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AGING AND VISUAL ATTENTION: THE EFFECT OF PERCEPTUAL LOAD ON DUAL-TASK PERFORMANCE

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The ability to use information that is not directly in front of us (information located in the periphery) is important in many aspects of everyday life (e.g., using a computer, driving). It may be critical that a person be able to effectively use the information in the periphery. The current study examined how age-related changes in perceptual processing capacity and display-related variations in perceptual load affected the spatial distribution of visual attention. The results suggest that displays that make high demands on perceptual processing capacity reduce the functional field of view in older adults. Younger adults, however, were unaffected by the perceptual load manipulation. The primary practical implication is that displays that are intended to be used by older adults should not make high demands on their limited perceptual processing capacity.

The ability to use information that is not located directly ahead (information located in the periphery) is important in many aspects of everyday life (e.g., using a computer, driving). One way to characterize these task situations is in terms of the amount of perceptual processing required by the task. Perceptual processing demand is the extent to which a task places demands on visual processing capacity (Lavie, 1995).

According to the load theory of selective attention, increases in perceptual processing demands should result in attention becoming more selective (Lavie, Hirst, de Fockert, & Viding, 2004). Thus, selective attention could be functionally equivalent to a narrowing of the spatial extent of attention. Similarly, low perceptual load should lead to “un-selective” attention which may be functionally equivalent to a broadening of attention.

Older adults have been shown to have less perceptual processing capacity than younger adults (Maylor & Lavie, 1998), thus, situations that require this capacity (i.e., searching for a menu option in a list) more quickly exhaust the capacity that older adults have. The result is that attention may focus into a very small functional area making it difficult or impossible to pay attention to information in the periphery (e.g., status indicators, warnings).

Much of the research examining how task factors affect the spatial extent of attention, or the functional field of view (FFOV), has focused on memory or cognitive load manipulations. Participants' performance in a briefly presented visual search task is severely reduced when they must simultaneously memorize or process other information. The pattern of performance decrement suggests that the “spotlight” of attention has narrowed (e.g., Williams, 1989) under simultaneous cognitive load.

Although the cognitive demands of the tasks used in previous studies have been manipulated, the perceptual aspects of the displays used in previous research have been

relatively uncontrolled. This may explain why some studies showed effects of perceptual load whereas others have not (Ball, Beard, Roenker, Miller, & Griggs, 1988; Sekuler & Ball, 1986).

The goal of the current study was to examine how *perceptual load* would affect the spatial extent of attention (using a divided attention task). The concept of perceptual load is particularly interesting because it is a display characteristic that is representative of a wide variety of tasks.

OVERVIEW OF THE STUDY

To examine the effect of perceptual load on the spatial extent of attention, participants engaged in a dual-task where the central (primary) task varied in perceptual load while the peripheral (secondary) task measured the spatial extent of attention. The inclusion of an older adult group allowed us to examine how perceptual processing demands would affect a group with lower perceptual processing capacity (Maylor & Lavie, 1998).

A major limitation of studies that have used percent correct (or percent error) as the dependent variable is that this kind of performance measure may reflect a mixture of attentional contributions and strategy differences. The use of signal detection analyses provides two dependent variables that are more meaningful than percent correct or error. They allowed us to explore the contributions of early attention or later decision-making in performance.

METHOD

Participants

Nineteen younger adults (aged 18-22, $M = 20.1$, $SD = 1.3$) and 17 older adults (aged 65 to 75, $M = 69.7$, $SD = 2.9$) participated in the study. Young adults received course credit whereas older adults were paid \$30. Participant characteristics

	Younger adults n = 19		Older adults n = 17	
	M	SD	M	SD
Age	20.1	1.3	69.7	2.9
Near vision ¹	20/21.3	2.3	20/22.1	4.0
Far vision ^{1*}	20/18.6	7.8	20/25.5	7.8
Digit symbol substitution ^{2*}	78.9	12.4	61.4	9.2
Shipley vocabulary test ^{2*}	31.6	1.9	35.9	5.1
Reverse digit span ^{3*}	10.6	1.7	9.0	3.6

Note. ¹Snellen visual acuity; ²Number of completed items (scale ranged from 0 to 40); ³Number of digits recalled in the correct order. * Indicates significant age group difference (p < .05).

Table 1. Participant characteristics

are described in Table 1. The pattern of age-related differences is consistent with that typically reported in the literature (e.g., Rogers, Hertzog, & Fisk, 2000).

Materials

Equipment. IBM-compatible computers (3.2 GHz Pentium 4, 1 GB RAM) connected to 19 inch cathode-ray tube displays were used in the current study. The refresh rate was set at 85 Hz. At this refresh rate, a complete scan of the display occurred every 11.77 ms. Viewing distance (21 inches) was stabilized with a chin rest.

Central letter search task. The central letter search task was a modification of that used by Maylor and Lavie (1998). A single target letter (H, K, V, W, X, or Z; subtending 0.6° × 0.5° of visual angle) appeared with equal probability at one of the six possible positions in a six-letter row (subtending 3.7° × 0.5° of visual angle) located in the center of the display. The background was black while the letters were white. The target was embedded in a low or high in perceptual load set of letters. In the low perceptual load condition, the target letter was embedded among five repeated letters different from the target (H, K, V, W, X, or Z).

An example of a low perceptual load central task would be “W W X W W W”. The target is the letter X and the distractors are the letters W. This is operationalized as a low perceptual load task because search of the target letter should be relatively easy due to the perceptual grouping of the distractors (Duncan & Humphreys, 1989). In this kind of search condition, the target letter X should be relatively easy to distinguish from the distractor letters. This is contrasted with an example of a high perceptual load condition, “K V X W H Z”. In this case, the heterogeneity of the distractors will make search of the target, the letter X, relatively difficult (Duncan & Humphreys, 1989).

Peripheral star detection task. In addition to the central task the participants simultaneously localized a white star (“*”; subtending 0.5° × 0.5° of visual angle) that was displayed either in a near or far ring around the central task. The radii of the two levels of eccentricity on which the

peripheral star could occur subtended 5.4° (near) and 16.4° (far) of visual angle from fixation.

The star appeared in one of 16 locations (Figure 1g) that were evenly spaced along the intersections of two imaginary rings (near and far) and the four cardinal directions and the four oblique directions. After stimulus presentation (central and peripheral stimuli), the participants were to indicate whether the central task target letter was present, and, if present, the location of the peripheral star. All responses were made with the mouse placed in the dominant hand. Mouse practice was provided.

DESIGN AND PROCEDURE

The study was a 3 (central task load: absent, low perceptual load, or high perceptual load) × 3 (peripheral task eccentricity: absent, near, or far) × 2 (age group: younger, older) factorial with central task load and peripheral task eccentricity as within subject factors while age group (younger and older) was a between subjects grouping variable. The dependent variable was central task response (“Yes”, “No”, or “No Star”) and peripheral task response (location of the star).

The experiment had three phases. In phases 1 and 3 (single task phase), participants completed 54 trials of the central task alone wherein they were randomly presented with one of six letters (the search target). Afterwards, a display of

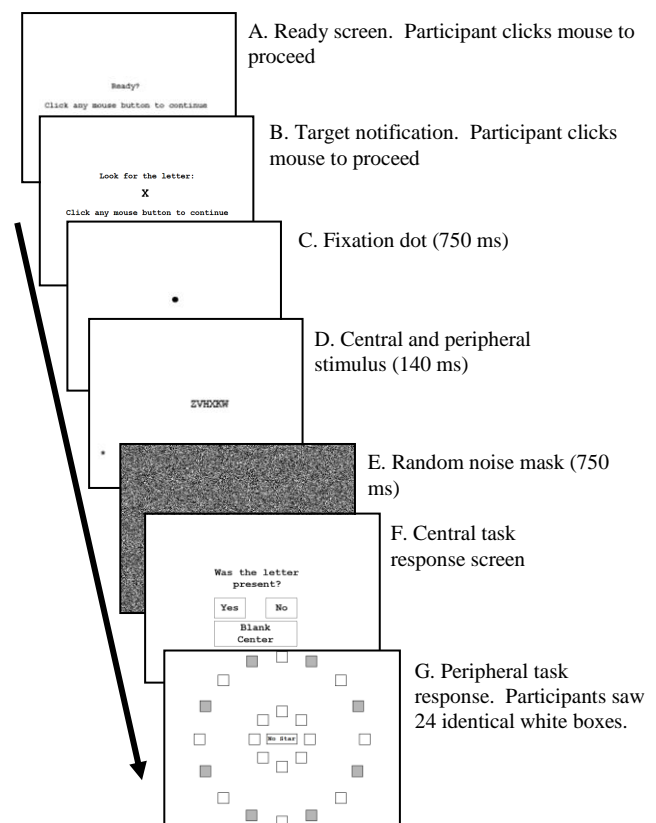


Figure 1. Event sequence for one trial.

six letters was shown for 140 ms. Participants indicated whether the previously identified target letter was present, absent, or the screen was blank.

In phase 2 (the dual-task phase), participants performed the central letter search task but also concurrently localized a star flashed in the periphery (at the same duration as the central task). Participants were instructed to concentrate their efforts on the central task and devote any remaining attention to the peripheral task. Phase 2 contained 432 trials distributed over 8 blocks.

Figure 1 illustrates the event sequence for one trial. Participants first saw a ready display (Figure 1a). After clicking a mouse button, they were shown the to-be-searched for target letter (Figure 1b). After clicking a mouse button, a fixation point (Figure 1c) and the central and peripheral tasks were concurrently displayed (Figure 1d). After 140 ms, a black and white random noise mask was displayed for 750 ms (Figure 1e). The purpose of the noise mask was to control the participant's stimulus processing time. Two consecutive response screens were then displayed. In the first response screen (Figure 1f), the participant made their central task response ("Yes", "No", or "Blank Center") using the mouse to click on their choice. In the second response screen, a display of 24 identical white boxes appeared (Figure 1g). At the center of this response screen was a button labeled, "No Star". While the peripheral task could only occur in any of the 16 peripheral target locations previously described, 8 additional boxes (shaded in the illustration) were added to the far ring. Pilot testing revealed that younger participants were more accurate in identifying the star appearing in the far ring than in the near ring. This was most likely due to the wider spacing between potential target sites in the far ring making it easier to guess. The extra eight boxes were added to equate difficulty between the near and far ring peripheral target localization performance. Subsequent pilot testing revealed that performance in the near and far rings was equated for younger adults.

Subsequent screens gave feedback for each task. The trials then started over with a display asking if the participant was ready to start the trial. After each 54-trial block, participants received block-level feedback indicating their center and peripheral task accuracy over the just-completed block as well as a break notification. To enforce the breaks between blocks, the study required experimenter intervention to proceed.

RESULTS

In the current paper, only data from phase 2 is presented (the dual task phase). Signal detection methods were used to examine how changes in the perceptual load of the display, the location of the stimuli, and the observer's age affected central and peripheral task sensitivity and bias. Because of space constraints, only signal detection statistics are presented (no hit and false alarm rates).

Central Task

For the central (primary) task, the hit rate indicates the proportion of trials that were correctly identified as having a target letter while the false alarm rate was the proportion of trials incorrectly identified as having a target letter. Using the hit and false alarm data, signal detection measures were computed for each participant. Signal detection theory is a way to describe subjects' performance when they must detect signals in the presence of noise or uncertainty (Green & Swets, 1988). The advantage of using signal detection statistics is that compared to overall percent correct, signal detection statistics allow us to decompose performance into two independent components: sensitivity (i.e., perceptual processes potentially influenced by the presence or absence of visual attention) and bias (i.e., post-perceptual processes; strategy differences).

Traditional signal detection measures (the measures d' for sensitivity and β for response bias or criterion) could not be calculated because the pattern of hits and false alarms did not conform to a normal distribution—a requirement for the computation of d' and β (Green & Swets, 1988). Thus, non-parametric signal detection statistics, which do not assume normally distributed responses, were computed (A' for d' and B'' for β). For each participant, sensitivity to the central task target letter (A') and criterion for deciding the presence of a central task target letter (B'') were computed (Grier, 1971; Pollack & Norman, 1964; Stanislaw & Todorov, 1999).

In this task, "sensitivity" refers to the participant's ability to detect the target letter embedded in distracters. Response bias indicates whether participant's were predisposed to respond liberally (more likely to say target present) or conservatively (more likely to say target absent).

It was expected that under a higher load central task, sensitivity would be reduced compared to lower load central task. The main effects of age, $F(1, 34) = 52.92$, $MSE = .23$, and load, $F(1,34) = 22.49$, $MSE = .07$, were significant. However, load interacted with age such that the load had differing effects for the younger and older adults, $F(1,34) = 6.26$, $MSE = .02$. Load had a significant effect on central task sensitivity in the younger adults but not in the older adults (suggestive of floor effects for older adults). So we see that for younger adults, the load manipulation had graded effects on sensitivity. However, for older adults, even the low load condition seemingly "exhausted" older adults perceptual processing capacity such that increasing the load had no effect. This finding is consistent with previous studies in the selective attention literature that have shown that older adults are more affected by lower levels of load than younger adults (Maylor & Lavie, 1998). More specifically, older adults exhibit selective attention under lower levels of perceptual load than younger adults (presumably because of older adult's reduced processing capacity). Response bias, however, was equivalently affected in both age groups with increasing load resulting in a more liberal bias.

To summarize, the central task in this study was used as a perceptual load manipulation. For younger adults, increasing load resulted in reduced sensitivity to detect the

embedded letter while for older adults increasing load did not result in a change in sensitivity. However, bias was significantly affected in both age groups.

While older adults' sensitivity seemed less affected (although the trend was in the right direction), it was evident that the load manipulation did have an affect the other measure of performance (response bias). As a manipulation check, we felt sufficiently confident that load had an effect on performance for both age groups. With this, we now examine peripheral task performance to determine how perceptual load (from the central task) affected the FFOV.

Peripheral Task

The purpose of the peripheral task was to indirectly assess the size of the FFOV (the breadth of attention) under varying levels of perceptual load (induced by the central task). The assumption was that if the size of the FFOV is affected by perceptual load and age, this would manifest itself as a decrease in localization performance for the peripheral task--a decreased ability to detect changes (e.g., Pringle, Irwin, Kramer, & Atchley, 2001).

For analysis, the peripheral task response was collapsed by ring. That is, as long as participants responded in the same ring as the stimulus occurred, it was counted correct (a "hit"). This level of analysis was deemed appropriate given the assumptions of attention acting as a roughly circular spotlight.

To examine the role of perceptual load on the performance measures of sensitivity and bias, non-parametric signal detection analyses (Grier, 1971; Pollack & Norman, 1964; Stanislaw & Todorov, 1999) were used to decompose the peripheral task hit and false alarm data into measures of the participant's ability to accurately localize the star (A') and response bias (B'').

The results showed a significant 3-way interaction between age, load, and eccentricity on localization accuracy (i.e., A'), $F(2,68) = 3.95$, $MSE = .001$. The locus of this interaction was a significant two-way interaction of load and eccentricity for the older adults ($p < .05$), but not younger adults. This result can be summarized as a steeper decline in sensitivity with increasing load and eccentricity for older adults than younger adults. As load increased for the older adults, it became more difficult for them to correctly localize the far star compared to the near star.

While overall response bias was conservative (positive values of B''), the age by eccentricity and load by eccentricity interactions were significant. The source of the age \times eccentricity interaction was that older adults' response bias became more liberal in the far condition compared to the near condition while younger adults' bias was unchanged. The source of the load \times eccentricity interaction was that increasing load significantly affected bias in the near condition, but not in the far condition. This suggests that in the far condition, older adults adopted more liberal strategies (i.e., adjusted to a more liberal criterion) compared to their criterion in the near condition.

DISCUSSION

The current study demonstrated that for older adults, the size of the FFOV is critically determined by the level of perceptual load engendered by the display. The three-way interaction between age, load, and eccentricity on sensitivity is indicative of visual attention that shrinks toward a unitary focus as perceptual load increased. However, for younger adults, increasing load did not affect peripheral task performance. The results also showed that perceptual load effects on the FFOV (for older adults) affect both localization sensitivity and response bias.

This age-related difference may be attributable to older adults' reduced perceptual processing capacity (Maylor & Lavie, 1998). Varying perceptual load had no effect on bias in the far ring, but significantly affected response bias in the near ring (for both age groups). If we assume that attention is required for response bias to be affected, the bias data are consistent with the sensitivity data in showing that attention constricts due to perceptual load.

The current results also extend Lavie's perceptual load model of attention into spatial attention (e.g., Lavie, 2005). While implied in the literature, the spatial attention implications of perceptual load have not been examined. In the current study, it was shown that high perceptual load conditions (that induce selective attention) also result in a change in the spatial extent of attention. Because perceptual load is an easily definable display characteristic, it may be possible to design displays that reduce perceptual demands, and thus enhance multitask visual performance.

Display Design Implications

An understanding of the basic mechanisms of attention and aging can guide the design of more effective interfaces and technology (e.g., Mead, Batsakes, Fisk, & Mykityshyn, 1999). What guidelines can be drawn from the current results?

Conclusions are limited by the specific kind of perceptual load manipulation used here (search difficulty induced by similar distractors). However, we can conclude that decreasing search difficulty may lead to less reduced FFOV, especially for older adults. For example, when searching for an icon in a toolbar, each icon should be as distinct as possible. This is somewhat contrary to current interface design convention that strives for consistency and similarity (e.g., formats, colors; Shneiderman, 1998).

For example, Figure 2 illustrates a toolbar in a popular word processing application. Each individual icon varies somewhat from each other, but otherwise, the icons are consistent in format, size and color scheme. Consistency is



Figure 2. Example of a toolbar from a popular word processing application.

often touted as a way for users to capitalize on previous experience (e.g., they can apply what they know in one application to another application). However, for novice or infrequent users, consistency may increase search difficulty (i.e., perceptual load) which may harm the user's ability to concurrently monitor other, important areas of the display. Consistency across applications is critical but differentiability of icons within an application is equally important.

Future research should identify other ways in which perceptual load can be manipulated and how/whether it has similar effects on the FFOV as the manipulation used here. Similarly, research should more directly characterize aspects of interfaces on the level of perceptual demands. Doing so can provide a type of formative evaluation of interfaces with the intent of minimizing perceptual load demands specifically for older adult users.

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