The Influence of Perceptual Load on Age Differences in Selective Attention

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The effect of perceptual load on age differences in visual selective attention was examined in 2 studies. In Experiment 1, younger and older adults made speeded choice responses indicating which of 2 target letters was present in a relevant set of letters in the center of the display while they attempted to ignore an irrelevant distractor in the periphery. The perceptual load of relevant processing was manipulated by varying the central set size. When the relevant set size was small, the adverse effect of an incompatible distractor was much greater for the older participants than for the younger ones. However, with larger relevant set sizes, this was no longer the case, with the distractor effect decreasing for older participants at lower levels of perceptual load than for younger ones. In Experiment 2, older adults were tested with the empty locations in the central set either unmarked (as in Experiment 1) or marked by small circles to form a group of 6 items irrespective of set size; the 2 conditions did not differ markedly, ruling out an explanation based entirely on perceptual grouping.

Efficient performance in cognitive tasks sometimes requires allocating attention to several sources of information or tasks. This crucially depends on the ability to divide attention between the different sources or tasks and is limited by the available attentional capacity. If the overall amount of information in the tasks exceeds available capacity, a cost in performance is typically observed. In other cases, attention has to be focused on just one source of information to allow the selective processing of goal-relevant information while avoiding any intrusions from irrelevant and potentially distracting information. Aging seems to involve a decline in focused as well as divided attention; however, the exact nature of the age-related deficit in attention remains unclear for both attentional functions (as we review shortly). In this article, we attempt to shed further light on the aging of attention by testing implications for aging of a recent proposal (e.g., Lavie, 1995) that efficient selective attention performance and the successful rejection of distractors crucially depend on capacity limits in the allocation of attention to relevant sources of information (as typically studied in the literature on divided attention).

We begin by briefly reviewing the evidence for age-related decline in attention. Divided attention is necessary when two or more tasks are carried out simultaneously or when two or more sources of information are monitored for targets. The difference between the performance of younger and older adults is usually greater under such dual-task conditions than under control (single-task) conditions (see Madden & Plude, 1993, for a summary). However, older adults appear to be no worse at performing two tasks simultaneously than would be expected on the basis of an overall increase in task complexity (McDowd & Craik, 1988; Somberg & Salthouse, 1982). In other words, the evidence is consistent with a general reduction in processing resources with aging rather than with a specific impairment in the ability to divide attention.

A similar issue is raised in the focused-attention literature. Here, the task is to focus on goal-relevant (target) information in the environment and to ignore goal-irrelevant (distractor) information. It has long been assumed that there is an age-related impairment in the ability to select or focus on a single input in the presence of competing inputs (see reviews by Hartley, 1992; McDowd & Birren, 1990). Evidence for this comes from a number of paradigms, including visual search tasks (e.g., Plude & Doussard-Roosevelt, 1989; Rabbitt, 1965), the Stroop task (e.g., Cohn, Dustman, & Bradford, 1984), and response competition tasks (see Hahn & Kramer, 1995, for a summary). For example, Rabbitt (1965) asked younger and older adults to sort cards according to which of two target letters was displayed on each card. Scoring times increased with the number of irrelevant letters also present (zero to eight), and this effect was significantly greater for older than for younger adults (see Sci-alfa & Joffe, 1997, for a recent review). Cohn et al. (1984) obtained a similar finding using the Stroop paradigm (i.e., the interference from incongruent words on color-naming times was larger for older than for younger adults).

The visual search and Stroop results were originally interpreted as evidence of a specific age-related deficit in the ability to...
ignore irrelevant information. More recently, failures to ignore irrelevant information have been attributed to an age-related decline in the efficiency of inhibitory processes within the context of a theoretical framework developed by Hasher and Zacks (1988). Evidence in support of this view comes from a number of tasks, such as studies of text processing in which the reading times of older adults are slowed more than those of younger adults by the presence of distracting material (Connelly, Hasher, & Zacks, 1991; Dywan & Murphy, 1996). Similarly, McDowd and Filion (1992) asked participants to listen to an auditorily presented story while either ignoring or attending to a series of tones. The magnitude of the skin conductance orienting response was reduced in the “ignore” condition relative to the “attend” condition, but this effect was greater for younger than for older adults. Such results are consistent with an age-related decline in the use of inhibitory mechanisms to prevent irrelevant information from entering working memory. Further support for Hasher and Zacks’s hypothesis comes from a number of studies demonstrating reduced negative priming effects in responses to targets that appeared as distractors on the previous trial (e.g., Hasher, Stoltzfus, Zacks, & Rypma, 1991; Kane, Hasher, Stoltzfus, Zacks, & Connelly, 1994; McDowd & Oseas-Kreger, 1991; Stoltzfus, Hasher, Zacks, Ulivi, & Goldstein, 1993; but see also Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Schooler, Neumann, Caplan, & Roberts, 1997; and Sullivan & Faust, 1993; for evidence of age-related equivalence in negative priming).

In both the visual search and Stroop cases, however, there is the possibility of a more general explanation, namely, age-related slowing (Cerella, 1985b; Cerella & Hale, 1994; Salthouse, 1996). The generalized slowing hypothesis of aging states that any manipulation that results in an increase in the response times (RTs) of younger adults will produce a larger increase in the RTs of older adults. It is often addressed by plotting the mean RTs for younger adults against the corresponding mean RTs for older adults across different experimental conditions, a method originally suggested by Bbrinley (1965). The usual result is a highly linear function with a slope greater than one, suggesting that the performance of older adults can be predicted from that of younger adults with high accuracy simply by multiplying their RTs by a constant slowing factor without regard for the particular condition. For example, a recent meta-analysis of data from Stroop tasks showed that a single Brinley plot with a slope of 1.9 provided a close fit to the data from both baseline and interference conditions, suggesting that the apparent age-sensitivity of the Stroop interference effect appears to be merely an artifact of general slowing (Verhaeghen & De Meersman, 1998).

The response competition paradigm is a variant of Stroop originally developed by Eriksen and Eriksen (1974). Participants are required to make a speeded choice response to a relevant target (say x vs. z) and to ignore irrelevant distractors that may flank the target on either side. These distractors may be compatible (a same-target letter), incompatible (an opposite-target letter), or neutral (a letter with no response association) with respect to the target. A failure to ignore the distractors typically results in slower RTs in the incompatible condition than in the neutral and compatible conditions. Several studies of age differences using this paradigm have shown that older participants suffer greater interference from an incompatible distractor (as indexed by a greater slowing of their RTs) than younger participants (e.g., Farkas & Hoyer, 1980; Harpur, Scialfa, & Thomas, 1995; Scialfa & Kline, 1988; Shaw, 1991). Such results converge with previous results from visual search and Stroop tasks to suggest an age-related decline in the efficiency of distractor suppression.

However, results showing little difference in the response competition paradigm between distractor effects for younger and older adults have also been reported (e.g., Hahn & Kramer, 1995; Kramer et al., 1994; Experiment 1 of Madden & Gotlob, 1997; Wright & Elias, 1979). In some of the conditions, the failure to find a difference in distraction with age could be attributed to age-related changes in peripheral acuity. Thus, the susceptibility to distraction in elderly participants may have been modulated by their reduced ability to clearly see the peripheral distractors (see Cerella, 1985a; Kline & Scialfa, 1996). This could also be related to evidence from the divided-attention literature for a reduction with aging in the useful field of view (UFOV; i.e., the spatial extent of the visual area that can be processed in parallel; Ball, Beard, Roenker, Miller, & Griggs, 1988; Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Scialfa, Kline, & Lyman, 1987). However, some of the failures to find greater distractor effects with age in the focused-attention situation have been reported in studies using foveal distractors (e.g., Hahn & Kramer, 1995; Kramer et al., 1994).

Moreover, as with the visual search and Stroop data, some of the previously discussed evidence for larger distractor effects in elderly participants in the response competition paradigm could be interpreted in terms of generalized slowing (see Cerella, 1985b; Cerella & Hale, 1994; Salthouse, 1996). In many cases, the age differences disappear when overall slowing is taken into account, for example, by considering RT differences as proportions of baseline RTs. In other words, the larger distractor effects in older adults may yet pertain to a similar proportion of their baseline RTs, which are typically slower than for younger adults. In such cases, it may not be necessary to invoke attentional mechanisms to explain the results. Thus, the main question of whether there is an age-related decline in selective attention, and specifically in the ability to ignore irrelevant distractors, remains open.

In this article, we propose that one major factor determining the occurrence of age differences in selective attention is the perceptual load involved in the relevant task. Our proposal arises from a recent model for selective processing by Lavie (1995; Lavie & Tsal, 1994). In her model, Lavie applied a limited-capacity approach (previously used in accounts of divided-attention tasks) to explain focused-attention situations, which are characterized by the requirement to ignore irrelevant information, as in the response competition paradigm described earlier. Perceptual processing is regarded as automatic (in the sense that it cannot voluntarily be prevented) but with limited capacity. Thus, processing proceeds from potentially relevant items to irrelevant items as long as there is attentional capacity available. Only when the relevant information exhausts or exceeds capacity can the processing of irrelevant items be prevented.

The relevant perceptual load is therefore proposed as the major determinant of selective attention. High perceptual load that consumes full capacity results in selective perception. Low perceptual load leaves spare capacity to spill over to the processing...
of irrelevant information, thus resulting in nonselective perception. A review of selective attention studies in young adults (Lavie & Tsal, 1994) supported this model; selective perception was typically found in experimental situations with high loads, whereas studies with low loads typically reported nonselective perception. This confirmed the role of perceptual load in selective attention and provided a resolution to the long-standing early- versus late-selection debate on whether perception can be selective.

More direct empirical support for this model has since been provided by a set of studies in which perceptual load was manipulated in several ways (Lavie, 1995; Lavie & Cox, 1997). These included varying the number of items relevant for processing or varying processing requirements for identical displays (e.g., simple detection of a character’s presence vs. difficult identification of its size and position or feature vs. conjunction tasks; cf. Treisman & Gelade, 1980). Interference from an irrelevant distractor was obtained under all conditions of low load, whereas the high load conditions consistently eliminated such interference.

Applying the perceptual load hypothesis to the study of age differences in selective attention led us to the following predictions. Studies of age differences in divided attention demonstrate reduced cognitive capacity in old age (see reviews by Hartley, 1992; Madden & Plude, 1993; Salthouse, 1991, 1992). We therefore expected that the capacity of older adults would be exhausted by lower levels of perceptual load than those required to exhaust the capacity of younger adults. This led us to predicting that smaller increases in perceptual load of relevant processing should be required for reducing distractor processing in older than younger adults because their capacity should be exhausted by lower levels of load as compared with those required to exhaust the capacity of younger adults. Under conditions of low perceptual load, we anticipated that older adults would suffer from distractor effects because we did not expect differences in capacity limits between younger and older adults to emerge in situations that imposed no or little demand on capacity as in cases of no load or a low level of load (e.g., with just one or two items relevant for processing). In fact, from both the reduced inhibition hypothesis (Hasher & Zacks, 1988) and the generalized slowing hypothesis (e.g., Cerella, 1985b) of aging, we predicted larger distractor effects for older than for younger adults at low levels of load. Note, however, that our prediction crucially concerns the more rapid reduction in the distractor effect for older than for younger adults with smaller increases in relevant processing load. Thus, although the efficiency of selective attention may be reduced with aging at low loads, apparent improvement in distractor suppression should be more pronounced for older adults than for younger adults as load is increased.

**Experiment 1**

To test the effect of perceptual load on age differences in the extent of distraction, we devised a variation of the response competition task that included a manipulation of perceptual load in the relevant processing. Participants were required to make a fast and accurate choice response to either an X or an N target that was presented in 1 of 12 possible positions arranged in a circle at the center of the display. Perceptual load in target processing was manipulated by varying the number of nontargets in the circle. The target could appear alone (relevant Set Size 1) or with one, three, or five nontarget letters to give relevant set sizes of two, four, and six, respectively. The nontarget letters were chosen from the set of Z, K, H, Y, and V, which had no response association in the task. Each display also contained an additional critical distractor presented in an irrelevant position to the left or right of the center (see Figure 1 for examples of stimuli). This distractor was equally likely to be incompatible (the distractor letter X for an N target or vice versa) or neutral (the letter T or L) with respect to the target response. Participants were emphatically instructed to ignore this irrelevant distractor throughout. Our main interest was in the interaction of perceptual load with the distractor compatibility effect and in whether this interaction would differ between younger and older participants.

**Method**

**Participants.** There were 16 younger participants (aged 19–30 years) and 16 older participants (aged 65–79 years). Some of the younger group and all of the older group were members of the volunteer panel at the Medical Research Council's Applied Psychology Unit (Cambridge, England). The remaining younger participants were recruited either through the university or through the local job center. The data from 2 participants (1 in each age group) were not included in the analyses because their error rates were more than 2.5 SDs greater than the mean for their age group. The mean ages for the remaining 15 participants in each group were 22.7 (SD = 2.7) and 73.0 (SD = 3.7) years. Vocabulary data from the multiple-choice section of the Mill Hill Vocabulary Scale (MHVS; Raven, Raven, & Court, 1988) were available for 8 of the younger participants (all university students) and all of the

![Figure 1. Examples of the displays used in Experiment 1 for relevant set sizes of 1, 2, 4, and 6 (A–D). In each case, the target letter is N with an incompatible distractor (X).](image-url)
older participants. As is often the case, the younger group had significantly lower scores than the older group (Ms 22.0 and 25.7, respectively), \( t(21) = -2.79, p < .02 \). Participants were each paid £6 for taking part in the study.

Stimuli and procedure. The experiment was created and run on a PC using Micro Experimental Laboratory (Schneider, 1988). Viewing distance was held fixed at 60 cm. At this distance, the target and nontarget letters each subtended a visual angle of 0.9° vertically and 0.4° horizontally and were positioned around the perimeter of an imaginary circle with a radius of 2.1° from a central fixation point. Center-to-center separation between letters in the circle was 2.1°. The irrelevant distractor subtended a visual angle of 0.9° vertically and 0.5° horizontally and appeared to the left or right of the circle of letters at a distance of 4.3° from fixation. A larger letter was used for the peripheral distractor to compensate for the reduced acuity with increased eccentricity (e.g., Anstis, 1974; Goolkasian, 1994). All letters were presented in upper case in light gray on a dark background. The positions of the whole group of target and nontargets were counterbalanced for each of Set Sizes 2, 4 and 6, as was the likelihood of any arrangement of target position within a group. Ninety-six displays were created according to these specifications.

Each trial started with a fixation point in the center of the screen for 1 s. This was then replaced by the display of letters for 100 ms, to which participants responded by pressing the 0 key on the computer keypad (right thumb) for an X target and the 2 key (right forefinger) for an N target. (Presentation time was deliberately short to preclude eye movements toward or away from the distractor.) Feedback for incorrect responses was given by a computer tone. All the responses were followed by a 1-s interval before the fixation point reappeared for the start of the next trial. Participants received three blocks of practice trials of 12, 12, and 96 trials, respectively. In the first practice block, the letter display remained on the screen until the participant responded. The instruction to ignore the irrelevant distractor was repeatedly emphasized before and after each block of practice trials. The practice blocks were followed by nine experimental blocks, each comprising 96 trials. The various relevant set sizes were intermixed at random and presented with equal probability in each block of trials. Participants were allowed to rest between blocks and to continue when ready by pressing the spacebar of the computer.

Data analysis. RTs greater than 3 s were discarded. For each participant, the nine experimental blocks were combined and median correct RTs and proportions correct were calculated for the incompatible and neutral conditions at Set Sizes 1, 2, 4, and 6.

Results

RT. An analysis of variance (ANOVA) was conducted on the median correct RTs, with age group (young vs. old) as the between-subjects factor and set size (one, two, four, and six) and distractor condition (incompatible vs. neutral) as within-subjects factors.1 There was a significant main effect of age group, \( F(1, 28) = 76.68, \text{MSE} = 62.421.38, p < .001 \); as expected, the older participants were slower than the younger participants (see Table 1 for the overall means). Set size produced a significant main effect. \( F(3, 84) = 176.43, \text{MSE} = 3.618.03, p < .001 \), which did not interact with age group, \( F(3, 84) = 2.15, \text{MSE} = 3.618.03 \). The RT increase with set size in both groups was approximately 50 ms for each additional item in the array.2 A main effect was also found for the distractor condition, \( F(1, 28) = 22.22, \text{MSE} = 1.848.69, p < .001 \), reflecting slower RTs with incompatible distractors. Finally, there were significant interactions between age group and distractor condition, \( F(1, 28) = 4.33, \text{MSE} = 1.848.69, p < .05 \); between set size and distractor condition, \( F(3, 84) = 19.76, \text{MSE} = 752.01, p < .001 \); and among age group, set size, and distractor condition, \( F(3, 84) = 6.35, \text{MSE} = 752.01, p < .002 \).

The highly significant three-way interaction in the RT data can be seen more clearly in Figure 2, in which the RT differences between the incompatible and neutral conditions have been plotted as a function of set size. For both age groups, there were significant response compatibility effects at Set Sizes 1, 2, and 4, with \( t(14) > 2.24, p < .05 \), but not at Set Size 6, \( t(14) = -1.18 \) and \(-1.88 \) for the younger and older groups, respectively. However, the response compatibility effect was significantly greater for the older than for the younger group at Set Size 1, \( t(28) = 5.04, p < .001 \). Moreover, the response compatibility effect decreased significantly from Set Size 1 to Set Size 4 for the older group, \( t(14) = 2.55, p < .03 \), but not for the younger group, \( t(14) = -1.41 \).

The results from Set Sizes 1 and 6 provide a replication of the low and high perceptual load conditions from Lavie (1995, Experiment 1). Thus, the incompatible distractor resulted in slower RTs compared with the neutral distractor at Set Size 1 (low perceptual load), but not at Set Size 6 (high perceptual load). More important, we found that perceptual load critically determined age differences in selective attention. Older participants showed a significantly larger distractor effect at the lowest level of load (Set Size 1), but their distractor effect was reduced by a smaller increase in perceptual load than was required to reduce distractor interference in the younger participants. (See Lavie & Cox, 1997, for a discussion of the nature of capacity limits in young adults.)

The question then arises as to whether the age differences observed in Figure 2 can be accounted for in terms of generalized slowing with age. To examine this possibility, we adopted the following two methods.3 First, response compatibility effects were calculated as proportions of baseline RTs, that is, (incompatible RT – neutral RT)/neutral RT. The results are shown in Figure 3. Note that because we are now considering response compatibility effects (i.e., the proportional differences between incompatible and neutral conditions), we predict a two-way interaction between age group and set size if the differential

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1 In the analyses of variance with repeated measures, wherever there was evidence of departure from the sphericity assumption, the reported probability levels have been adjusted accordingly (Greenhouse-Geisser corrections).

2 A separate analysis of variance on reaction times from the neutral condition alone was conducted to assess the effect of set size without the contribution of compatibility effects to the slope. This analysis revealed a significant interaction between age group and set size, \( F(3, 84) = 5.11, \text{MSE} = 2.290.78, p < .05 \), such that the reaction time increase with set size was greater for the older group than for the younger group. This replicated the results of visual search studies in which older adults were more adversely affected by increasing numbers of nontargets than younger adults (e.g., Humphrey & Kramer, 1997; Madden, Pierce, & Allen, 1996; Plude & Doussard-Roosevelt, 1989; Rabbit, 1965). However, the present interaction could be regarded as an example of generalized slowing, with the older group taking approximately 1.5 times longer to respond in the neutral condition than the younger group (cf. Cerella, 1985b).

3 A traditional Brinley analysis was not used because of recent demonstrations of its insensitivity to specific age effects (e.g., Perfect, 1994).
effects of load on distraction occur regardless of the overall RT differences between the age groups. Indeed, this is what we found. An ANOVA on these proportional scores revealed a significant effect of set size, $F(3, 84) = 18.69, MSE = 0.003, p < .001$, and, more important, an interaction between age group and set size, $F(3, 84) = 5.03, MSE = 0.003, p < .005$. As before, the response compatibility effect was significantly greater for the older than for the younger group at Set Size 1, $t(28) = 4.07, p < .001$, and the response compatibility effect decreased significantly from Set Size 1 to Set Size 4 for the older group, $t(14) = 3.44, p < .005$, but not for the younger group. $t(14) = -0.89$. Thus, the analysis of proportional effects replicated the results found in the earlier analysis of RTs.

Second, we used a procedure described by Madden, Pierce, and Allen (1992; see also Salthouse & Kersten, 1993) in which the best fitting linear function relating the mean RTs for the two age groups across the eight experimental conditions (older RT = 1.20 younger RT + 167; $R^2 = .95$) was used to transform the younger participants’ data. A three-way ANOVA was then carried out in which the transformed younger group’s RTs were compared with the untransformed older group’s RTs, with set

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**Table 1**

*Median Response Times (in Milliseconds) and Accuracy (Proportion Correct) for Incompatible and Neutral Distractor Conditions as a Function of Relevant Set Size for Younger and Older Groups in Experiment 1*

<table>
<thead>
<tr>
<th>Condition</th>
<th>1</th>
<th>2</th>
<th>4</th>
<th>6</th>
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<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
<td>$SD$</td>
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<td></td>
<td></td>
<td></td>
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<td>79</td>
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<td>.021</td>
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<tr>
<td>Accuracy</td>
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<td>.021</td>
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<tr>
<td>Accuracy</td>
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<td>Accuracy</td>
<td>.968</td>
<td>.017</td>
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*Note.* RT = reaction time.

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**Figure 2.** Mean reaction time (RT) differences (with standard error bars) between the incompatible and neutral conditions as a function of set size and age group in Experiment 1.

**Figure 3.** Mean reaction time (RT) differences (with standard error bars) between the incompatible and neutral conditions as a proportion of RT in the neutral condition as a function of set size and age group in Experiment 1.
size and distractor condition as within-subjects factors. If this procedure results in the loss of statistically significant effects involving age group, it can be concluded that generalized linear slowing can account for the age differences observed in the original data. In fact, the crucial three-way Age Group × Set Size × Distractor Condition interaction remained highly significant, \(F(3, 84) = 5.11, MSE = 858.90, p < .005\), and, as before, the response compatibility effect was greater for the older group than for the young group at Set Size 1, \(r(28) = 4.55, p < .001\). The overall pattern was highly similar to that shown for the untransformed data in Figure 2.

Accuracy. An ANOVA was conducted on the proportions correct (after an arcsine transformation), with the same three factors as before (see Table 1 for the overall means before the transformation). There were highly significant effects of age group, \(F(1, 28) = 53.09, MSE = 0.117, p < .001\), and set size, \(F(3, 84) = 144.18, MSE = 0.020, p < .001\), with an interaction between them, \(F(3, 84) = 19.37, MSE = 0.020, p < .001\). Thus, the decrease in accuracy with increasing set size from one to six was greater for the older group (.96, .92, .84, and .75, respectively) than for the younger group (.98, .98, .97, and .91, respectively). There was a highly significant effect of distractor condition, \(F(1, 28) = 16.06, MSE = 0.016, p < .001\), which interacted with set size, \(F(3, 84) = 3.80, MSE = 0.014, p < .02\). Thus, accuracy was higher in the neutral condition than in the incompatible condition for Set Size 1 (.98 and .97, respectively), Set Size 2 (.96 and .94, respectively), and Set Size 4 (.93 and .89, respectively), but not for Set Size 6 (.84 and .84, respectively). The interactions between age group and distractor condition, and among age group, set size, and distractor condition, were not significant (Fs < 1).

Although perhaps less sensitive, the accuracy analysis generally supported the RT data and certainly showed no evidence of any trade-off between speed and accuracy. Thus, the older group was both slower and less accurate than the younger group. Similarly, with increasing set size, performance became slower and less accurate. For Set Sizes 1, 2, and 4, the incompatible distractor resulted in slower and less accurate performance than the neutral distractor.

Discussion

In summary, as predicted from the reduced inhibition hypothesis of aging (Hasher & Zacks, 1988), there were larger distractor effects for the older group than for the younger group at the lowest level of perceptual load (relevant Set Size 1). Moreover, this effect was greater than expected on the basis of generalized slowing, as revealed by response compatibility effects expressed as a proportion of baseline RT. The distractor effect was then reduced significantly by a lower level of perceptual load for the older group (Set Size 4) than for the younger group (Set Size 6), as predicted by combining Lavie’s (1995; Lavie & Tsal, 1994) perceptual load hypothesis of selective attention with the assumption that processing capacity decreases with age (Salthouse, 1991, 1992).

However, two potential problems with Experiment 1 need to be addressed. The first concern is that the older group was fairly inaccurate, particularly at the highest level of perceptual load (i.e., the mean proportion correct at Set Size 6 was .75). In fact, this does not affect the main interaction of interest in Experiment 1, which occurred between Set Sizes 1 and 4. Note that the crucial Age Group × Set Size × Distractor Condition interaction in the RT analysis remained significant when the data from Set Size 6 were excluded, \(F(2, 56) = 5.15, MSE = 702.90, p = .01\). Similarly, the two-way interaction between age group and set size remained significant in the analysis of proportional response compatibility effects, \(F(2, 56) = 5.61, MSE = 0.003, p < .01\). Nevertheless, as a further examination of the influence of accuracy, we divided the older group into high- and low-accuracy groups by a median split on the basis of overall mean accuracy (8 participants at or above .87; 7 participants below .87). An ANOVA was then performed on the RT data with accuracy group (high vs. low), set size, and distractor condition as factors. There was no overall effect of accuracy group (\(F < 1\)), and there were no two- or three-way interactions involving accuracy (Fs < 1.40). The pattern of data was very similar for the high- and low-accuracy groups. It can be concluded, then, that the inaccurate performance from the older group at Set Size 6 was probably not an important influence on the main conclusions from Experiment 1.

A second possibility relates to the structure of the display (see Figure 1). It can be seen that as the number of relevant items in the center of the display increased, so did the visual cues that helped to distinguish between the relevant item or items and the distractor. Thus, for relevant Set Size 1, the target and distractor differed only in size and distance from fixation. However, with relevant Set Sizes 2, 4, and 6, there was an additional cue as a result of the “perceptual group” formed by the relevant items, particularly in the case of Set Size 6 (in which the relevant letters formed a complete circle). Lavie and Cox (1997, Experiment 1) have already shown that the perceptual load of a relevant search task (e.g., whether the search involves nontargets that are similar [high load] or dissimilar [low load] to the target) can determine the processing of an irrelevant distractor in the periphery, even when the central search array forms a clear and distinct perceptual group (a complete circle) at all levels of load. However, this was shown only for young adults, and it could be argued that the increase in distraction with age at low load (Set Size 1) is a consequence of a specific age-related difficulty in localizing the target and distinguishing it from the distractor. This would be consistent with Plude and Hoyer’s (1985) “spatial localization hypothesis,” which states that age decrements in selective attention can be attributed to a decline in the ability to locate task-relevant information in the visual field. It is also related to work on perceptual grouping and to the suggestion that older people have difficulty imposing perceptual organization on a visual array when task-relevant and task-irrelevant information cannot be differentiated easily (Farkas & Hoyer, 1980). The finding that the older group in the present study, like the younger group, was fast and highly accurate (the proportion correct was .96) at Set Size 1 in comparison with Set Sizes 2–6 would seem to argue against a spatial localization or perceptual grouping problem. Nevertheless, Experiment 2 was designed to investi-

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4 The means reported here are from the results of the analysis of variance, transformed back to proportions correct.
gate a possible influence of perceptual grouping on the results of Experiment 1.2

Experiment 2

There were two conditions in Experiment 2, ungrouped and grouped, and these were manipulated within subjects. The ungrouped condition was identical to that in Experiment 1 (see Figure 1). In the grouped condition, the empty locations in the center of the display (ns = 5, 4, and 2, for Set Sizes 1, 2, and 4, respectively) were marked by small circles so that the relevant set of items always formed a complete group of six. The participants were all older adults. We predicted that if the large distractor effect observed in the older group in Experiment 1 at low perceptual load (Set Size 1) was at least partly the result of a deficit in localizing the target in the absence of perceptual grouping cues, then the distractor effect should be smaller in the grouped condition than in the ungrouped condition. Moreover, if the distractor effect at low load was reduced by grouping to the level observed in the younger group in Experiment 1, then a specific age deficit in target localization could entirely explain the observed increase in the distractor effect with age at low perceptual load.

Method

Participants. Twenty people (aged 66–81 years) were tested. They were all members of a volunteer panel involved in studies of cognitive aging at the University of Warwick. Two participants failed to follow the experimental instructions correctly, so we did not include their data in the analyses. For the remaining 18 participants, the mean age was 71.0 years (SD = 4.1), and the mean vocabulary score on the multiple-choice section of the MHVS (Raven et al., 1988) was 23.5 (SD = 2.9). Payment for taking part in the study was £5.

Stimuli and procedure. The stimuli and procedure were the same as in Experiment 1, except for the following changes. In the grouped condition, the empty locations in the central relevant part of the display (Set Sizes 1, 2, and 4) were marked by small circles each subtending a visual angle of 0.2° at a viewing distance of 60 cm. (The ungrouped condition was identical to that used in Experiment 1, as illustrated in Figure 1.)

There were 11 blocks of trials. The first was a short block of 20 trials, which was used to explain the task and the different conditions. There were 96 trials in each of the remaining 10 blocks. Blocks of trials in the ungrouped condition alternated with blocks of trials in the grouped condition (5 blocks of each). Half the participants began the 10 blocks with a block of trials in the ungrouped condition, whereas the remaining half began with a block of trials in the grouped condition.

Data analysis. RT differences greater than 3 s were discarded. The first main block in each condition (ungrouped and grouped) was regarded as practice, so the data were not included in the analysis. For each participant, the 4 experimental blocks in each condition were combined and median correct RTs and proportions correct were calculated for the incompatible and neutral conditions at Set Sizes 1, 2, 4, and 6.

Results

RT. An ANOVA was conducted on the median correct RTs, with grouping (ungrouped vs. grouped), set size (one, two, and four), and distractor condition (incompatible vs. neutral) as within-subjects factors. Set Size 6 was omitted from this analysis for two reasons: (a) Accuracy was again low (.78 correct) and (b) Set Size 6 did not, of course, differ between the un-

grouped and grouped conditions. (In fact, the results were qualitatively similar with and without Set Size 6.) The overall means are presented in Table 2. There were significant effects of set size, F(2, 34) = 59.33, MSE = 8,567.39, p < .001, and distractor condition, F(1, 17) = 45.36, MSE = 5,912.98, p < .001, with a significant interaction between them, F(2, 34) = 4.20, MSE = 2,775.59, p < .05. There was no significant effect of grouping, F(1, 17) = 2.94, MSE = 6,792.80, and there were no interactions involving grouping (Fs < 3.18).

The RT differences between the incompatible and neutral conditions are shown in Figure 4 as a function of set size. As in Experiment 1, there were significant response compatibility effects at Set Sizes 1, 2, and 4 in both the ungrouped and grouped conditions, ts(17) > 2.09, ps < .05, but not at Set Size 6, ts(17) = 1.73 and 1.35 for the ungrouped and grouped conditions, respectively. The interaction between set size (one, two, and four) and distractor condition replicated the general pattern for the older group in Experiment 1 of greater distraction at Set Sizes 1 and 2 (74 and 94 ms, respectively) than at Set Size 4 (44 ms); in the present case, the only difference to reach significance was the decrease in the distractor effect from Set Size 2 to Set Size 4, t(17) = -2.62, p < .02.

Although there were no overall effects or interactions involving grouping, suggesting no role for perceptual grouping, it can be seen from Table 2 and Figure 4 that, as predicted from the grouping hypothesis, the response compatibility effect at Set Size 1 was smaller in the grouped condition (58 ms) than in the ungrouped condition (89 ms). Separate comparisons between the response compatibility effects in the ungrouped and grouped conditions revealed a significant difference at Set Size 1, t(17) = 2.15, p < .05, but not at Set Sizes 2 or 4 (ps > .1). However, the response compatibility effect in the grouped condition for these older participants in Experiment 2 was still significantly greater than for the younger participants in Experiment 1 at both Set Sizes 1, t(31) = 2.62, p < .02, and 2, t(31) = 2.27, p < .05, but not at Set Size 4, t(31) = 1.05.

Analysis of response compatibility effects expressed as proportions of baseline RTs (incompatible RT – neutral RT)/neutral RT revealed a generally similar pattern of results (see Figure 5 for the means). Separate comparisons between the proportional response compatibility effects in the ungrouped and grouped conditions produced marginally significant differences at Set Sizes 1, t(17) = 1.88, p < .08, and 4, t(17) = 1.79, p < .1, but not at Set Size 4, t(17) = -1.41, p > .1. The proportional response compatibility effect in the grouped condition for the older participants in Experiment 2 was marginally greater than for the younger participants in Experiment 1 at both Set Sizes 1, t(31) = 1.77, p < .09, and 2, t(31) = 1.70, p = .1, but not at Set Size 4, t(31) = 0.55.

Accuracy. An ANOVA was conducted on the proportions correct (after an arcsine transformation), with grouping, set size (one, two, and four), and distractor condition as within-subjects factors (see Table 2 for the overall means). There were significant effects of set size, F(2, 34) = 54.94, MSE = 0.042, p < .001, and distractor condition, F(1, 17) = 42.13, MSE = 0.045, p < .001, but no interaction between them, F(2, 34) =

2 We thank an anonymous reviewer for suggesting this experiment.
Table 2

<table>
<thead>
<tr>
<th>Condition</th>
<th>M</th>
<th>SD</th>
<th>M</th>
<th>SD</th>
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<th>SD</th>
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<td>2</td>
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<tr>
<td>Incompatible RT</td>
<td>819</td>
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<td>892</td>
<td>191</td>
<td>954</td>
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<tr>
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<td>.896</td>
<td>.069</td>
<td>.846</td>
<td>.093</td>
<td>.761</td>
<td>.103</td>
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<tr>
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<td>158</td>
<td>784</td>
<td>144</td>
<td>923</td>
<td>183</td>
<td>974</td>
<td>144</td>
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<td>Accuracy</td>
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<td>.943</td>
<td>.037</td>
<td>.887</td>
<td>.077</td>
<td>.784</td>
<td>.073</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incompatible RT</td>
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<td>157</td>
<td>877</td>
<td>203</td>
<td>942</td>
<td>183</td>
<td>999</td>
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<tr>
<td>Accuracy</td>
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<td>.031</td>
<td>.897</td>
<td>.058</td>
<td>.842</td>
<td>.091</td>
<td>.760</td>
<td>.083</td>
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<tr>
<td>Neutral RT</td>
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<td>796</td>
<td>140</td>
<td>886</td>
<td>195</td>
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<tr>
<td>Accuracy</td>
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<td>.953</td>
<td>.052</td>
<td>.883</td>
<td>.070</td>
<td>.800</td>
<td>.082</td>
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</table>

Note. RT = reaction time.

1.68, MSE = 0.033, p > .1. (Note, however, that with Set Size 6 included in the analysis, the interaction between set size and distractor condition was significant, F(3, 51) = 3.41, MSE = 0.028, p < .05. As in Experiment 1, the response compatibility effect was reliable for Set Sizes 1, 2, and 4, but not for Set Size 6, with mean differences between the incompatible and neutral conditions after transformation of 0.22, 0.22, 0.12, and 0.07, respectively.) More important, there was no effect of grouping, F(1, 17) = 2.08, MSE = 0.040, and no two- or three-way interactions involving grouping (Fs < 2.40).

Discussion

The overall pattern of data from Experiment 2 replicated that of the older group in Experiment 1, namely a significant reduction in the distractor effect for RT by Set Size 4 (as compared
with Set Size 6 for the younger group in Experiment 1). Contrary to a perceptual grouping hypothesis, there were no effects of grouping and no interactions involving grouping in the ANOVAs on RT and accuracy. Nevertheless, as predicted from the grouping hypothesis, there was a significant reduction in the distractor effect for RT at Set Size 1, with a similar trend found in the proportional data. This suggests that the large distractor effect observed in the older group in Experiment 1 at Set Size 1 could be attributed to some extent, to a deficit in localizing the target in the absence of perceptual grouping cues. However, the distractor effect at low load in Experiment 2 was not reduced by grouping to anywhere near the level observed in the younger group in Experiment 1, thereby ruling out a specific age deficit in target localization as the entire explanation for the earlier increase in the distractor effect with age at low perceptual load.

General Discussion

The results from Experiment 1 were as predicted from Lavie's (1995; Lavie & Tsal, 1994) perceptual load hypothesis of selective attention and from the assumption that processing capacity decreases with age (Salthouse, 1991, 1992). Thus, there was a larger distractor effect for the older than for the younger group (consistent with Hasher & Zacks, 1988), but only under conditions of low perceptual load (relevant Set Size 1). The distractor effect was reduced significantly by a lower level of perceptual load for the older (Set Size 4) than for the younger (Set Size 6) group. It seems that elderly participants are not always more susceptible than younger ones to distraction from irrelevant peripheral stimuli. Experiment 1 suggested that at least one crucial factor appears to be the level of perceptual load.

Experiment 2 replicated the effect of perceptual load on distractibility for the older group found in Experiment 1 while demonstrating that the large distractor effect for the older group at low perceptual load could be reduced somewhat by providing perceptual grouping cues. However, the distractor effect at low perceptual load in Experiment 2 remained greater than the distractor effect observed in the younger group at low perceptual load in Experiment 1, thus discounting a complete explanation based on perceptual grouping and the spatial localization hypothesis (Farkas & Hoyer, 1980; Plude & Hoyer, 1985).

Returning to the issues raised earlier, first, the role of perceptual load in age-related decline in visual processing has been most extensively investigated in the context of the UFOV (Ball et al., 1988, 1993; Scialfa et al., 1987). Studies of the UFOV have demonstrated that the detection and localization of targets in the visual periphery is particularly sensitive to the extent to which central vision involves perceptual load, as in the case of visual clutter, or with a demanding secondary task. Moreover, older adults' UFOV appears to shrink more than younger adults' UFOV with increasing central load. The present research converges with these previous results in showing that the processing of peripheral distractors by older adults is particularly sensitive to increases in the perceptual load of a central task. However, our research departs from previous studies of the UFOV as well as other aging studies on the ability to divide attention in demonstrating that the decline in processing capacity with age (and hence the greater shrinking of the UFOV with greater load in central vision) can be usefully applied by older adults in situations of selective attention, in which it is desirable to ignore irrelevant and potentially distracting items in the periphery. In such situations, we have shown that older adults can actually benefit more than younger adults from smaller increases in the relevant processing load.

Second, any age-related change in peripheral acuity is not relevant here. This is because the critical result from Experiment 1 was the influence of perceptual load (in this case, set size) on the difference between the distractor effects in younger and older adults, with the distractor item presented at a constant distance from fixation in all conditions.

A third point to emphasize is that the age difference in the distractor effect under conditions of low perceptual load (Set Size 1) in Experiment 1 was significantly greater than expected solely on the basis of generalized slowing. For example, having taken baseline RT differences into account, the distractor effect was still almost three times greater for the older than for the younger adults. Note that this is consistent with three recent studies that have demonstrated age-related increases in Stroop interference as expressed as a proportion of baseline RTs (Kwong See & Ryan, 1995; Spieler, Balota, & Faust, 1996; Weis, Braun, & Barber, 1997).

Thus, there is at least partial support here for Hasher and Zacks's (1988) reduced inhibition hypothesis such that it applies in situations in which relevant processing requires less than the total available capacity. Spare capacity is then automatically allocated to the processing of irrelevant distracting information, and this is significantly more disruptive in old age. (See also Madden, 1990, and Madden, Connelly, and Pierce, 1994, for other demonstrations of the greater disruption from distractors with aging in tasks requiring shifts of attention.) As predicted from Lavie's (1995) perceptual load hypothesis, with increased load, the selective processing of older adults improves more rapidly than younger adults, presumably because they run out of available resources at lower levels of load (e.g., Salthouse, 1991, 1992). Thus, aging of attention seems to involve (at least) two components. One is the reduction of an active inhibition mechanism (see also Tipper, 1991), leading to reduced suppression of potent distractors. The other is reduced processing capacity, which leads, by contrast, to improved selectivity in older adults with smaller increases of load relative to the levels required for younger adults. This has its effects via "passive" selectivity (i.e., simply not processing the distractor; see also Neisser, 1976), which follows as a natural and inevitable consequence when capacity is exhausted by the relevant processing (e.g., Lavie, 1995).

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Received January 20, 1997
Revision received March 5, 1998
Accepted March 19, 1998 •

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