provide a replication and confirmation of their findings with young adults.

A very different pattern emerges from the results of the older adults. In this case, Lag-1 sparing continues to be in evidence at every SOA. This suggests that the focus of attention in older adults remains broad even after 133 ms from the onset of the first target. With reference to Fig. 2b, c, this could mean either that the change in the spatial extent of attention is very slow or that no change at all occurs over the first 133 ms.

One interpretation of this finding is that the older adults experience a delay before initiating the process of narrowing attention to the location of the first target, but once the process of narrowing is initiated, it occurs at approximately the same rate as for younger observers. This interpretation meshes neatly with the endogenous cueing results reported by Folk and Hoyer (1992), who found that older adults were slower at extracting meaning information from a central cue, but the process of shifting attention was unimpaired once the meaning was extracted. Comparably, older adults in the present experiment may have been slower than younger adults at extracting the target letter from the stream of digit distractors, causing them to be delayed in narrowing the focus of attention to the location of the first target. However, this conjecture cannot be verified from the results of Experiment 1 because, at the SOAs tested, the process of narrowing had not yet begun (Fig. 4, open symbols). To determine if older adults are delayed in initiating the narrowing process, and that they are in fact able to narrow the focus of attention to the location of the first target, a longer SOA must be tested. This was done in Experiment 2.

Experiment 2

In Experiment 2 we tested older adults with a longer SOA of 266 ms. We expected that with this additional 133 ms in which to narrow the focus of attention to the location of the first target, older adults would exhibit a Lag-1 deficit similar to that exhibited by younger adults at shorter SOAs.

Participants

Twenty older adults (mean age 68.35 years, SD 4.68) participated in the experiment. They were recruited and screened as in Experiment 1, but none had participated in that experiment.

Stimuli and procedure

The stimuli and procedure were identical to those in Experiment 1 with two exceptions. First, only a single SOA of 266 ms was tested. Second, we did not use a young adult comparison group because second-target identification accuracy with such a long SOA would be at ceiling at all lags.

Results and discussion

First-target accuracy

First-target accuracy was similar to that of the older participants in Experiment 1. Averaged across observers, Same/Different streams, and Lag, T1 accuracy was 71.7 %.

Second-target accuracy

The results of Experiment 2 indicated that older adults do narrow the focus of attention to the first-target stream, but that it takes them longer than younger participants to do so. This conclusion was based on the following statistical analyses.

Figure 5 illustrates the percentage of correct T2 responses as a function of Stream and Lag, which shows a large Lag-1 deficit in Different-streams trials but none in Same-stream trials. This was confirmed by a 2 (Stream: Same, Different) × 3 (Lag: 1, 3, 9) within-subject ANOVA conducted on the data illustrated in Fig. 5. The analysis revealed significant effects of Lag, $F(2,38) = 46.86$, $p < .001$, $\eta_p^2 = .711$, and Stream, $F(1,19) = 45.34$, $p < .001$, $\eta_p^2 = .71$. The interaction was also significant, $F(2,38) = 40.0$, $p < .001$, $\eta_p^2 = .678$.

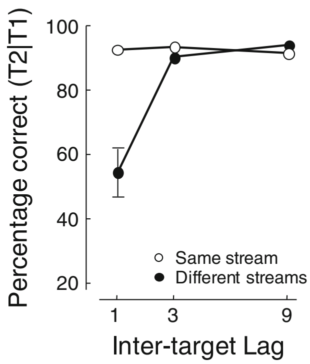

Fig. 5 Mean percentages of correct identifications of the second target in Experiment 2. The *filled circles* represent data from trials in which the targets were presented in the Same-stream; *open circles* represent data from trials in which the targets were presented in Different-streams. The *error bar* represents the average standard error of the mean

The difference between T2 accuracy in the Lag 1 and Lag 3 conditions is an index of the magnitude of a Lag-1 deficit or a Lag-1 sparing. In Experiment 1, young adults showed a rapid change from Lag-1 sparing to Lag-1 deficit as a function of increasing SOA, consistent with a rapidly narrowing focus of attention, but the pattern of results for older adults was consistent with a focus of attention that did not begin to narrow for at least the first 133 ms (Fig. 4). However, in the present experiment, which used a longer SOA (266 ms), older adults exhibited a large Lag-1 deficit, which is consistent with the idea that they narrowed the focus of attention to the T1 stream.

Considered together, the results of Experiments 1 and 2 suggest that older adults are relatively slow at disengaging attention and initiating the process that narrows attention to the target location. However, given sufficient time older adults do narrow the focus of attention to the appropriate location, as evidenced by the finding that they exhibited Lag-1 deficit of approximately the same magnitude as the younger adults. As has been shown by Posner, Walker, Friedrich, and Rafal (1984), the processes of disengaging attention and shifting it to another location are independent from one another. It is thus plausible that older observers may be impaired in disengaging but not in narrowing the focus of attention.

Experiment 3

In Experiments 1 and 2, the differences in the results of young and older observers were ascribed to the rate of narrowing the spatial focus of attention. In the present experiment we consider the possibility that peripheral factors—namely, optical changes associated with ageing—may also have played a role. It is known that there is an average .5 log-unit reduction in retinal illuminance by the age of 60 (Weale, 1961, 1963). Of this loss, it has been estimated that increased opacity of the lens and the clouding of the vitreous humour account for approximately .2 log units and the reduced dilation capability of the pupil for the .3 log unit balance (Elliott et al., 1990). This decrease in retinal illuminance means that any given visual stimulus is seen as dimmer by older eyes. The objective of Experiment 3 was to rule out this peripheral, optical change as the causal factor underlying the pattern of results in Experiments 1 and 2. Eliminating optical factors allows us to be confident that the observed pattern of results is not simply due to changes in the eye, but rather to changes in attentional processes.

Experiment 3 controlled for age-related optical loss by presenting the stimuli to a group of young adults under conditions that simulate the reduction in retinal illuminance associated with ageing. This was accomplished by covering the computer monitor with a neutral-density filter that reduced retinal illuminance in young adults by .5 log units, matching the average known .5 log unit decline experienced by older adults. If the results for young adults viewing displays through this filter are similar to those obtained from the young adults in Experiment 1, we can conclude that age-related changes in retinal illuminance did not contribute significantly to the differences between young and older adults obtained in that experiment. Alternatively, if the results are similar to those of the older adults in Experiment 1, we can conclude that differences in retinal illuminance account for the observed age-dependent differences in Experiment 1.

It is important to clarify that the decrease in retinal illuminance produced by a .5 log-unit decrease in display luminance, and the consequent dimming of the visual stimulus, is known to strongly effect low-level visual processes such as visible persistence (Coltheart & Arthur, 1971; Di Lollo, 1984; Eriksen & Rohrbaugh, 1970; see also Coltheart, 1980) and to slow reaction times for detecting the onset of stimuli (Rains, 1963). It is also known to have no effect on higher-level processes such as letter identification (Eriksen & Rohrbaugh, 1970). We therefore expect to see no effect of the filter on the AB per se; that is, no effect on overall identification accuracy of either the first or the second target. We are instead interested in whether the narrowing of focal attention, as indexed by the changes in the magnitude of Lag-1 sparing across SOA, is influenced by a decrease in retinal illuminance.

Participants

Seventeen undergraduate students (mean age 22.06 years, SD 3.51) from McMaster University participated in Experiment 3 for course credit.

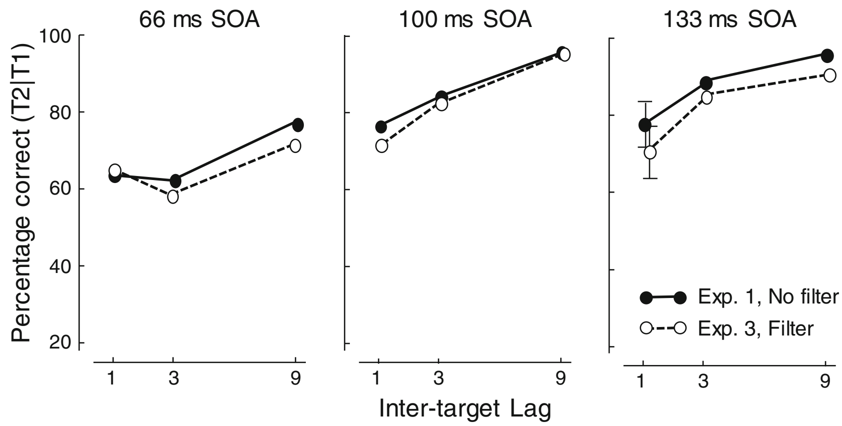

Fig. 6 Mean percentages of correct identifications of the second target in the Different-Stream condition at each SOA. The *segmented lines* represent data from Experiment 3 (filter); the *solid lines* represent data from the young adults in Experiment 1 (no filter). The *error bar* represents the average standard error of the mean in Experiments 1 (no filter) and 3 (filter), respectively

Stimuli and procedure

The stimuli and procedure were identical to those of Experiment 1 except that neutral density filters were placed in front of the monitors. These filters reduced the luminance of the display by .5 log units, but left contrast unchanged.

Results and discussion

First-target accuracy

Averaged across observers, Lag, and Same/Different streams, identification accuracy for T1 was 74.5, 92.3, and 92.5 % for SOAs of 66, 100, and 133 ms, respectively. As expected, first-target accuracy in this experiment closely matches that of the young adults in Experiment 1, consistent with previous studies showing no effect of changes in retinal illuminance on letter identification accuracy (Eriksen & Rohrbaugh, 1970).

Second-target accuracy

As noted above, only the data from the Different-streams condition are relevant for assessing the rate of attentional focusing. In order to optimize the visual comparison between the results of the young adults with and without the ½ log-unit neutral density filter (Experiments 1 and 3), therefore, only the Different-Stream data have been plotted in Fig. 6. Further, the data for both experiments have been superimposed on a single graph for each SOA. The segmented lines represent the data from Experiment 3 (filter); the solid lines represent the young adult data from Experiment 1 (no filter). It is clear from Fig. 6 that the results of Experiment 3 (filter; segmented lines) match closely the results from Experiment 1 (no filter; solid lines), strongly suggesting that reducing luminance did not materially alter the pattern of results. In other words, simulating the reduction in retinal illuminance associated with ageing did not account for the differences observed between young and older adults in the previous experiments. This conclusion was based on the following analyses.

The results in Fig. 6 were analyzed in a 2 (Experiment: filter, no-filter) × 3 (SOA: 66, 100, 133) × 2 (Stream: Same, Different) × 3 (Lag: 1, 3, 9) ANOVA. The analysis revealed significant main effects of SOA, $F(2,66) = 190.77$, $p < .001$, $\eta_p^2 = .853$, Stream, $F(1,33) = 32.05$, $p < .001$, $\eta_p^2 = .493$, and Lag, $F(2,66) = 39.71$, $p < .001$, $\eta_p^2 = .546$. The main effect of Experiment (filter, no-filter) was not significant, $F(1,33) = 1.3$, $p = .245$. There were significant two-way interactions between SOA and Lag, $F(4,132) = 5.20$, $p = .001$, $\eta_p^2 = .136$, and Lag and Stream, $F(2,66) = 35.06$, $p < .001$, $\eta_p^2 = .515$. There was also a significant three-way interaction among SOA, Stream, and Lag, $F(4,132) = 2,64$, $p = .037$. Notably, neither the main effect of Experiment (filter, no-filter) nor any of the interactions involving Experiment were significant.

These results demonstrate that reductions in retinal illuminance associated with ageing were not a significant determinant of the differences observed between young and older adults in the narrowing of focal attention in Experiment 1. It seems clear, therefore, that the age differences found in Experiment 1 were due to changes in high-level attentional processing that occur as a function of age rather than to changes in peripheral input.

General discussion

The principal objective of the present work was to examine age-related differences in the time course of attentional focusing. To this end, we employed an AB paradigm with two concurrent RSVP streams, one on either side of fixation, in which two letter targets appeared unpredictably in the Same-stream or in opposite streams. We built on the fact that Lag-1 sparing occurs only if the second target falls within the focus of attention; otherwise, Lag-1 deficit occurs. Because the first target occurred unpredictably in either stream, we reasoned that the observer would initially employ a broad focus of attention to encompass both streams. Once the first target appeared, the focus of attention should narrow to the stream containing the first target while withdrawing from the opposite stream. Therefore, on trials in which the second target appears in the opposite stream, the magnitude of Lag-1 sparing or Lag-1 deficit would depend on the rate at which the focus of attention contracts. Fast rates of contraction would result in the second target falling outside the focus of attention relatively quickly, causing a rapid decrement in the magnitude of Lag-1 sparing and the emergence of Lag-1 deficit.

In Experiment 1 we varied the SOA between successive items in the RSVP stream and indexed the magnitude of Lag-1 sparing by subtracting accuracy of T2 identification at Lag 3 from that at Lag 1. Using this measure, it was possible to track the change from Lag-1 sparing (indicative of a broad spatial focus of attention) to Lag-1 deficit (indicative of a narrow focus) across SOAs, as shown in Fig. 4. Differences in the slope of this function indicate differences in the rate at which the focus of attention narrows. The main finding in Experiment 1 was that the rate of narrowing was faster in young than in older adults. In fact, unlike younger adults, older adults showed no evidence of narrowing within a period of 133 ms. Experiment 2 showed that older adults can indeed narrow the focus of attention if that period is increased to 266 ms. Experiment 3 ruled out the option that the differences between young and older observers seen in Experiment 1 arose from age-related reductions in retinal illuminance, pointing instead to central attentional factors.

Considered collectively, the results indicate that older adults exhibit a marked delay in initiating the attentional narrowing process, presumably due to a delay in the disengagement of attention from the first target. This delay in disengagement is consistent with the hypothesis that any attentional impairments that appear with normal ageing are not due to impairments in the attentional mechanisms per se, but rather to longer-lasting capture of attentional resources (see Lien, Gemperle, & Ruthruff, 2011). It has been shown, for example, that inhibition-of-return is delayed, but not abolished with increasing age (Castel et al., 2003) and that disengagement from attentional capture is delayed but not impaired in older adults (Cashdollar et al., 2013). The present results dovetail with these previous findings.

The present finding that older adults are delayed in disengaging attention can also be related to age-dependent changes in the cortical networks that mediate the temporal dynamics of attention. Posner and colleagues (Posner & Cohen, 1984; Posner & Petersen, 1989; Posner & Raichle, 1994) have examined the neurophysiological correlates of the three steps in attentional shifting: disengage, move, and engage. Most pertinent to the present work is the finding that the disengage operation is governed primarily by networks in posterior parietal cortex. As noted in the introduction, a reduction in grey matter volume and in cerebral blood flow to posterior parietal cortex is one of the hallmarks of normal cognitive ageing (Bentourkia et al., 2000; Good et al., 2001; Kalpouzos et al., 2009; Martin et al., 1991). Our findings that older adults are slower at disengaging attention are in line with these neurophysiological findings.

Two leading hypotheses have been advanced to account for age-related cognitive deficits. One is the *processing-speed hypothesis*, which postulates a general slowing in the rate of information processing as a function of age (e.g., Salthouse, 1985). Although this hypothesis has been questioned recently and there is evidence that the slowing might not be as general as once supposed (e.g., Lima, Hale, & Myerson, 1991; Yordanova, Kolev, Hohnsbein, & Falkenstein, 2004), there is still clear evidence of slowing in a variety of cognitive tasks and the hypothesis remains viable (e.g., Bugg et al., 2007). The other is the *inhibitory deficit hypothesis*, which posits that an age-related reduction in the ability to suppress task-irrelevant information is a core deficit that causes changes to many cognitive abilities (e.g., Hasher & Zacks, 1988; Kane, Hasher, Stoltzfus, Zacks, & Conelly, 1994).

According to the processing-speed hypothesis, the relatively slow transition from Lag-1 sparing to Lag-1 deficit in the older adults (Fig. 4) could have arisen from slower processing at any or all steps involved in narrowing the focus of attention: identifying the first target (necessary for triggering the next two steps), disengaging attention from the opposite stream, and narrowing the focus of attention to the location of the first target. Because slowing at any of these steps would cause the focus of attention to remain broad for a longer period of time, the second target would appear at an attended location for a correspondingly longer period; thus Lag-1 sparing would occur over longer SOAs. The inhibitory-deficit hypothesis makes the same predictions for different reasons: older adults showed a slower transition from Lag-1 sparing to Lag-1 deficit because they were less able to suppress the irrelevant distractor that appeared in the opposite stream at the same time as the first target. Since attention was not withdrawn as readily from that distractor, the focus of attention remained broad, resulting in the second target appearing at an attended location.

Given its focus on the temporal characteristics of attentional focusing, the present work does not distinguish between these alternatives. Both hypotheses can account for the main finding that older adults are slower in disengaging attention and/or initiating attentional narrowing. Although the processing-speed and the inhibitory-deficit hypotheses have been regarded as competing with one another (Salthouse, 1996), more recent work has shown that slower processing and impaired inhibition may act concurrently (Gazzaley et al., 2008). The present results are also consistent with this hypothesis.

The attentional blink

The goal of the present research was to examine how the dynamics of attentional focusing differ in younger and older adults. To that end, we employed an AB paradigm that provides a sensitive way of tracking changes to the breadth of focused attention over space and over time. Although not the focus of this research, the source of the AB itself is worth a brief consideration, especially as it pertains to older adults. Previous research has shown that the magnitude of the AB increases with age (e.g., Lahar, Isaak, & McArthur, 2001; Lee & Hsieh, 2009; Georgiou-Karistianis et al., 2007; Maciokas & Crognale, 2003). To determine whether the same was true in the present work, we selected the conditions in our study that most closely matched those in the earlier studies, specifically, the Same-stream condition at 100-ms SOA, and compared the magnitude of the AB in young and older adults. We defined the magnitude of the AB as the difference between second-target accuracy at Lags 3 and 9 on those trials in which T1 was identified accurately (see Georgiou-Karistianis et al., 2007). A 2 (Lag: 3, 9) × 2 (Age: Young Adults, Older Adults) ANOVA revealed significant effects of Lag, $F(1,39) = 32.56$, $p < .001$, $\eta_p^2 = .455$, and Age, $F(1,39) = 27.56$, $p < .001$, $\eta_p^2 = .413$. Importantly, the interaction effect was also significant, $F(1,39) = 7.43$, $p = .01$, $\eta_p^2 = .160$. This confirms the graphical evidence in the two middle panels in Fig. 3 (filled symbols) that the magnitude of the AB (Lag 9 − Lag 3) was greater in older adults than younger adults. Although this result is consistent with the earlier findings, it must be noted that the measure of second-target accuracy in younger adults was constrained by a ceiling imposed by the 100 % limit of the response scale. This ceiling effect therefore might have resulted in an underestimation of the AB magnitude in younger observers.

Hemifield effects

Recent work by Verleger et al., (2009) examined visual hemifield effects in a dual-stream AB paradigm. They presented two RSVP streams, one in each visual field, and found that the second target was identified more accurately when it appeared in the left visual field. The authors attributed this improved T2 accuracy to the fact that the right hemisphere is better able to single out targets that are presented rapidly in time. Since the paradigm used in the present research closely matches that employed by Verleger et al., (2009) we tested for hemifield effects in our data, both to provide confirmation of Verleger et al.'s findings and to determine whether hemifield effects differ between young and older adults.

We considered those trials from Experiment 1 in which the first and second targets appeared in Different-streams. As expected, there was a hemifield effect: in both age groups, response accuracy was higher when the second target appeared in the left visual field. The hemifield effect was evident at all SOAs, although it was most pronounced at an SOA of 66 ms. The average difference between second-target accuracy in the left and right hemifields for young adults was 19.7, 8.1, and 8 % at SOAs of 66, 100, and 133 ms, respectively. The corresponding hemifield effects for older adults were 19.2, 10.3, and 7.1 %, for SOAs of 66, 100, and 133 ms, respectively. These findings confirm the report by Verleger et al. (2009) that targets presented in RSVP are identified better in the left visual field. Furthermore, this effect appears to remain intact for older adults, strongly suggesting that the right hemisphere maintains its advantage in terms of the temporal precision required to extract items presented in rapid sequence.

Concluding comments

The present study shows that reflexive narrowing of the spatial focus of attention, to identify a briefly presented stimulus, is delayed in normal cognitive ageing. In particular, our findings indicate that older adults show a marked delay in initiating the focusing process, presumably due to a delay in attentional disengagement from a previously attended stimulus. Given sufficient time, however, older adults are able to fully narrow the focus of attention. In future studies it may be important to pursue the possibility that changes in attentional focus are influenced by decision criteria. Recent studies have reported, for instance, that the tendency for older adults to respond more slowly on identification tasks is accompanied by an increase in accuracy (Falkenstein, Hoormann, & Hohnsbeing, 2001; Hoffmann & Falkenstein, 2011; Wild-Wall, Falkenstein, & Hohnsbein, 2008). Whether the dynamics of attentional focusing is also subject to such decisional biases is an important issue that remains to be investigated.

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