AN INVESTIGATION OF PERCEPTUAL LOAD, AGING, AND THE FUNCTIONAL FIELD OF VIEW

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An Investigation of Perceptual Load, Aging, and
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SUMMARY

A common metaphor for visual attention is the spotlight (Posner, 1980). It follows from the spotlight metaphor and other similar models (e.g., zoom-lens model; Eriksen & Yeh, 1985) that attention can, according to task-demands, be constricted into a focused beam (i.e., analogous to selective attention) or dilated to encompass a larger breadth (i.e., analogous to divided attention). It is currently unclear how variations in perceptual load of a display affect the FFOV. Lavie (1995; Lavie et al., 2004) proposed that the critical determinant of selective attention (i.e., a constriction of the FFOV) was the perceptual load imposed by the task—selective attention is a necessary outcome of limited perceptual processing capacity. Age-related differences in perceptual processing capacity (e.g., Maylor & Lavie, 1998) may then explain observed age-related differences in FFOV size (e.g., Ball, Beard, Roenker, Miller, & Griggs, 1988). The current study examined how perceptual load and aging affected the FFOV. Younger and older participants viewed brief displays in which they engaged in two tasks: the first task was a perceptual load manipulation, while the second task was a measure of the FFOV. Multiple measures of peripheral task performance suggest that the size of the FFOV for older adults' was significantly reduced by increasing perceptual load and this effect of load was greater with increasing distance from fixation. As predicted from the perceptual load model, when perceptual load of the task increased, perceptual sensitivity for the distant peripheral task decreased for older adults. This decrease was greater when the task was farther from fixation—indicative of a shrinking spotlight. However, for younger adults, increasing load did not affect peripheral task performance. This age-related difference may be attributable to older adults' reduced perceptual processing capacity. The current results support the notion that older adults' reduced perceptual processing capacity may be one cause of their reduced FFOV. Limitations of the current study as well as future research are discussed.

CHAPTER 1

INTRODUCTION

Dividing attention (i.e., time-sharing) to more than one area of the visual field is an important ability that underlies many of our daily activities. One determinant of time-sharing efficiency between two or more visual tasks may be whether an individual has sufficiently distributed his or her attention across both tasks. If the distribution of attention is too focused on one of the tasks, performance in the other task may suffer.

The functional field of view (FFOV) is a measure of the breadth of attention over the visual field. Existing research has examined how various task factors affect the FFOV, for instance, how cognitive load of a task affects the FFOV (e.g., Williams, 1989). In general, increasing cognitive demand of the primary task has been shown to reduce performance on the secondary task. This has been taken as evidence of a reduction in the size of the FFOV due to cognitive load. However, cognitive load has often been defined very broadly in the literature. Many studies that purportedly manipulated cognitive load have manipulated *working memory load* (e.g., a memory search task). How *perceptual load* affects the FFOV is less clear.

The difference between perceptual and working memory load can be illustrated with an example: looking for a specific computer file among many other files (high perceptual load) versus trying to remember the name of a specific file and the folder in which it was stored (high working memory load). The difference between perceptual load and working memory load is related to the stage of information processing on which the task places the most demand. A task that is high in *perceptual load* places heavy demands on visual processing capacity (early in information processing) while a task that is high in memory load places demands on the working memory system (later in the stream of information processing; post-perceptual processes).

Increasing the number of items to be searched in a display (i.e., the display set size) is one operational definition of increased perceptual load. However, relative perceptual load can also be manipulated by keeping display set size constant, and changing the difficulty of the search task (e.g., target/distractor similarity; Duncan & Humphreys, 1989). In an easy search task, where the target and distractor are highly *dissimilar*, the perceptual load is low because little processing is required to detect the target (Lavie & Cox, 1997). However, in a more difficult search task, where the target and distractor are highly *similar*, the perceptual load is relatively higher because more perceptual processing is required to detect the target among the similar distractors.

The role of perceptual load on the distribution of attention (i.e., FFOV) can be hypothesized based on existing models of attention. The perceptual load model of attention (Lavie, 1995; Lavie et al., 2004) suggests that increases in the perceptual load of a primary task may reduce the FFOV, thereby potentially causing secondary task performance to suffer. This is due to perceptual processing capacity being exhausted by a perceptually demanding primary task leaving no spare perceptual processing capacity available for the secondary task. This may be functionally equivalent to a constriction of the FFOV. The result is that people will not be able to efficiently divide attention between two visual tasks. On the other hand, a primary task that is *low* in perceptual load would leave spare perceptual processing capacity that can be devoted to other tasks in the visual field. This would be functionally equivalent to a broad distribution of attention (i.e., large FFOV) which could facilitate the performance of multiple visual tasks.

However, other research has suggested the non-intuitive possibility that two unrelated tasks may be better time-shared when they are separated rather than when they are close to each other (e.g., McCarley, Mounts, & Kramer, 2004; Weinstein & Wickens, 1992; Wickens 2002). The multiple resource model of attention (Wickens, 2002) suggests that time-sharing efficiency would be increased with increasing separation of tasks because separate resources potentially serve different areas of the visual field. As long as two tasks draw upon different resources (i.e., tasks are widely separated) a high level of performance can be maintained in each task. However, when two visual tasks are in close proximity, they compete for similar resources leading to a performance decrement in either task.

The Functional Field of View (FFOV) as the Size of Visual Attention

The functional field of view (FFOV) is the visual area in which one can extract useful information without eye or head movements (Sanders, 1970); essentially, the size or scope of attention (Rantanen & Goldberg, 1999). Different researchers sometimes use different terms to describe the same concept. For example, researchers interested in studying reading use the term *perceptual span* to describe "the region of the visual field from which useful information can be acquired during a given eye fixation" (e.g., Henderson & Ferreira, 1990, p. 417). Other researchers use the term *useful field of view* (UFOV) to describe the "total visual field area in which useful information can be acquired without eye and head movements" (Ball, Beard, Roenker, Miller, & Griggs, 1988, p. 2210). In the current paper, FFOV is synonymous with the above terms to describe the area in which one can extract information within an eye fixation, which will be inferred to be the scope of attention.

In a typical FFOV experimental paradigm (e.g., Williams, 1989) participants are engaged in a primary task and simultaneously presented with a secondary task of identifying or localizing a "target" presented some distance away from central fixation (i.e., the fovea). To prevent participants from scanning the display, the stimulus duration is usually below the speed at which participants can initiate and complete a saccade. FFOV is operationalized as the accuracy at which one can locate or identify stimuli that are presented at varying distances or *eccentricities* from the fixation point. Studies have shown that the size of the FFOV, inferred from secondary task performance, varies with task demands (Chan & Courtney, 1993, 1994; Ikeda & Takeuchi, 1975; Mackworth, 1965, 1976; Rantanen & Goldberg, 1999; Sanders, 1970; Scialfa, Kline, & Lyman, 1987; Sekuler & Ball, 1986; Williams, 1982, 1989, 1995).

Cognitive/Memory load and the FFOV

Increasing mental load of the primary task has been shown to decrease secondary, peripheral task performance (i.e., reduce the size of the FFOV). Even the simple presence of a foveal stimulus has been shown to reduce the FFOV (Leibowitz & Appelle, 1969). Ikeda and Takeuchi (1975) found that the ability of younger individuals to detect and localize (report the location of) peripherally presented stimuli was reduced in the presence of a cognitively demanding foveal task. This was suggestive of a shrinking of the FFOV in the presence of a foveal task.

Williams (1982, 1989, & 1995) manipulated mental load by using a foveally presented Sternberg memory search task (Sternberg, 1975). In this task, participants memorized a set of letters (the memory search set) and determined whether a single letter on the display matched the letters that were memorized. Williams' found that under low mental load conditions (i.e., a memory set size of 2), the FFOV, as measured by peripheral task localization accuracy, was unaffected. That is, participants were able to detect and localize peripherally presented stimuli across 5 degrees of visual angle. However, under conditions of high mental load (a memory set size of 6), participants' performance on the peripheral task decreased with increasing distance from the fixation point—indicating a reduction in the size of the FFOV.

Another mental load manipulation that has been shown to affect the FFOV is a mental addition task. Chan and Courtney (1998) examined how different "cognitive loads" affected the FFOV. Participants in their task were presented with two single-digit numbers in the central portion of the display. The task was to add the two numbers together while simultaneously looking for a target letter presented at varying distances to the right or left of the summation task. Chan and Courtney found that under low levels of cognitive load (adding 1 and 2) participants were able to detect the peripheral target at all distances. However, under conditions of high cognitive load (adding 8 and 7) they found that peripheral task performance gradually got worse with increasing distance.

Perceptual load and the FFOV

Studies that have examined the relationship between cognitive/memory workload and the FFOV have reasonably shown that increasing demand affects the FFOV. However, studies that have manipulated *perceptual* load of the central task have found inconsistent effects on the FFOV (Sekuler & Ball, 1986; Ball, Beard, Roenker, Miller, & Griggs, 1988). Sekuler and Ball (1986) manipulated load of the primary central task by having participants determine if a cartoon face was smiling or frowning. They found that this central task manipulation had no effect on peripheral target localization performance for younger and older adults across a display that subtended 15 degrees of visual angle (from the center to the edge). However, this null finding may have been due to the relative ease (i.e., low perceptual load) of even the high load condition task (determining whether faces were smiling or not).

In another study that used a perceptual load manipulation, Ball et al (1988) had three levels of load. In the lowest load, participants had to determine if a cartoon face was present or absent, in the intermediate load condition, participants determined if a cartoon face was smiling or frowning, and in the highest load condition, participants compared whether two cartoon faces were the same or different. They found that increasing central task demand led to decreasing performance in the peripheral localization task in displays that subtended 30 degrees. Seiple, Szlyk, Yang, and Holopogian (1996) subsequently replicated this finding. However, compared to the Sekuler & Ball (1986) study, the study by Ball et al (1988) utilized shorter display durations (90 ms versus 125 ms) and larger displays (30 degrees of visual angle versus

15). Thus, it is uncertain whether effects on the FFOV were due to increased perceptual load or shorter stimulus durations. Brief stimulus durations have been shown to reduce the size of the FFOV (e.g., Williams, 1989).

To summarize, the effect of primary task memory load on the FFOV seems to be consistent across different studies; that is, increasing memory load reduces the FFOV. However, the role of perceptual load manipulations is less consistent. FFOV as a function of perceptual load has been less studied by researchers, and in studies that do manipulate perceptual load, the results are inconsistent, with some studies showing effects on the FFOV and other studies not showing effects. The inconsistency of perceptual load effects on the FFOV could be due to methodological differences such as how perceptual load was induced, the stimulus display durations, and whether visual distractors were used in the display. Visual distractors constitute a kind of perceptual load manipulation.

Visual Distractors and the FFOV

In addition to mental load, the presence of distractors is a critical factor determining one's distribution of attention (e.g., Mackworth, 1976). Distractors are items in the display that are irrelevant to the task (i.e., items that are not the target). Mackworth (1976) suggested that constriction of FFOV is a way to cope with visual overload brought on by displays with many distractors. In a visual display with many distractors, we deliberately constrict our attentional scope to make it easier to find potential targets. Sekuler and Ball (1986) manipulated the presence of distractors in the target localization task (no distractors or 47 distractors) and found that when distractors were present, older adults had more difficulty with the task (i.e., reporting the location of the target) while younger adults were not significantly affected.

However, when distractors were not present within the secondary task both younger and older adults were able to localize and identify peripherally presented information across displays as wide as 15 degrees (Sekuler & Ball, 1986; Scialfa, Thomas, & Joffe, 1994). Scialfa, Kline, and Lyman (1987) examined whether the amount of distractors, and not simply the presence or absence of distractors, made a difference in peripheral target localization performance. In their study, they manipulated the amount of distractors by presenting peripheral targets that were either flanked by distractors (low noise condition), or embedded in a row of distractors (high noise condition). They found, similar to Sekuler and Ball (1986) that older adults were greatly affected by the presence of noise, but also older adults' performance in the peripheral target identification task was worse as a function of the amount of noise compared to younger adults.

Most studies that have examined the role of distractors in the FFOV have manipulated either the presence or absence of distractors (e.g., Sekuler & Ball, 1986; Ball et al, 1988) or the amount of distractors (e.g., Scialfa, Kline, & Lyman, 1987). Most previous studies have also used distractors evenly spaced throughout the display (e.g., Scialfa, Kline, & Lyman, 1987) or distractors embedded within a secondary task (e.g., Ball et al, 1988) so that the number of distractors necessarily increases as distance from central fixation increases. When the amount of distractors (a perceptual load manipulation) and eccentricity (distance from fixation) is confounded, it is difficult to determine the relative contributions of each of these factors to task performance and the scope of attention. When distractors are used throughout the display, it becomes difficult to understand how perceptual load might affect the spatial distribution of attention. However, the role of perceptual load on the FFOV can be inferred from existing models of attention.

Models of Attention and their Relation to the FFOV

Perceptual load model

Lavie's perceptual load model (1995; Lavie et al., 2004) is an attempt to explain why some studies show evidence of early selection and other studies show evidence of late attentional selection. Proponents of the early selection view of attention believe that attentional selection occurs at the perceptual processing stage of information processing. Selected (i.e., attended) stimuli then enter working memory for further processing. Unselected stimuli are not further processed. Late selection theorists believe that everything in a display is perceptually processed, and enters working memory. It is here in working memory where attentional selection occurs. The critical difference between early and late selection views is at what stage attentional selection occurs (i.e., perception or working memory).

Lavie (1995; Lavie et al., 2004) has presented a hybrid model of attention that attempts to resolve the early versus late controversy. The perceptual load model proposes that early selection is observed under task conditions where a person's perceptual processing capacity is exceeded; that is, early selection is a necessary outcome of limited perceptual processing capacity. Under conditions of low perceptual load, relevant and irrelevant information (i.e., distractor items) is perceptually obligatorily processed until perceptual capacity is exhausted. This information enters working memory where attentional selection takes place (late selection).

Of course, a critical component of the model is the definition of perceptual load. Lavie and colleagues (1995; 2004) have operationalized perceptual processing load as either the number of items in the display (i.e., display set size), or keeping display set size constant and changing the type of processing required. For example, searching for a target among 2 distractors is less perceptually demanding than searching for a target among 6 distractors. Similarly, a feature search (searching for a target that varies on one dimension) is less perceptually demanding that a conjunction search (searching for a target that varies on two dimensions). Lavie and colleagues (1995, 1997, 2003, and 2004) have manipulated many different operational definitions of perceptual load and found that when perceptual load was defined as being "high" (e.g., more items in display) adjacent distractors did not interfere with responding. This finding is compatible with a reduction in the size of the FFOV due to high perceptual load.

Maylor and Lavie (1998) have found that perceptual load was also a determinant of selective attention in older adults. However, because of older adults' reduced initial perceptual processing capacity, older adults' attention was more selective at lower perceptual loads. That is, selective attention (i.e., which is consistent with a constriction of the FFOV) occurred at lower levels of perceptual loads for older adults than for younger adults. However, under the lowest level of perceptual load (when capacity was presumably not exhausted), both younger and older adults were affected by adjacent distractors which could be interpreted as a wide FFOVhat encompassed targets and distractors in the display.

A strong inference from the perceptual load theory is that for attention to be efficiently divided between two tasks (the opposite of selective attention), perceptual load of one of the tasks must NOT approach or exceed the upper limit of available capacity. More specifically, if a primary task is *low* in perceptual load (and thus does not exhaust perceptual processing capacity) spare processing capacity will be available for the secondary task. This is functionally consistent with a wide FFOV. Conversely, if a high perceptual load primary task exhausts perceptual processing capacity, there will be no spare capacity available for the secondary task. Performance in the secondary task will suffer. This is consistent with a shrinking of the FFOV.

Four-dimensional multiple resource model

The multiple resource model (Wickens, 2002) predicts that successful time-sharing between any two tasks is dependent on the extent to which two tasks share particular task dimensions. The task dimensions are *processing stages*, *processing codes, perceptual modalities*, and *visual channels*. The *processing stages* dimension refers to what stage of information processing a task primarily relies on (perception, cognition, or responding). Two tasks that share similar processing stages (e.g., two tasks that require cognition) may interfere with each other while two tasks that do not share processing stages (e.g., one task that requires cognition with another task that requires responding) will not interfere with each other. The *processing codes* dimension refers to whether the task is primarily spatial or verbal in nature. If two tasks are of different codes (i.e., one task is spatial, one task is verbal), they are less likely to interfere. For example, a manual tracking task (e.g., following a target with a joystick) is less likely to interfere with a verbal task (e.g., making a vocal response).

Similarly, two tasks that place demands on the same *modality* (e.g., two auditory tasks) may interfere with each other more than two tasks that place demands on different modalities (e.g., one visual task and one auditory task). The exception is with the visual modality. Some research has shown that within the visual modality, there appears to be two relatively independent *channels* that may draw upon unique resources (focal/ambient channels; e.g., Weinstein & Wickens, 1992). When two different tasks are distributed between the focal and ambient visual channels, time-sharing of the two tasks *may* be more efficient (e.g., Horrey & Wickens, 2004). Then, in a sense, distance between tasks can be a resource that supports efficient time-sharing.

A focal/ambient distinction within the visual system is neurologically plausible due to the different ways the foveal and peripheral areas of the retinal are represented in the visual cortex. Carrasco, McElree, Denisova, and Giordano (2003) present evidence consistent with a focal/ambient distinction in the visual field. In their study, they found that stimuli (Gabor patches) presented in the ambient channel (9 degrees of visual angle from central fixation) were processed faster than stimuli presented closer to central fixation (4 degrees of visual angle). They attributed this speed advantage in the ambient channel to the way the visual cortex is structured. Because the fovea (the focal channel) has a larger representation in the visual cortex (i.e., more neural tissue) than the periphery (ambient channel), more integration of information must occur for stimuli presented in foveal regions of the retina. On the other hand, stimuli presented in the periphery do not undergo as much processing because there is less cortical area devoted to this region of the retina.

Recent evidence that may support the focal/ambient visual channel distinction in older adults comes from two studies. McCarley, Mounts, and Kramer (2004) found that as two target stimuli became closer in a display, task accuracy to detect a target was reduced while Hahn and Kramer (1995) found that older adults, when pre-cued, were able to divide attention in two widely separated tasks (tasks separated by 12 deg of visual angle). In McCarley, Mounts, and Kramer's study, participants were searching a display for two targets of varying distances from each other. The participant's task was to determine if the two targets were the same or different. Task response time (i.e., "same" or "different") in this dual-task was faster when the two targets were *farther* apart than when the two targets were closer together. The authors attributed this to "localized attentional interference" or the phenomena of suppression of stimuli that is near other stimuli that have been selected for processing.

Further evidence that may support the focal/ambient distinction comes from a study by Hahn and Kramer (1995) where younger and older participants were able to split their attention between two distant locations. When participants were pre-cued to the locations of potential targets, they were able to effectively ignore distractors that occurred elsewhere in the display. Taken together, these different studies suggest that when the two simple tasks are closer together, attentional (not sensory; McCarley et al, experiment 2) interference results in decreased task performance. When the tasks are separated, less interference is observed. McCarley, Mounts, and Kramer's results nicely fit within Wicken's (2002) focal/ambient distinction—when two tasks are presented in close proximity they compete for the same resource, which could slow responding. When tasks draw upon different resources, performance in one task may be independent of performance in the other task. Similarly, Hahn and Kramer's study that used large distances between tasks could have allowed the two tasks to be processed in different visual channels, and potentially drawing upon different "pools" of resources.

We can make relatively straightforward predictions based on the multiple resource model. If we assume that focal and ambient visual channels constitute independent visual channels, time-sharing performance between two visual tasks will primarily depend on how close the two tasks are to each other—as the tasks move farther apart, they are more likely to draw upon separate resources compared to when they are near. Unlike the perceptual load model, the multiple resource model predicts that variations in perceptual load of a task should not interfere with secondary task performance *as long as the secondary task utilizes a different resource* (i.e., is far away from the primary task).

CHAPTER 2

OVERVIEW OF THE STUDY

The current study was designed to examine how systematic variations in the perceptual load of a primary task, eccentricity, and age affect the FFOV. A novel contribution of the current studies was the use of signal detection analysis in the study of the FFOV. Using signal detection analysis allowed the computation of separate sensitivity and response bias statistics. Traditional use of overall accuracy as a measure of performance may reflect a mixture of varying sensitivity, response bias, or both. When perceptual load is manipulated, do differences in secondary task performance reflect changes in observer sensitivity (e.g., due to a reduction in perceptual attention resources), or a change in response bias?

Previous research examining task-related factors that affect the FFOV have not specifically controlled perceptual load demands of the task and thus it is difficult to say how perceptual load might affect the FFOV. The current study was designed to test two models of visual attention that make different predictions concerning the role of perceptual load, age, and distance between tasks on the FFOV.

Additionally, the current study examined how aging and perceptual load interact to affect the FFOV. Physiological changes in the visual system due to aging can cause blurring of the retinal image (Artal, Ferro, Miranda, & Navarro, 1993) which could require the recruitment of additional perceptual processing capacity to adequately perceive stimuli. To exacerbate older adult's visual perceptual processing difficulties, aging is associated with reduction in processing capacity; that is, older adults, in general, have less processing capacity (e.g., Crossley & Hiscock, 1992; Maylor & Lavie, 1998; Tsang & Shaner, 1998). If a task is reliant on perceptual processing, older adults may be at a greater disadvantage because they require more perceptual processing capacity and they have less of this capacity than younger adults do. Finding such a pattern would lend further support to the idea that perceptual load is a critical determinant of the size of the FFOV. This pattern of results would also suggest that age-related decrements in the FFOV may be, at least in part, due to age-related differences in perceptual capacity.

However, age-related differences in perceptual capacity may not manifest itself as age-related differences in the FFOV because older adults may be able to compensate for their reduced perceptual capacity by using different strategies, or ways of doing the task. Older adults may adopt a different resource allocation strategy (i.e., focusing on one task to the detriment of the other task). To control potential individual and age-related differences in resource allocation strategies, participants in the study will be told to focus on the primary task.

Predictions from Lavie's perceptual load model (Lavie, 1995, Lavie et al., 2004) suggest that relative perceptual load imposed by the primary task will determine secondary task performance; a *high* perceptual load primary task will lead to *low* secondary task performance. Specifically, low secondary task performance should be manifested as a reduced sensitivity to detect stimuli. Presumably, the high perceptual load primary task will consume all available attentional capacity, leaving none for the secondary task. A *low* perceptual load primary task will lead to *high* secondary task performance because spare attentional capacity that is not used by the primary task will be available for the secondary task. This pattern of data is consistent with the conception of visual attention as drawing upon a single resource "pool."

However, the multiple resource model (Wickens, 2002) makes different predictions. The multiple resource model suggests that different areas of the visual field may draw upon independent resources leading to the counterintuitive prediction of better time sharing with increasing distance between the primary and secondary tasks. If the primary and secondary tasks compete for the same resource (i.e., both tasks are located close to each other) performance in one task will be dependent on the extent to which the other task does not exhaust capacity. However, if two visual tasks are located far apart, they no longer compete for resources, instead they utilize separate resources; in which case, performance in one task may be to some extent *independent* of performance in the other task. This hypothesis has yet to be directly tested.

The current study is designed to examine the effect of perceptual load manipulations on FFOV. To isolate the effect of varying perceptual load on the FFOV, distractors will not be throughout the display, but instead limited to the center portion of the display. Moreover, in the primary task, the number of distractors will be kept constant across experimental conditions. The study is also designed to examine the alternate possibility that different areas of the visual field may independently support task performance (i.e., no interference between tasks in different areas of the visual field).

For this task context, depending on which model of attention is correct, there may be two distinct patterns of results. Varying perceptual load may lead to a change in the size of the FFOV (as measured by secondary task performance). A primary task that induces a high perceptual load may result in reduced secondary task performance because all perceptual processing capacity will be exhausted, leaving no spare capacity available to process the secondary task. A low perceptual load task may result in an increased FFOV (better secondary task performance) because spare perceptual processing capacity is available to process the secondary task.

The alternate hypothesis is that instead of perceptual load, eccentricity (i.e., distance between the primary and secondary task) will determine performance in the secondary task. As the secondary task increases in distance from the primary task, performance will be better than when the secondary task is closer to the primary task. As distance between the tasks increases, there is a higher likelihood that they will be drawing up on separate resources (i.e., focal and ambient resources). These hypotheses are discussed further in the Predicted Results section below.

Method

Participants

Two age groups of participants completed this study: Nineteen younger adults (aged 18-22, *M* = 20.1, *SD* = 1.3) and twenty-two older adults (aged 65 to 75, *M* = 69.7, *SD* = 3.2). Five older adults were excluded because their primary task hit rate was lower than two standard deviations from the older adult group average. The subsequent analyses are of the remaining 17 older adults (aged 65 to 75, *M* = 69.7, *SD* = 2.9).

The younger adults were recruited from introductory psychology courses at the Georgia Institute of Technology and were offered course credit or $20 for two hours of

Table 1

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

participation. The older adults were recruited from the surrounding metropolitan area and were paid $30 for three hours of participation. Older adult participants were screened over the phone to ensure that they were generally in good health and did not suffer from any ophthalmologic disease or condition that would affect vision. Additionally, general health information was collected before the study. Participant's visual status was checked again by examining their self-reported health information form. None of the younger or older participants reported conditions that could have affected visual acuity (e.g., glaucoma or recent cataract surgery). General participant characteristics are presented in Table 1. There were no age-related differences in near vision acuity; both age groups had normal near vision. Younger adults had better far vision acuity than older adults. Younger adults also scored higher in the digit symbol substitution test (a measure of speed) and the reverse digit span (a memory measure). However, the older adults had a higher vocabulary score than younger adults.

Materials

Ability tests

Three standardized cognitive ability tests were used to describe the participants in this study. The tests were the Digit Symbol Substitution (Wechsler, 1981; a measure of perceptual speed), the Shipley Vocabulary Test (Shipley, 1940; a measure of crystallized intelligence), and the Reverse Digit Span (Wechsler, 1997; a measure of working memory).

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. This interval constituted the potential error rate of all stimulus displays (i.e., displays were presented "display time +/- 11.77 ms"). All stimulus displays were created with E-prime Version 1.1 for Windows XP (Schneider, Eschman, & Zuccolotto, 2002).

Task

Participants engaged in a dual task visual search of extremely brief displays. The primary task, always located in central fixation, was a search for a pre-defined letters embedded in distractors. Participants simultaneously searched the peripheral areas of the display for a star that appeared in random locations. Each task is described in further detail below.

Central letter search task (primary 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 letter was embedded in a *low* or *high* perceptual load letter set. In the *low* perceptual load condition, the target letter was embedded in a row of a single type of distractor repeated five times (H, K, V, W, X, or Z). An example of a low perceptual load central task would be "WWXWWW". 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 task, "KVXWHZ". In this case, the heterogeneity of the distractors will make search of the target, the letter X, relatively difficult (Duncan & Humphreys, 1989).

The central task stimuli used by Maylor and Lavie (1998) contained consistently mapped targets and distractors. That is, the letter X or N was always a target while the letters Z, K, H, Y, or V were always distractors. To assure that search for targets in the central task remained a controlled, effortful process throughout the study and to prevent the formation of an automatic attention response to a consistently mapped target (Schneider & Shiffrin, 1977), targets and distractors were variably mapped. That is, a potential target or potential distractors were drawn from the same pool of letters (H, K, V, W, X, or Z). A target on one trial served as a distractor in another trial, and vice versa. Only 50% of the trial letter sets (target embedded in distractors) contained a valid target letter. When a target was not present in a high load trial, one of the distractor letters was repeated in a non-consecutive position (e.g., the target is X, the letter set is "KVZWHZ"). In the previous example, the target letter X is not present and the letter Z is used twice to fill in the remaining position. When a target was not present in a low load trial, a random letter that was not the target was substituted (e.g., the target is X, the letter set is "WWZWWW"). In this case, the target letter X is not present, and was replaced with the letter Z. Each of the potential letters (H, K, V, W, X, or Z) had an approximately equal likelihood of serving as a target or distractor on a particular trial.

Peripheral star detection task (secondary 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 star could appear in one of 16 locations (Figure 1g) that were evenly spaced along the intersections of two imaginary circles and the four cardinal directions and the four oblique directions. After stimulus presentation (central and peripheral stimuli), the participant's responses 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.

Figure 1 illustrates the event sequence for one trial. Participants first saw a display asking them if they are ready to proceed to click a mouse button (Figure 1a). After the participant clicked a mouse button, a display indicated to the participant the target letter they should be looking for in the center of the screen (Figure 1b). After clicking a mouse button, a white fixation dot appeared in the center of the display (Figure 1c). The fixation dot subtended 0.5° × 0.5° of visual angle. After 750 ms, the central and peripheral tasks were displayed concurrently (Figure 1d). The central task was to search for the previously defined target letter among the other distractor letters. The peripheral task was to report the position of the star. The star appeared with equal likelihood in one of 16 locations along two imaginary circles.

The radii of the two levels of eccentricity on which the peripheral star can occur subtended 5.4° and 16.4° of visual angle from fixation. On a given trial condition, the participant saw one of nine displays. The central task was either absent or present. When present, the task was either a high or low in perceptual load while the peripheral task was absent, present-near, or present-far. After 140 ms, a random black and white noise mask was displayed for 750 ms (Figure 1e). The purpose of the noise mask was to obliterate any remaining image on the phosphors of the cathode-ray tube, as well as to eliminate any iconic memory of the stimulus display. After the noise mask, two consecutive response screens were displayed. In the first response screen (Figure 1f), the

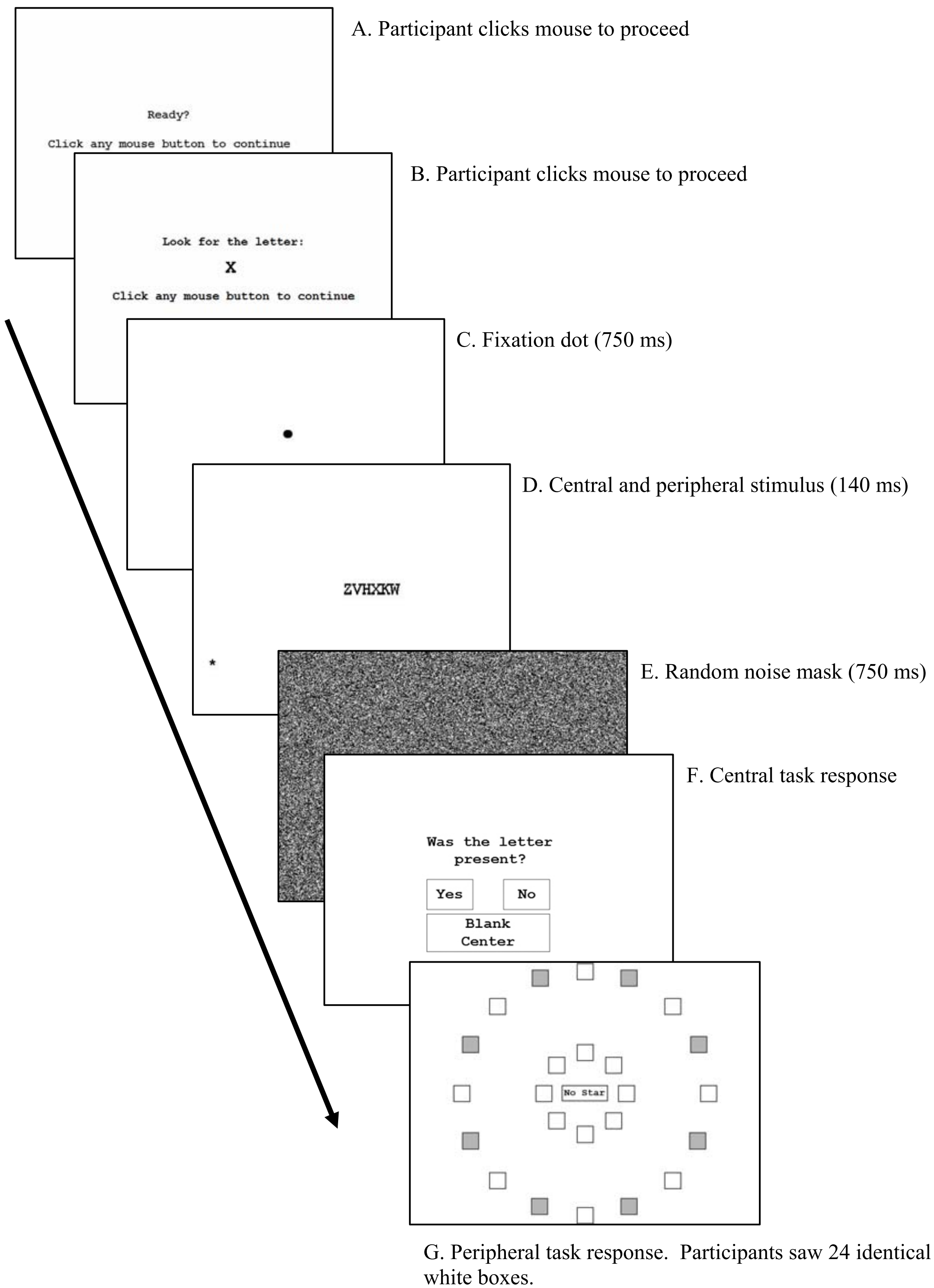


Figure 1. Event sequence for one trial (not drawn to scale and shown in reverse contrast).

participant made their central task response (“Yes”, “No”, or “Blank Center”) using the mouse to click on their choice.

After the participant indicated a central task response, 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 were added to the far ring. The extra boxes are shown as gray squares in Figure 1g. 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. Because there was more space between boxes in the far ring, it was easier to guess the correct peripheral target position if the participant was aware of which quadrant of the screen the star occurred. 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. The participant responded by using the mouse to click on the box in which the previously presented target occurred.

After the participant responded, the next screens displayed feedback for both the center and peripheral task. If the central task response (“yes”, “no”, or “blank center”) was correct, the participant saw a display with the sentence, “Central task: Correct” in green. If the central task response was incorrect, the display read, “Central task: Incorrect” in red.

If the peripheral task response was correct, the display read, “Target task: Correct” in green, if incorrect, the display read, “Target task: Incorrect” in red. Each feedback display was presented for 1500 ms. The trials 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 display indicating their center and peripheral task accuracy as well as a break notification. To enforce the breaks between blocks, the study required experimenter intervention to proceed.

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 primary task response ("Yes", "No", or "No Star") and peripheral task location (position of the star). Appendix A illustrates how the trials were distributed over display types. The 432 trials were randomly distributed across eight experimental blocks of 54 trials each.

Upon arriving at the laboratory, participants read and signed an experimental consent form. They then completed the demographics forms and completed the visual tests outlined in the materials section of this paper. After completing the consent, demographics, vision screening, and ability tests, participants started the experiment. If participants reported no previous experience with a computer mouse, they were given the opportunity to practice using a mouse in a task that was similar to the way the mouse was utilized in the study (instructions for the mouse practice located in Appendix B).

Participants were seated approximately 21 inches from the display. Viewing distance was stabilized with a chin rest.

The study was divided into three main phases, of which only data from blocks 1 to 8 of phase 2 was analyzed. In the first phase (single-task phase), participants completed 48 trials of a central task only condition. The main purpose of this phase was to provide extensive practice in the central letter search task. Because of the extremely brief stimulus durations extensive practice was required. Another benefit of extensive practice in the center letter search was that it instilled in the participants the importance of this task over the later introduced peripheral task. In the second phase of the study, participants engaged in the dual-task study where they had to complete the central and peripheral task simultaneously. This phase of the study involved 432 trials distributed over eight blocks as well as a "re-run" block (block 9) that re-displayed all the error trials from the previous eight blocks. A break of at least 5 minutes was required at the end of each block. The third and final phase (single-task phase) was 48 trials of center-task only trials.

Participants were given oral and computer-based instructions at the beginning of each of the three phases of the study (Appendix C, D, and E). Before the first phase of the study (48 trials of center-task only), participants were given five trials of practice on the task. After completing the first phase of 48 single-task trials, participants were required to take a 5-minute break. Before starting the second phase of the study (dual-task phase) they were told that they were about to start a task that required them to do two things at once. They were given oral and computer-based instructions on the central task (target present or absent) and the peripheral task (target localization task). Participants were encouraged to try their best on both tasks; however, emphasis was placed on the central task. Participants were given 6 trials of practice in the dual-task. After the practice tasks, the experimenter answered any remaining questions and again emphasized the central task. All participants were required to take a minimum 5-minute break after each block. The beginning of the last phase (center-task only block) was preceded by computer-based instructions that reminded the participant as to the nature of the task. The general procedure is outlined in Appendix F.

Hypotheses

Table 2 illustrates the potential patterns of data from this study. The table represents the potential patterns of peripheral task sensitivity by central task load (no load, low load, high load) and peripheral task eccentricity (near, far).

If FFOV is conceptualized as the spatial distribution of attention in the visual field, the perceptual load model suggests that as the perceptual load of the central task increases (and perceptual processing capacity reduces), peripheral task sensitivity will decrease due to a reduction in the size of the FFOV, or distribution of attention. This is because the high perceptual load central task consumes perceptual processing capacity, leaving less available to process the peripheral task (i.e., attention becomes selective). More specifically (Figure 2), in the *high load condition*, sensitivity for the peripheral localization task should be relatively low (compared to the single-task baseline) in both near and far positions. When the central task is low in perceptual load, peripheral task sensitivity should be relatively high for the near and far positions. This is because there is spare perceptual processing capacity available to process the peripheral task.

Additionally, the study will examine how aging interacts with perceptual load to affect peripheral task performance (i.e., FFOV). Aging is associated with a reduction in perceptual processing capacity (Maylor & Lavie, 1998). Because older adults have less initial perceptual processing capacity, a lower level of perceptual load may exhaust their capacity relative to younger adults. When perceptual load of the task is low, both younger and older adults will be able to process the peripheral task, but older adults may be less sensitive than younger adults because they have less initial capacity (Figure 2). The predicted effect of age on sensitivity within the low perceptual load condition reflects the different initial perceptual processing capacities between younger and older

Table 2.

Peripheral task sensitivity predictions

<table>
<tr><th rowspan="2" colspan="2"></th><th colspan="3">Central Task Load</th></tr>
<tr><th>No central task</th><th>Low perceptual load</th><th>High perceptual load</th></tr>
<tr><td rowspan="4">Peripheral Task Location</td><td rowspan="2">Near</td><td rowspan="2">Near task baseline</td><td>Perceptual load hypothesis:
Sensitivity reduced
(low load should have small effect on peripheral task sensitivity compared to baseline)</td><td>Perceptual load hypothesis:
Sensitivity reduced
(high load should have large effect on peripheral task sensitivity compared to baseline)</td></tr>
<tr><td>Multiple resource hypothesis:
Sensitivity reduced
(low load should have small effect on peripheral task sensitivity compared to baseline; peripheral task drawing on focal resources)</td><td>Multiple resource hypothesis:
Sensitivity reduced
(high load should have large effect on peripheral task sensitivity compared to baseline peripheral task drawing on focal resources)</td></tr>
<tr><td rowspan="2">Far</td><td rowspan="2">Far task baseline</td><td>Perceptual load hypothesis:
Sensitivity reduced
(low load should have small effect on peripheral task sensitivity compared to baseline)</td><td>Perceptual load hypothesis:
Sensitivity reduced
(high load should have large effect on peripheral task sensitivity compared to baseline)</td></tr>
<tr><td>Multiple resource hypothesis:
Sensitivity slightly reduced
(because of the distance between tasks, no effect of load; peripheral task drawing on ambient resources)</td><td>Multiple resource hypothesis:
Sensitivity slightly reduced
(because of the distance between tasks, no effect of load; peripheral task drawing on ambient resources)</td></tr>
</table>

adults.

When perceptual processing load is high, leaving little attentional capacity to process the center and peripheral task, both age groups will be less sensitive to the peripheral task (i.e., both age groups will attend selectively to the central task). Even though older adults may have less initial processing capacity, if the task can sufficiently exhaust capacity for younger adults, performance (i.e., sensitivity) may be similar for younger and older adults under conditions of high load.

In sum, the predictions that follow from the perceptual load model (Lavie, 1995, Lavie et al., 2004) are a main effect of perceptual load on peripheral task sensitivity. High perceptual load should lead to reduced peripheral task sensitivity while low perceptual load leads to relatively better peripheral task sensitivity. The model also predicts an interaction between age and perceptual load on peripheral task performance such that the high perceptual load condition should not result in age differences in peripheral task performance while the low perceptual load condition should result in age differences in peripheral task performance. The difference is due to the *initial* perceptual processing capacity differences between younger and older adults. The relative size of visual attention under low and high levels of perceptual load is illustrated in Figure 3a and 3b.

According to the perceptual load model there should be no effect of eccentricity (near or far) on peripheral task sensitivity. These results would suggest that the perceptual load imposed by the task critically determines the FFOV. A finding of no differences between peripheral task distances (near or far) as a function of load would also show that the constriction of attention due to perceptual load demands may not be

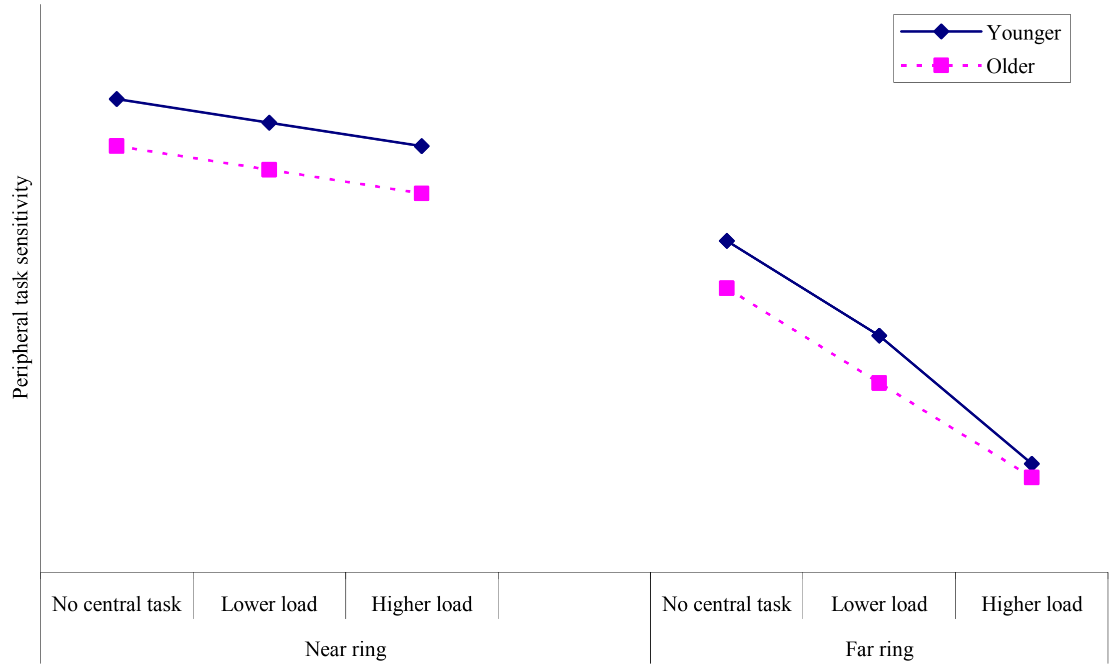


Figure 2. Predicted results from Perceptual Load Model: Peripheral task performance by central task load, peripheral task location, and age.

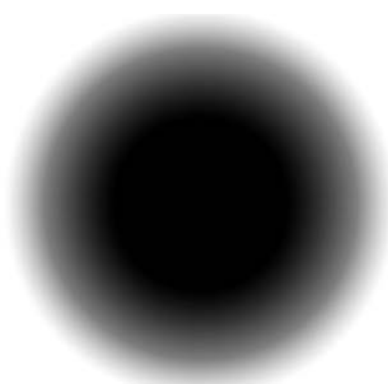


Figure 3a. Perceptual load model: Hypothesized size and shape of visual attention in a low central task load condition. Attention is broadly distributed over the visual field.

Figure 3b. Perceptual load model: Hypothesized size and shape of visual attention in a high central task load condition. Attention is constricted toward fixation.

graded (with attention falling off gradually from fixation; Laberge & Brown, 1989), but instead may be global over the entire visual field. However, with only two levels of eccentricity, the current study may not be sensitive enough to determine whether changes in the FFOV are graded or global.

The multiple resource model makes critically different predictions (illustrated in Figure 4) compared to the perceptual load model. If the central and peripheral task (localization task) share resources (i.e., are close to each other) performance in the peripheral task will be relatively low. This is because participants will be told to emphasize the central task. If the central and peripheral task do not share resources (i.e., are in different areas of the visual field), peripheral task performance will be relatively good compared to when the tasks are close. It is hypothesized that as the distance between the center and peripheral task is reduced, peripheral task accuracy will be lower (compared to the single-task baseline). However, when the peripheral task is in the far position, peripheral task accuracy will be better relative to the near position. The drop in sensitivity seen in the far ring from "no center task" to "lower load" represents the "cost of concurrence" (Navon & Gopher, 1979), or the additional resources required for time-sharing two tasks compared to a single task (the no center task condition).

The predictions regarding the effect of age on the FFOV from the multiple resource model are less clear. No research has been conducted that specifically examines the focal/ambient distinction and how age-related changes in vision and attention would affect the resource pools. The previous research that has been conducted in paradigms similar to the current one (e.g., Hahn & Kramer, 1995; McCarley et al, 2004) suggest that older adults may have preserved focal and ambient attentional resources available to

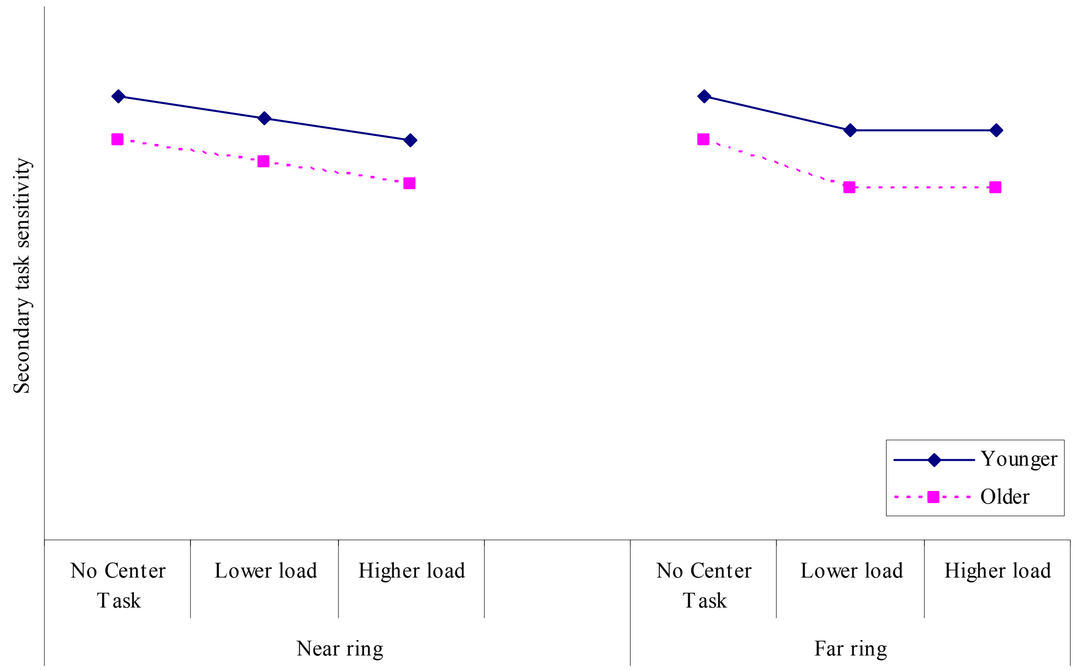


Figure 4. Predicted results from Multiple Resource Model: Peripheral task performance by primary task load, peripheral task location, and age.

Figure 5a. Multiple-resource model: Hypothesized size and shape of visual attention in a low load primary task condition. Notice the large diameter of attention, as well as the outer ring representing separate resources.

Figure 5b. Multiple-resource model: Hypothesized size and shape of visual attention in a high load primary task condition.

support performance when the tasks are far apart (Hahn & Kramer, 1995). However, when tasks are close to each other, there may be attentional interference due to resource competition, and this interference is greater for older adults (e.g., McCarley et al, 2004).

To summarize the multiple resource model predictions, there should be a main effect of eccentricity (e.g., near or far) on peripheral task sensitivity such that when tasks are close to each other, sensitivity for the peripheral task will be reduced. When the central and peripheral tasks are further apart, peripheral task sensitivity will be better relative to when they are closer together. The hypothesized distribution of attention, from the multiple resource model, is illustrated in Figures 5a and 5b.

There are no specific hypotheses regarding response bias and the literature does not provide guidance toward making specific predictions. Under conditions of uncertainty (either due to age or experimental manipulations) participants could respond conservatively (i.e., less likely to report peripheral target was present) or liberally (i.e., more likely to report peripheral target present). Given that participants were urged to focus on the central task, participants of both age groups may adopt a liberal response criterion for the peripheral task. On the other hand, there may be age differences such that older adults, who in previous visual search studies exhibit conservative response bias (Batsakes & Fisk, 2000), may exhibit a conservative bias while younger adults exhibit a liberal response bias.

CHAPTER 3

RESULTS

Overview of Analyses

To review the study design, the central task was the means by which perceptual load of the display was manipulated. The central task was always located at central fixation. The peripheral star detection task was the indirect measure of the breadth of attention, or FFOV. The peripheral task involved correctly localizing a star presented at various locations along one of two rings around the fixation point.

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 the distribution of visual attention over a display (i.e., FFOV). Previous studies that have examined the FFOV have used measures of performance (e.g., proportion correct, error rate) that confound sensitivity and response bias (i.e., they reflect a mixture of sensitivity and response bias). Thus, it is difficult to determine, by using overall percent correct or error rate, whether person- and task-related changes in the FFOV are moderating changes in the distribution of attention (that would be manifested primarily in changes in perceptual sensitivity) or changes in response criteria. Therefore, signal detection methods, in addition to an analysis of hit and false alarm rates, were used to compute separate measures of sensitivity and response bias as a function of experimental conditions and age group.

How aging and level of perceptual load might affect the distribution of attention is suggested by two theories of visual attention. Perceptual load theory suggests that perceptual load of the display is the critical determinant of the size FFOV. As the perceptual load of the display increases, attentional resources are consumed which results in a constriction of the FFOV (analogous to a constriction of the spotlight of attention). This should lead to a corresponding decrease in sensitivity to detect targets that are presented farther away from fixation (i.e., as the breadth of attention decreases like a spotlight, far targets become more difficult to perceive). Lavie and colleagues (e.g., Lavie et al., 2004) have found that this withdrawal of attention due to increasing perceptual load manifests itself as ease of ignoring peripheral distractors in a response competition paradigm (i.e., selective attention).

The four-dimensional multiple resource model (Wickens 2002) suggests that independent resources (i.e., focal/ambient) serve different areas of the visual field to potentially support dual-task performance (one focal task, one ambient task). Thus, perceptual load differences in the display may not necessarily affect performance in other areas of the display because separate resources support performance in different areas of the visual field.

In the current study, the effect of perceptual load on the FFOV was examined by analyzing the participant's perceptual sensitivity to detect a peripherally presented star and bias in responding. The critical analysis was to determine how peripheral task sensitivity and bias were affected by the a) central task perceptual load, b) the location of the peripheral task (i.e., distance from fixation, or "eccentricity"), and c) age. According to perceptual load theory, increases in the perceptual load central task should lead to decreased perceptual sensitivity to detect peripherally presented stimuli. Additionally, perceptual sensitivity should also be affected by age. Older adults are presumed to have less initial processing capacity than younger adults (Maylor & Lavie, 1998). This should lead to the observation of a main effect of age—older adults will be less sensitive to detect a target than younger adults will. The multiple resource model would predict no change in perceptual sensitivity to detect a stimulus based on perceptual load, but would predict a change in sensitivity with location of the peripheral task. Sensitivity for the peripheral task should be better farther from central fixation compared to nearer.

Five older adults were excluded from all analyses because their hit rate was more than two standard deviations below the mean of the age group. Removing these five older adults only altered the statistical significance of one effect: a three-way interaction. Repeated measures analysis of variance (ANOVA) was used to compare performance by age group and experimental conditions. The criterion of statistical significance was .05. ANOVA tables for each of the analyses are located in Appendix I. When proportion data are illustrated in a graph (e.g., hit rate), the actual proportions are illustrated in the graph, however, statistical tests were carried out on the arc-sine-transformed data. The transformation was necessary to more closely approximate a normal distribution (Zar, 1974).

The results from the study are presented in two main sections, each answering a different question. The first section contains the analyses of the hits, false alarms, and signal detection statistics for the *central letter search task* data. The goal of these analyses is to determine if the manipulation of perceptual load was successful—recall that the central task was how perceptual load was manipulated, in which case central task letter search performance should decrease with increasing perceptual load (i.e., letter search difficulty should be affected).

The second section contains the analyses of the hits, false alarms, and signal detection statistics for the *peripheral task* data. Recall that the peripheral task was the indirect measure of the FFOV.

Central task: Letter Search Task

Hits and False Alarms

Central task hit rate (proportion of trials that were correctly identified as having a target letter) and false alarm rate (proportion of trials incorrectly identified as having a target letter) are illustrated in Figure 6 as a function of load (lower load, or higher load) and age group (and in Table H1).

Although the main effects of age, $F(1,34) = 12.42$, $MSE = .23$, and load, $F(1,34) = 8.67$, $MSE = .04$, were significant, age significantly interacted with load. The load manipulation had different effects for each age group, $F(1,34) = 8.41$, $MSE = .04$, with load having a slight but significant *beneficial* effect on hit rate for the older adults, but no significant effect for the younger adults. The complete ANOVA table is presented in Table I1.

However, older adults' false alarm rate was significantly higher than younger adults, $F(1, 34) = 56.31$, $MSE = 1.75$. More false alarms occurred in the higher load

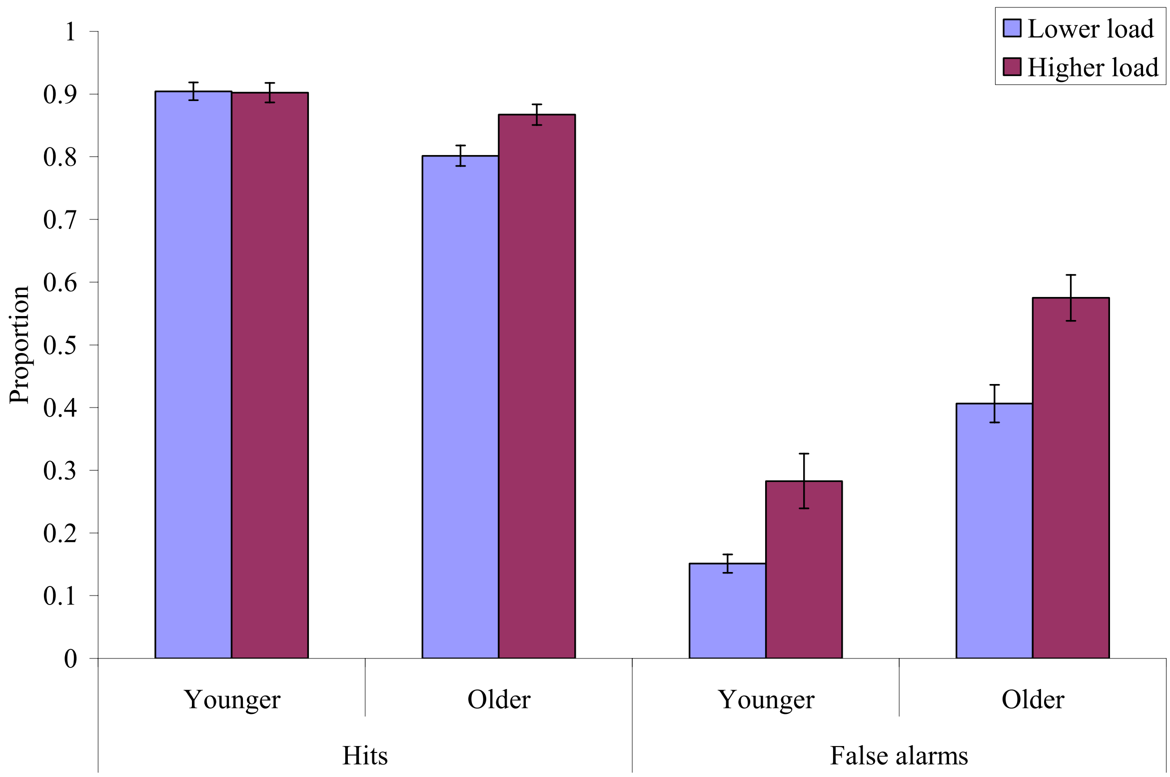


Figure 6. Central task hits and false alarms by age group, perceptual load

condition than the lower load condition, F(1, 34) = 25.95, MSE = .49. The complete ANOVA table is presented in Table I2.

To summarize, older adults' hit rate was lower and false alarm rates higher than for younger adults. The central task perceptual load manipulation had no effect on central task hit rate for younger adults suggesting that even the higher load condition was relatively easy for the younger adults. Increasing central task perceptual load also resulted in an increase in hit rate for the older adults. However, increasing perceptual load resulted in increased false alarm rates for both age groups.

The slightly higher hit rate due to higher perceptual load among older adults, and no effect on hit rate for younger adults is puzzling, but may be readily explainable through signal detection analyses. If older adults relaxed their response criterion in the high load condition (i.e., were more willing to respond, "target present") this would explain their simultaneous increase in hit rate and false alarm rate in the high perceptual load condition. Similarly, if younger adults became more liberal in their responding, it would explain why there was no change in hit rate, but an increase in false alarm rate. To explore this possibility, signal detection analyses were conducted on the central task hit and false alarm data.

Signal Detection Analyses

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 affected by 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) 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 B (Green & Swets, 1988). Thus, non-parametric signal detection statistics, which do not require normally distributed responses, were computed (A' for d' and B'' for β). For each participant, sensitivity to detect the central task target letter (A') and criterion for

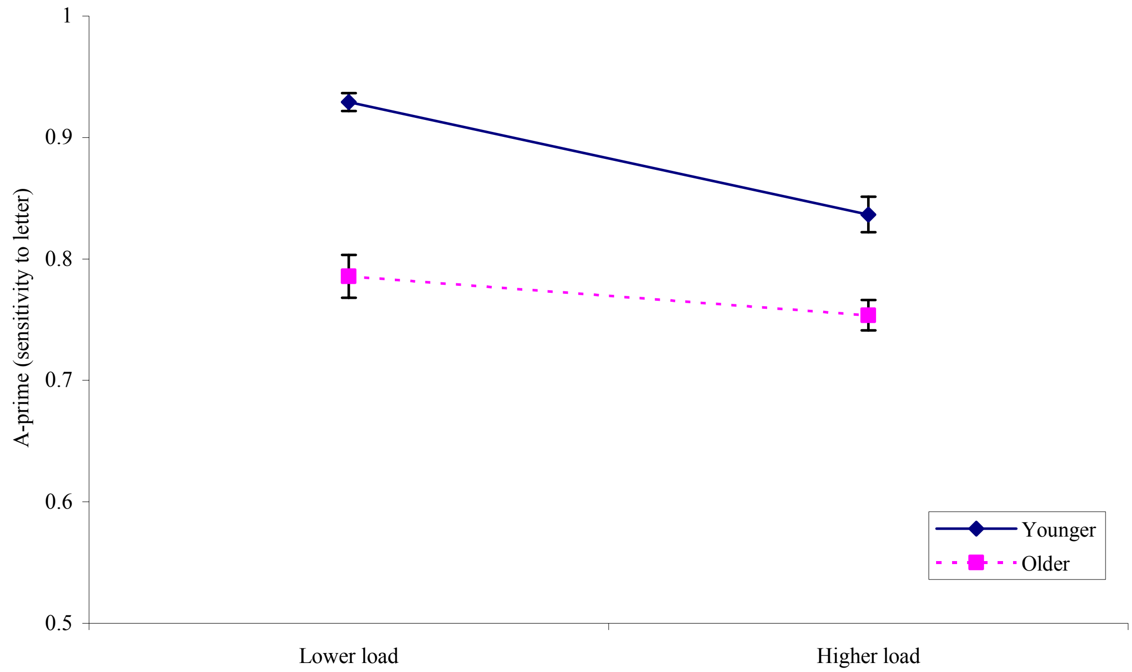


Figure 7. Central task signal detection analysis: Sensitivity as a function of perceptual load and age group (A'). Perfect sensitivity to the target letter is indicated by 1.0, no sensitivity is indicated by 0.5.

deciding the presence of a central task target letter (B'') were computed (Grier, 1971; Pollack & Norman, 1964; Stanislaw & Todorov, 1999). The equations used to calculate A' and B'' are presented in Appendix G.

Signal detection measures cannot be computed when individual hit or false alarm values are equal to 0 (e.g., no false alarms) or 1.0 (e.g., perfect hit rate). In the cases where false alarm rate was 0, 1/2N was used instead, where N was the maximum number of false alarms possible. Similarly, when hit rate was 1.0, 1 – 1/2N was used where N was the maximum possible number of hits (Wixted & Lee, 2005).

Sensitivity

Central task sensitivity (A') as a function of load and age group is represented in Figure 7. In this case, sensitivity refers to the participants' ability to detect the presence of the target letter within the central task when it was embedded in different perceptual load conditions. The A' statistic ranges from 0.5, indicating no sensitivity to the presence of the target letter (i.e., chance performance), to 1, indicating perfect sensitivity to the target letter. Under conditions of high perceptual load, perception is made more difficult but not impossible. Thus, the only time we should observe A' at or near 0.5 is if the participant could not see anything and was responding randomly.

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 between 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. Means and standard deviations are presented in Table H3 and the complete ANOVA table is presented in Table I5.

To summarize, changes in perceptual load altered younger adults' central task sensitivity but not for the older adults'. This is potentially problematic because a change in sensitivity as a function of perceptual load would have provided an experimental manipulation check—that perceptual load was indeed manipulated. However, examining how response bias was affected by load and age provides evidence that older adults' performance was affected by the manipulation of load.

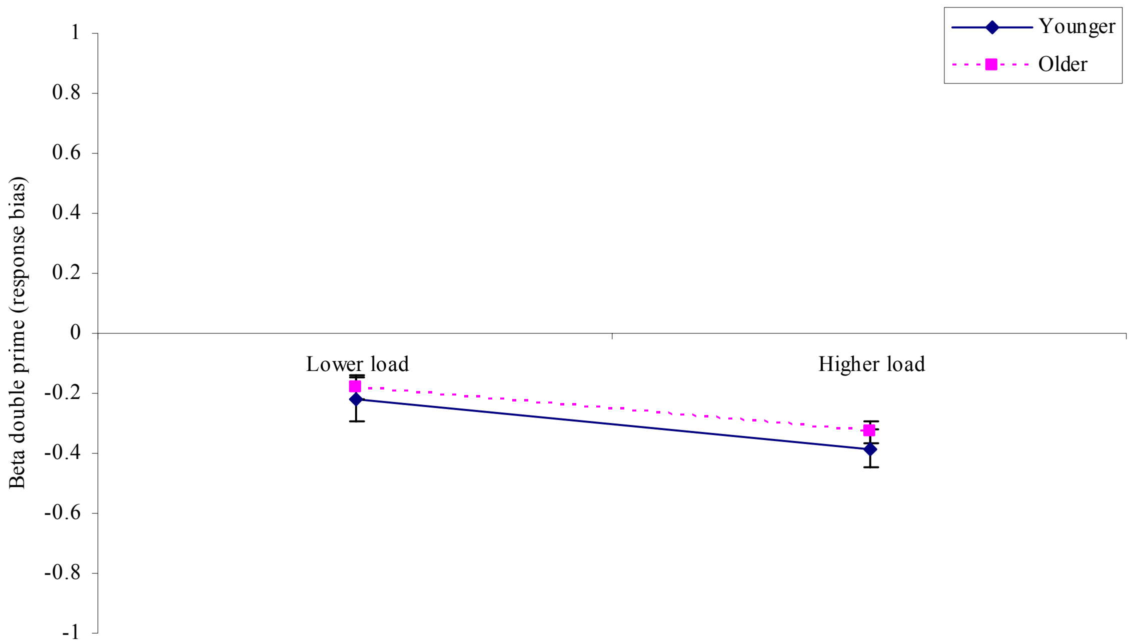


Figure 8. Central task signal detection analysis: Bias as a function of perceptual load and age group (B''). Positive values indicate conservative bias, negative values indicate liberal bias, zero indicates no bias.

<u>Bias</u>

Bias indicates a preference for responding in a particular way under uncertainty. The bias statistic, B'', ranges from -1 (indicating a liberal bias; more likely to respond "target letter present") to +1 (indicating a conservative bias; more likely to respond "target letter absent"). Bias as a function of load and age group is illustrated in Figure 8.

The main effect of load on central task response bias was significant, $F(1,34) = 9.79$, $MSE = .46$, indicating that as load increased, participants became more liberal in their responding (more likely to say a target letter was present than not). There was no significant effect of age group on bias and no interaction between load and age group on central task bias—the change in bias was nearly equivalent across the age groups. Both age groups became more liberal in their pattern of responses as load increased which could be expected if increasing load has the effect of making letter search more difficult. As the letter search task became more difficult, participants may have been more likely to guess (i.e., to relax their criterion for a target present).

Although older adults' sensitivity in the central task was not affected by increasing load, load did affect older (and younger) adults' response bias. The means and standard deviations are presented in Table H3 while the complete ANOVA table is presented in Table I6.

The signal detection analyses confirm and extend the hit rate and false alarm data. Recall that older adults' hit rate actually increased under high load compared to lower load. The signal detection statistics show that the cause may have been a shift to a more liberal response criterion (more likely to respond "target present") paired with a nearly constant sensitivity across levels of load.

There were no age-related differences in response bias which indicated that both younger and older adults approached the task with similar strategies (e.g., older adults did not become differentially more conservative as the task became more difficult). However, the response bias did change as a function of perceptual load for both age groups with responding becoming more liberal as load increased—that is, under high load conditions, participants were more willing to respond that a target letter was present in the display when it was not.

In sum, analysis of the central task show that load was successfully manipulated for younger adults (affecting sensitivity and bias) and for older adults (affecting only bias).

Peripheral Task: Star Detection

The peripheral task was the star localization 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. 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 or a decreased ability to detect changes (e.g., Pringle, Irwin, Kramer, & Atchley, 2001). The participant was required to localize a star that was briefly shown at the same time as the central task. Participants then used the mouse to click on a location in which they thought the star appeared. The star could have appeared randomly in 16 locations along eight "spokes." Hit rate did not differ between spokes (see Appendix K for a summary) so the eight spokes were collapsed and analyzed as two rings: near and far. The criterion of statistical significance was .05. All proportion data were transformed for analyses, but are illustrated in proportions.

Hits and False Alarms

Peripheral task hit rate and false alarm are illustrated in Figure 9 as a function of central task load (no load, lower, or higher), eccentricity (near or far ring), and age group (younger, older). While there were many other ways to define a hit and false alarm (e.g., by partitioning the display into quadrants and defining a hit as a response within a particular quadrant of the display) the ring distinction was most appropriate given the

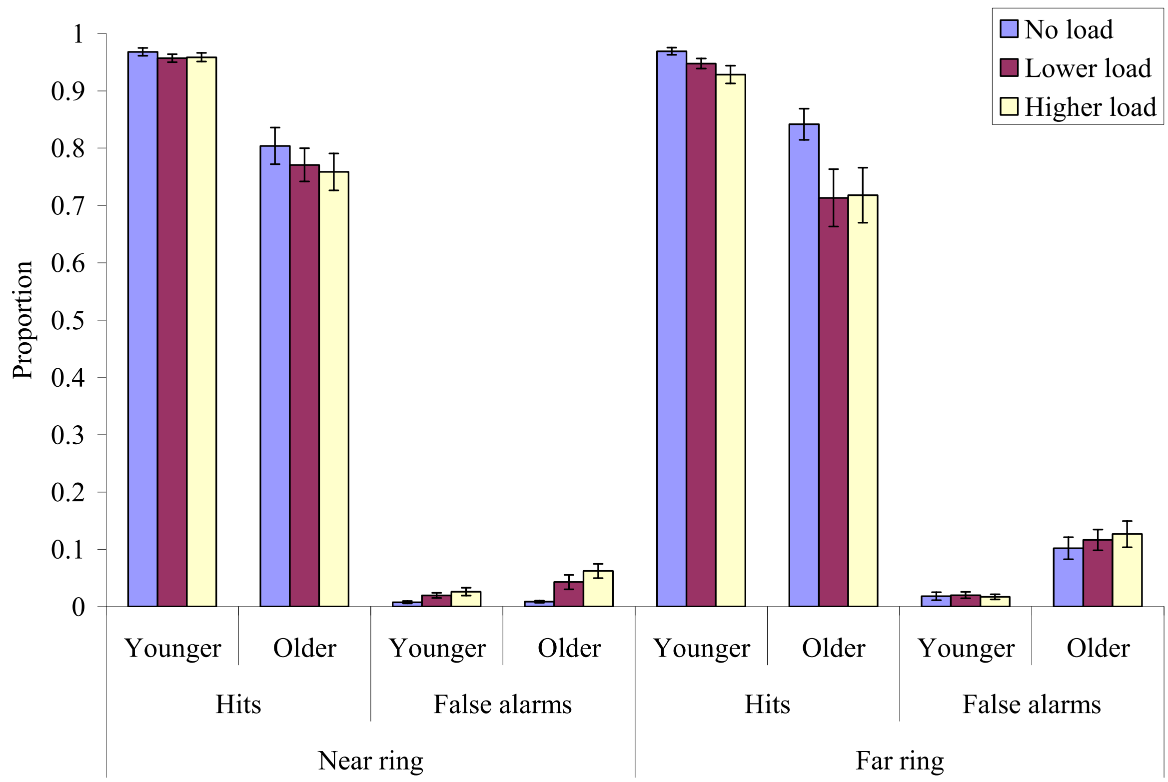


Figure 9. Peripheral task hits and false alarms by central task condition (no load, lower load, higher load) and age group (young, old). Error bars represent the standard error.

purposes of the study and the assumption that visual attention behaved as a circular spotlight.

A response was considered a 'hit' in a particular ring if the star appeared in a ring and participants responded with that ring. For example, the hit rate in the near ring was the total number of times the participant responded "near" divided by the total number of times the star was actually presented in the "near" ring. Thus, a hit rate of 1.0 indicates that the participant always correctly identified the correct ring in which a star appeared. A false alarm is when the participant mistakenly thinks that a stimulus occurred in a location where it did not. In this task, a response was considered a 'false alarm' when participants localized a star in one ring when it actually occurred in the other ring. For example, false alarm rate in the near ring was the total number of “near” responses when the star was actually present in the far ring divided by the total number of times the star was in the far ring. Similarly, false alarm rate for the far ring was the total number of times the participant responded “far” when the star was actually in the near ring divided by the total number of times the star was in the near ring. Thus, for the near ring, a false alarm rate of zero indicates that participants never made the mistake of saying a star presented in the far ring occurred in the near ring; 0 near responses / 48 occurrences of a far star = 0. Similarly, for the near ring, a false alarm rate of .5 indicates that half the time, participants responded a star occurred in the near ring when it was actually in the far ring; 24 near responses / 48 occurrences of a far star = .5.

The false alarm rate computed above is specifically for localization false alarms, not *detection* false alarms. Specifically, this means that the trials in which no peripheral star was presented were not included in the false alarm calculations. The rationale for computing false alarms without including trials in which there was no peripheral star was that since the participant responded with a ring location (near or far) and not the “no star” button they must have detected the star. Thus, given the participants detected a star, what was their hit and false alarm rate for correctly localizing the detected star?

However, the false alarm data were also re-computed by including trials in which no peripheral task was presented. For example, false alarms for the near ring were calculated as the total number of times a participant responded “near” when the star was actually in the far ring or *was absent from the display* (the no peripheral task trials). Computing false alarms (and signal detection statistics) in this way did not lead to any major changes in the interpretation of the data. That is, false alarm rate did not differ in a meaningful way when false alarms were calculated to detection or localization. This supports the notion that participants were not under data-limited conditions (i.e., sensory), but more likely resource limited conditions (i.e., attention). For a summary of the results from re-computing false alarms, see Appendix L.

The proportion data (hits and false alarms; Table H2) were transformed and submitted to a repeated-measures ANOVA (Table I3). Older adults' peripheral task hit rate was lower than the younger adults' hit rate, $F(1, 34) = 62.7$, $MSE = .72$. Also, as the *central task* perceptual load increased, hit rate in the *peripheral task* decreased, $F(2, 68) = 9.06$, $MSE = .14$. Central task perceptual load had different effects on peripheral task hit rate depending on the location of the star, $F(2, 69) = 5.23$, $MSE = .03$. In the near ring, changes in central task load had no effect on peripheral task hit rate. However, in the far ring, increases in central task load (from no load to low load) resulted in a significant decrease in peripheral task hit rate.

This pattern of data is consistent with an attentional spotlight that changes size depending on perceptual load. As perceptual load increases, the size of the attentional spotlight shrinks as attention is withdrawn from distant areas. The result is that it becomes more difficult to accurately detect the presence and location of the peripherally presented star. In this task, the near ring was presumably still within the scope of attention (hence load did not affect performance) but the far ring received less of the attentional spotlight as perceptual load increased.

For false alarms, the main effects of age, $F(1,34) = 40.34$, $MSE = .15$, load, $F(2,68) = 16.32$, $MSE = .07$, and eccentricity, $F(1,34) = 30.59$, $MSE = .33$, were significant. However, the interaction between age group and eccentricity was significant, F(1,34) = 31.05, MSE = .33, because for younger adults, increasing eccentricity had no effect on false alarm rates but for the older adults, increasing eccentricity resulted in a significant increase in false alarm rate. The interaction between load and eccentricity on false alarm rate was also significant, F(2, 34) = 4.72, MSE = .03, indicating that varying central task load significantly affected peripheral task false alarm rates in the *near* position but not in the *far* position. This is consistent with the notion that with increasing distance from fixation, the resolving power of attention is lower, leading to more false alarms. The complete ANOVA table is presented in Table I4.

To summarize, older adults' hit rate was lower and false alarm rate higher than younger adults'. Across both age groups, central task perceptual load only affected peripheral task performance in the far ring. This pattern is supportive of a spotlight of attention that shrinks in the presence of a centrally located high perceptual load. The age-related pattern of hits and false alarms from this study replicates earlier studies that have examined aging and the FFOV (e.g., Ball, Beard, Roenker, Miller, & Griggs, 1988).

However, a major limitation of studies that have used percent correct (or percent error) as the dependent variable is that this kind of performance measure reflects a mixture of perceptual/attentional contributions and cognitive biases. Thus, it is unclear if aging and variations in perceptual load affected the distribution of visual attention (which would primarily affect perceptual sensitivity) or simply altered participants response strategies (bias). For example, are age-related changes in the FFOV found in this and previous studies due to age-related changes in attention and perception or are older adults simply more cautious in responding (i.e., less likely to report a target as "present" even if they saw it)? To determine the roles of sensitivity and bias in responding, signal detection statistics were computed from the hit and false alarm rates.

Signal Detection Analyses

Sensitivity

The signal detection statistics (A' and B'' for sensitivity and bias, respectively) were computed from each participant's hit and false alarm data. The equations used to calculate A' and B'' are presented in Appendix G. To review, according to the perceptual load theory central task perceptual load increases should cause the FFOV to constrict leading to decreased peripheral task sensitivity because increasing perceptual demands of the display utilizes limited perceptual processing capacity. As perceptual processing capacity declines, the breadth of attention should shrink. According to the multiple resource model, sensitivity to detect the peripheral task should be best when the peripheral task is presented far from the central task. When the peripheral task is far away, it will presumably be drawing upon a separate visual resource—one that is not shared with the central task.

If we assume that increases in perceptual load have the effect of using up attentional resources, this should lead to more difficulty in correctly localizing the peripheral task. Thus, perceptual load manipulations should affect bias, but it is uncertain how bias might be affected. For example, when it difficult to correctly localize the star

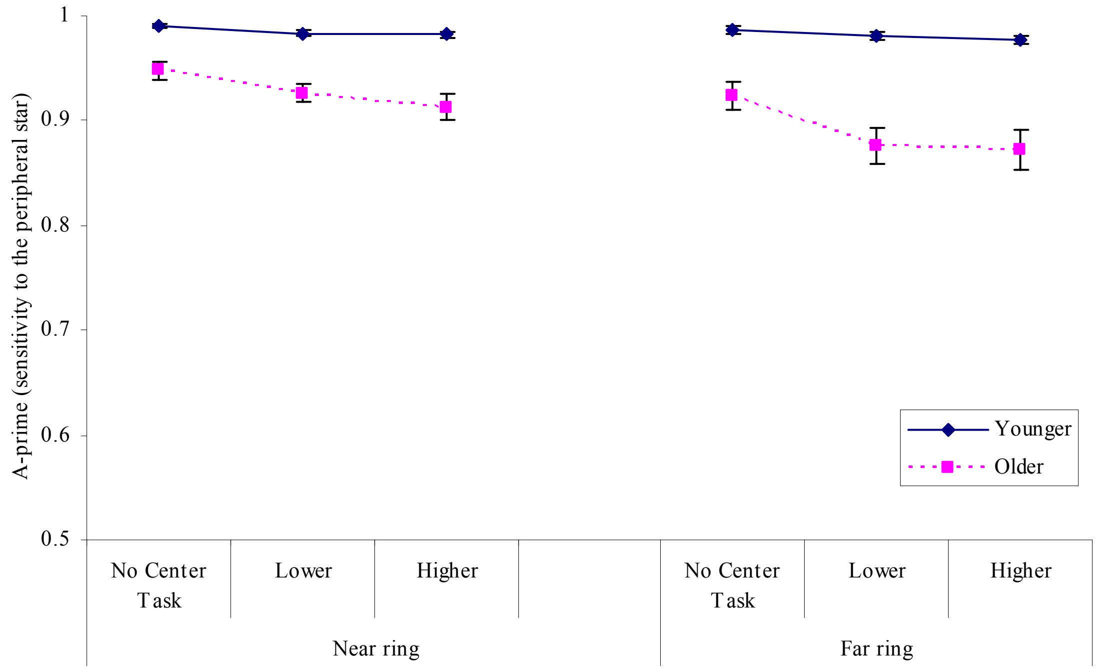


Figure 10. Peripheral task signal detection analysis: Sensitivity as a function of peripheral task position, central task load, and age group (A'). Perfect sensitivity is equal to 1.0 while no sensitivity is 0.5.

(due to experimental manipulations or aging) participants could adopt a bias toward responding that the star occurred in one ring or another.

Figure 10 illustrates peripheral task sensitivity (A') as a function of central task load and eccentricity (location in which the peripheral task appeared). Because the three-way interaction between load, eccentricity, and age group was significant, the significant main effects and 2-way interactions will not be elaborated upon (see Table I7). The three-way interaction of load × eccentricity × age group interaction was significant, $F(2,68) = 3.95$, $MSE = .001$, indicating that load had different effects on sensitivity depending on the position of the peripheral task and age group.

The source of this three-way interaction was a significant two-way interaction of load × eccentricity, $F(2,34) = 3.78$, $MSE = .001$, for the older adults, but not for the younger adults. As illustrated in Figure 10, for older adults increasing central task load had greater effects on sensitivity in the far position compared to the near position (the slope of the lines representing older adults' sensitivity is steeper in the far ring compared to the near ring). Follow up tests revealed that for younger adults, load and eccentricity had no significant effect on sensitivity. However, for older adults, the main effects of load and eccentricity were significant. The interaction between load and eccentricity was only significant for the older adults.

A significant load × eccentricity among older adults (but not younger adults) is consistent with the perceptual load model where attention could be thought of as a changeable spotlight with a focus at fixation. For older adults, when perceptual load was higher, there was a decrease in sensitivity and this decrease was greater with increasing distance from central fixation (the steeper slope in Figure 10). For younger adults, peripheral task sensitivity was unaffected by load or eccentricity. Continuing the spotlight metaphor, under higher perceptual load older adults' spotlight of attention shrunk in size and became dimmer while younger adults spotlight of attention did not change. Presumably, this is because older adults' more limited perceptual processing capacity, compared to younger adults resulted in a constriction of attention toward fixation with increasing load. For older adults, as perceptual processing resources were consumed by the central task, less was available to process the peripheral task. The means and standard deviations are presented in Table H4 while the complete ANOVA table is presented in Table I7.

Bias

To recall, response bias is a participant's likelihood of responding in one way or another. In the current task, response bias indicates a participant's preference for responding that the peripheral target appeared in one ring or another. The importance of examining how response bias was that differences in response bias as a function of load and age may explain the observed relationships between load and age and the FFOV. It is important to distinguish whether aging and load manipulations affect sensitivity, which may be related to differences in visual attention, or bias, which may reflect changing decision criteria.

Figure 11 illustrates the peripheral task bias as a function of central load and peripheral task eccentricity. As before, the bias statistic, B'', ranges from -1 (indicating a liberal bias; more likely to respond signal present) to +1 (indicating a conservative bias; less likely to respond signal present). Overall, both younger and older adults, regardless of experimental condition, responded conservatively (positive values of B''). A conservative bias indicates that, in general, false alarms, or mis-identifications of the target ring location, were low.

However, the interaction between eccentricity and age group was significant, $F(1,34) = 14.41$, $MSE = 4.49$. The source of this interaction was a significant effect of eccentricity on older adults' bias but not for younger adults. For younger adults, response bias remained unchanged whether the peripheral task was presented near or far from fixation, whereas older adults' response bias became more neutral (closer to 0) when the peripheral task was in the far ring.

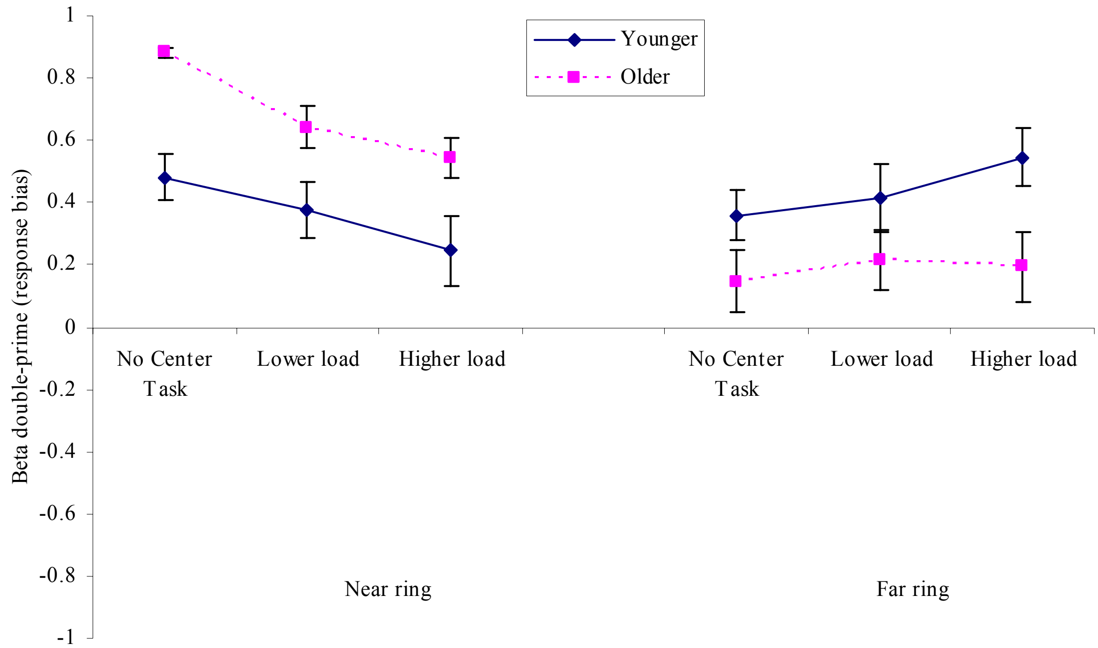


Figure 11. Peripheral task signal detection analysis: Bias as a function of peripheral task position, central task load, and age group (B''). Positive values indicate conservative bias, negative values indicate liberal bias while zero is no bias.

The interaction between load and eccentricity was also significant, $F(2, 68) = 6.07$, $MSE = .74$, indicating that in the near ring (closest to fixation), increasing central task load resulted in an increasingly neutral response bias (all pair-wise comparisons of load were significant). However, in the far ring, increasing load had no significant effect on response bias. The three-way interaction between age, load, and eccentricity was not significant. The means and standard deviations are presented in Table H4. The complete ANOVA table is presented in Table I8.

To summarize, the results from the signal detection analyses of the peripheral task sensitivity were predicted by the perceptual load theory. That is, the distribution of visual attention was critically determined by the perceptual processing demands of the display. However, the relationship between perceptual processing demands and the distribution of attention (as measured by perceptual sensitivity) was moderated by age. Older adults, who presumably had less initial perceptual processing capacity, were more greatly affected by perceptual processing demands of the task as evidenced by their reduced perceptual sensitivity. Additionally, the load by eccentricity interaction found for the older adults' perceptual sensitivity suggest a pattern of visual attention that was predicted by perceptual load theory (but not expected from the multiple resource model)—the pattern of greater sensitivity loss at greater eccentricities than nearer eccentricities for older adults. The results also demonstrate the importance of perceptual load and perceptual processing capacity of the observer as important determinants of the size of the FFOV.

In relation to the test of the perceptual load model or the multiple resource model, the key finding from the analysis of response bias was that increasing perceptual load affected response bias when the peripheral task was near fixation but not when the peripheral task was far from fixation. This is supportive of a model of visual attention similar to a zoom-lens model (Eriksen & Yeh, 1985)—one that has a unitary focus and a limited spatial extent.

CHAPTER 4

DISCUSSION

A common metaphor for visual attention is the "spotlight" (Posner, 1980). That is, we can think of a person's distribution of visual attention as a spotlight that "illuminates" parts of the visual field making stimulus detection easier. The size of this spotlight can change size depending on various task-related and person-related factors. For example, it has been shown that cognitively demanding tasks (e.g., Williams, 1982) reduce the size of the spotlight of attention. When this happens, information located in the periphery is more difficult to detect and process.

Existing research has shown that concurrent memory loads affect the breadth of attention, or FFOV. That is, when a demand is placed on working memory, the FFOV is negatively affected. However, the relationship between perceptual load and the FFOV is less clear. Previous studies that may have manipulated memory or cognitive load left perceptual load uncontrolled. Previous research has shown that the perceptual demand of the task *may* affect spatial aspects of attention. However, no research has directly examined the relationship between perceptual load and the dynamics of visual attention (i.e., FFOV).

The goals of the current study were to a) examine the role of perceptual load on FFOV, b) examine how distance between tasks affects concurrent task performance, c) and if/how aging affects the FFOV. Aging may be associated with a reduction in perceptual processing capacity (Maylor & Lavie, 1998) which may explain why older adults' FFOV is smaller than other age groups.

There were some unique aspects about this investigation. First, the perceptual processing demands of the stimuli were rigorously controlled. Previous studies have left the perceptual processing demands of the task uncontrolled (via distractors) making it unclear how perceptual processing demands uniquely affect the FFOV. The current study controlled for perceptual processing demands by altering the search difficulty of the central task while leaving the number of items to be searched unchanged. Additionally, distractors were limited to the central portion of the display and not distributed throughout the display.

Second, target and distractors were variably mapped instead of consistently mapped. Consistently mapped targets (as used in previous investigations of perceptual load) engender an automatic attention response, which could dilute the search difficulty and therefore the perceptual demands of the task. In the current study, perceptual load was manipulated as search difficulty while holding constant the number of items to be searched.

Third, in addition to an analysis of hits and false alarms, signal detection analyses were used to examine the extent of the FFOV. The use of signal detection analyses allowed the separate of aspects of performance that may have been due to perception/attention and those aspects of performance due to decision biases. Previous studies of effects of various factors on the FFOV may then be due to alterations of response bias and not due to aspects of attention (which would affect perceptual sensitivity).

General Summary

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 was indicative of visual attention that shrinks toward a unitary focus (akin to a spotlight) as perceptual load increased. As predicted from the perceptual load model, when perceptual load of the task increased, perceptual sensitivity for the distant peripheral task decreased for older adults. This decrease was greater when the task was farther from fixation—indicative of a shrinking spotlight. However, for younger adults, increasing load did not affect peripheral task performance. This age-related difference may be attributable to older adults' reduced perceptual processing capacity. Younger adults may not have shown a similar pattern because the current experimental task was not perceptually demanding enough—they had spare perceptual processing capacity available to process both center and peripheral tasks.

The current results do not support the main hypothesis derived from the multiple resource model; namely that performance in the peripheral task would increase as distance from fixation increased because of multiple resource. Recall that this prediction came from the idea that different areas of the visual field were potentially served by separate resources: focal and ambient. If this were the case, performance in the far ring should not have been affected by perceptual load variations at fixation.

Interpreting the Age-Related Effects and Attention

The relationship between aging and the size of the FFOV is well supported in many studies (e.g., Ball & Sekuler, 1986; Pringle, et al., 2001) . Only recently, however, have researchers begun to ask why aging may be related to a decrease in attentional breadth. Maylor and Lavie (1998) found that older adults' attention became selective at lower levels of perceptual load than younger adults. They interpreted this to mean that older adults had less initial perceptual processing capacity than younger adults. Because of older adults' reduced initial perceptual processing capacity, even small increases in perceptual load, which may not have affected younger adults' performance may have significantly reduced the older adults' perceptual processing capacity (leading to selective attention). Given this background, an effect of age on the size of the FFOV was expected (and found) such that older adults would have more restricted FFOV compared to younger adults at any given level of load. Additionally, as perceptual load of the task increased, it was expected that older adults would experience a steeper drop in perceptual sensitivity compared to younger adults. This may be due to several reasons. First, aging may be associated with a reduction in a general attention resource (perceptual processing capacity). Additionally, because of age-related changes in visual perception, older adults may need to use more of this capacity to perceive stimuli.

Predictions regarding age-related performance from the multiple resource model were not as direct. Previous research has shown that age is associated with a general reduction in attentional resources (e.g., Tsang & Shaner, 1998); however, no research has shown whether different resources are differentially affected by age (e.g., focal/ambient visual channels). This was a distinct possibility given that focal and ambient channels roughly correspond to foveal and peripheral areas of the retina, and each of these areas is represented in different areas of the brain, which may be differentially affected by aging (see Raz, 2000, for a review). In the current study, it was shown that aging is indeed associated with general attentional differences that contributed to poorer peripheral task performance (i.e., reduced FFOV) for older adults. Given that the primary manipulation of perceptual load was associated with peripheral task sensitivity changes, it can be assumed that the attentional resource was perceptual processing capacity.

Signal Detection Analysis and the FFOV

The current study utilized signal detection methods to analyze peripheral task performance. Recall the major contribution of signal detection methods to the current study is the decomposition of performance into its sensitivity component and the response bias component. Because of the nature of the perceptual load manipulation (specifically affecting the perceptual processing stage) perceptual load manipulations should have specifically affected perceptual sensitivity. The current study showed that this was indeed the case; when older adults were exposed to a high perceptual load central task, their peripheral task sensitivity significantly decreased. This tradeoff is indicative of the two tasks competing for a single resource (i.e., perceptual processing capacity) instead of multiple, independent resources (i.e., independent visual channels). For younger adults, however, load affected overall sensitivity, but not differently for difference distances from fixation.

The response bias results may also support the perceptual load model of visual attention; namely the idea that increases in perceptual load should cause a constriction of attention (i.e., selective attention). The analyses of response bias showed that in the near ring, response bias was shifted toward neutral as load increased—increases in perceptual load resulted in an alteration of bias. However, in the far position, varying load had no significant effect on response bias. If perceptual load does indeed affect the scope of visual attention, and the presence of attention affects sensitivity and response bias, the observed effect of load on bias could be taken as corroborative evidence, along with the analysis of sensitivity, that attention did change under high perceptual load.

Relevance to Attention Theories

Perceptual Load Model

This study was specifically designed to contrast two different models of visual attention. Lavie's perceptual load model of attention implicates the role of perceptual load on selective attention. Displays of high perceptual load "exhaust" perceptual processing capacity, leading to selective attention that is obligatory—selective attention is a necessary outcome of limited perceptual processing capacity. When perceptual processing capacity is exhausted, there is none left to attend to other stimuli.

Evidence of the primary role of perceptual load as a determinant of selective attention comes from studies using the response competition paradigm. In the response competition paradigm, observers are asked to judge the presence of a particular target in a display. The target may be flanked by response-incompatible stimuli. The extent to which response time is affected is an indicator of whether participants attended to the flanking stimuli. Many studies have found that under conditions of high perceptual load, response-incompatible flankers do not affect responding whereas under low perceptual load, adjacent flankers slow responding. This has been taken as evidence that when perceptual load is high, there is not enough perceptual processing capacity to process both the main target and the distractors. When perceptual load is low, attention obligatorily processes the target and the flankers.

The effect of perceptual load variations on the shape and size of spatial attention have never been fully elaborated by Lavie (but see Lavie, 2005), however, it can be assumed that when attention becomes selective under high perceptual load conditions visual attention may constrict akin to a constriction to the FFOV. Similarly, under low perceptual load conditions when attention is not selective the FFOV is dilated. This conceptualization is certainly consistent with the evidence from the response competition paradigm—under conditions of high perceptual load, the FFOV shrinks, withdrawing attention from potential response-compatible distractors.

According to the perceptual load theory, if perceptual load of the display is the determinant of the FFOV, high perceptual load should result in a constriction of the FFOV toward fixation; the diameter of the spotlight of attention shrinks. As attention shrinks toward fixation it should be more difficult to detect and localize peripherally presented stimuli. Decreases in perceptual sensitivity to detect peripherally presented stimuli were assumed to be the result of a decrease in the FFOV. In the current study, eccentricity, or location of the peripheral task was also manipulated. If visual attention acts as a spotlight that decreases in size with increasing perceptual load, areas of the display farther from fixation should show more sensitivity declines than areas that are closer to fixation.

The current study showed a significant three-way interaction between age, load, and eccentricity. For younger adults, sensitivity did not change as a function of load and eccentricity while for older adults peripheral task sensitivity depended on load. This was expected under the perceptual load model of attention. As load increased, visual attention becomes constricted toward fixation (i.e., FFOV shrinks). As this happens, the peripheral task that is farther away will receive less attention. Meanwhile, when the peripheral task is closer to fixation, it may receive relatively more attention (compared to the far position). This situation is more pronounced for older adults, who may have less perceptual processing capacity.

A central assumption in the current study was that selective attention caused by a high perceptual load task was analogous to a shrinking of the FFOV. A constriction of the FFOV could be considered a kind of selective attention caused by a lack of adequate attentional resources. This study has found support for the notion that selective attention is a necessary outcome of limited perceptual processing capacity. In Lavie's previous studies using the response competition paradigm, selective attention caused by high perceptual load was a desirable outcome (it reduced response competition effects) however, in the current dual-task study, selective attention due to load resulted in poorer dual-task performance (i.e., reduced sensitivity in peripheral areas of the display).

One major issue that should be addressed is the role of working memory load on the FFOV. Previous studies (e.g., Williams, 1995) showed that increasing cognitive load had the effect of decreasing the extent of the FFOV. However, this is inconsistent with Lavie's perceptual load theory. According to Lavie (Lavie, et al., 2004) demands on perceptual processing should lead to selective attention (i.e., constriction of the FFOV) but demands on working memory should lead to unselective attention (i.e., dilation of the FFOV).

This difference between results from the FFOV literature and perceptual load literature may lie in the different methodologies used in FFOV and perceptual load studies. Previous investigations of the FFOV have used a dual-task paradigm, similar to this study, where the participant is engaged in two unrelated tasks. Perceptual load studies, however, have always used a response competition paradigm, where the goal is to ignore distracting peripheral stimuli and to selectively attend to a single, central task. Level of distraction is measured by examining how long it takes participants to respond with a target absent or present. The rationale is that when peripheral distractors are perceived, they will compete for responding, slowing performance in the central task. When perceptual load is high, Lavie et al (2004) explain that the central task is exhausting all perceptual processing capacity leaving no capacity available to process the distractors. When perceptual load is low but working memory load is increased, attention becomes unselective—that is, in the response competition paradigm, distractors now disrupt performance in a central target search task.

Interpreting this pattern of results in terms of the dynamics of visual attention, it seems as if the FFOV was distributed broadly over the display encompassing the peripheral distractor as well as the central target search task. This is inconsistent with previous studies examining the FFOV and working memory (e.g., Williams, 1989).

These studies show that when working memory load is increased, performance in a peripheral task (the measure of the FFOV) decreases. This discrepancy may be due to several methodological differences between studies (e.g., how working memory load was created, size of displays).

Multiple Resource Model

To recall, the multiple resource model suggested that different areas of the visual field may be served by different resources. The focal channel corresponds to the fovea and in the current study represented central fixation while the ambient channel represented peripheral areas. The critical hypothesis from the multiple resource model was that in the far location, sensitivity should be unaffected by variations in perceptual load of the central task. When the peripheral task is near fixation, two tasks are drawing upon focal resources. When the peripheral task is far from fixation, performance in each task may appear such that they are drawing upon relatively separate resources. Thus, peripheral task sensitivity may be paradoxically better when located far from fixation compared to near fixation. Additionally, a tradeoff between primary and secondary performance (indicating competition for a single resource) should not be observed in the far eccentricity (presumably when the tasks are not competing for similar resources).

In the current study, the hypothesis that different areas of the visual field could potentially be served by different resources was directly tested. The main hypothesis regarding the multiple resource model was that if focal and ambient channels constituted independent processing resources, peripheral task performance in the *far ring* should not have been affected by central task perceptual load.

When the peripheral task was near fixation (i.e., the near ring) sensitivity to detect it should have reduced. However, when the peripheral task is farthest from fixation (i.e., the far ring) sensitivity should have been unaffected by variations in perceptual load (i.e., the central task). In the current study, the focal/ambient distinction within the visual channel was not supported. For both age groups, peripheral task sensitivity in the far ring was significantly related to the load imposed by the central task. However, while the current study did not support the focal/ambient distinction in the visual channel, there are some caveats to the current study that limit what conclusions can be drawn in reference to the multiple resource model.

Limitations of the Current Study

One major potential limitation of the current study in reference to the multiple resource model is the nature of the peripheral task. Wickens (2002) states that one of the major differences between the focal and ambient channel is that the focal channel is suited to detailed pattern-recognition and perception of fine detail while the ambient channel is suited to the sensing of orientation and ego-motion. Recall that the peripheral task used in the current study, the measure of the FFOV, did not involve motion detection or ego-motion detection. This may explain why the current study showed no benefit for peripheral tasks in the ambient channel. However, the assumption that the focal and ambient visual channels are particularly suited to different kinds of information processing may be questionable, and hence may not reflect a limitation of the current study. Weinstein and Wickens (1992) found that motion was not better detected in the periphery than object location (i.e., no differential ability of the ambient channel to detect motion over other kinds of stimulus characteristics).

Another limitation of the current study may be the manner in which multiple resources were studied. A major difference between this study and another study that found support for multiple resources in the visual channel (Horrey & Wickens, 2004) was that in this study, eye movements were controlled using brief displays. The logic of this decision was that eye and head movements would complicate the interpretation of performance. For example, if the current study found that people were able to efficiently monitor a peripheral display and maintain performance in a foveal task, it would be difficult to determine whether this was due to a wide distribution of attention (FFOV) or more efficient visual sampling of the environment.

However, eye and head movements in Horrey and Wickens (2004) study were left uncontrolled. In their task, participants in a driving simulator were supposed to stay in their own lane and monitor a display located 38 degrees from the horizon. Thus, it may be more accurate to qualify the results of Horrey and Wickens' (2004) study by saying that the ability to make efficient eye and head movements to monitor displays in-vehicle is preserved, but it remains uncertain if the distinction of focal/ambient channels exists within the visual field. Thus, to what extent do multiple resources exist in the visual channel? That answer may depend on the way in which multiple resources are measured and defined.

Questions for Future Research

The key finding from this study was that, for older adults with reduced perceptual processing capacity, the level of perceptual load of a display was related to the size of the FFOV. It was presumed that the mechanism behind the relationship between perceptual load and the FFOV is that increasing perceptual load of the display results in less perceptual processing capacity available to process other stimuli (i.e., a peripheral task). This pattern was not found for younger adults (who presumably had a high level of perceptual processing capacity). As perceptual load increased, peripheral task perceptual sensitivity decreased. This suggests that enhancing the perceptual characteristics of the peripheral task may be one way to prevent reductions in the FFOV (i.e., prevent the reduction in sensitivity). It also suggests the possibility that age-related differences in the FFOV may be reduced or eliminated by perceptual enhancement of the peripheral task. One perceptual enhancement would be to increase the size of the peripheral task in relation to the central task.

The fovea and periphery are differentially represented in the visual cortex. The vast majority of the visual cortex is dedicated to processing information received from the fovea (80%). The remaining visual cortex is responsible for processing of the periphery. Additionally, the visual system prioritizes and magnifies visual input from the fovea, resulting in the foveal input being over-represented in the visual cortex compared to input from peripheral areas. One way to compensate for this over-representation of the fovea is to increase the size of the peripheral stimulus in relation to the central stimulus size. The cortical magnification factor has been computed by examining the relative areas of the cortex that are dedicated to the fovea and the periphery (Rovamo & Virsu, 1979). When peripheral stimuli are M-scaled, they activate approximately the same amount of visual cortex as unscaled foveal stimuli.

Chan and Courtney (1998) found that magnifying peripherally presented tasks eliminated a reduction in the FFOV. In their first study, they found, as expected, that a foveally presented cognitive load resulted in a reduced ability to detect and locate a peripherally presented task—as eccentricity increased (distance from fixation) more errors were made in a peripherally presented target detection task. However, when the peripherally presented stimuli was increased in size, task-related constriction of the FFOV was eliminated; that is, peripheral task performance was equalized across 10 degrees of visual angle. This suggests that augmenting the perceptual characteristics of the peripheral task may be one way to prevent reductions in the FFOV. It may also be a way to reduce age-related FFOV declines. Recall that it was hypothesized that older adults' smaller FFOV may be due to a reduced perceptual processing capacity and a need to use more perceptual processing capacity because of age-related changes in visual acuity. By enhancing the peripheral task, older adults may not need to recruit additional perceptual processing capacity to process peripherally presented stimuli. Whether cortically magnifying peripherally presented stimuli would ameliorate age-related declines in the FFOV are unknown.

Practical Relevance

The goal of the current study was to understand how perceptual load and aging would affect performance in a visual dual task situation. The hope was that the results would provide support for the notion that perceptual load was related to the spatial extent of attention. However, the results of the study have direct implications for the design of tasks and displays. Indeed, the impetus for the current investigation to better understood the characteristics of visual displays that could support multiple-task performance.

In certain situations (e.g., using a computer; monitoring a control panel) people must distribute their attention broadly in order to be able to detect events that occur outside of foveal view (e.g., status or notification indicators). However, the perceptual load of the display may affect attentional distribution.

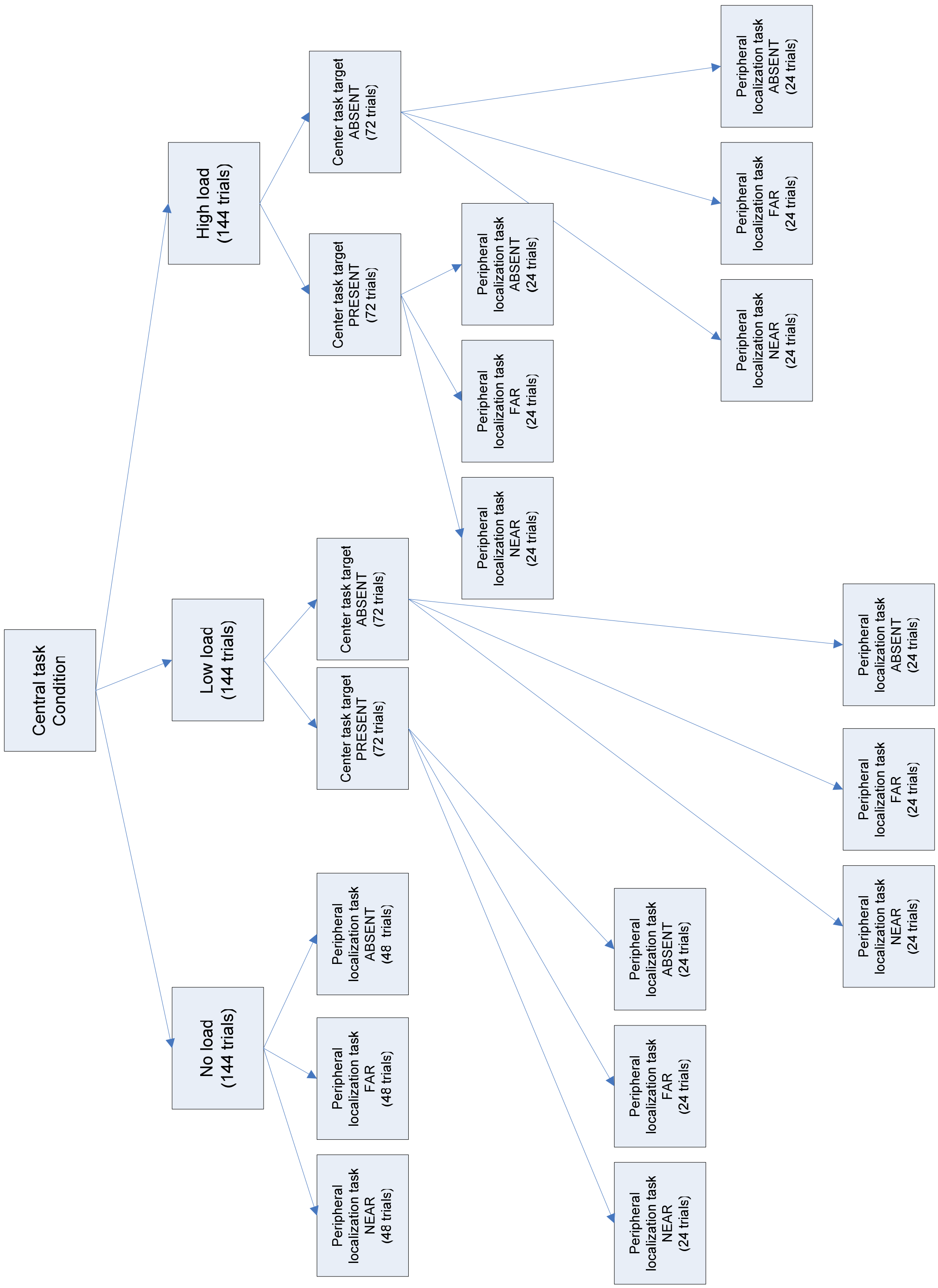
Search difficulty was the way in which perceptual load was manipulated. Search difficulty, engendered by perceptual load, is a highly representative characteristic of many displays. The task of looking for a specific item in a menu of similar looking items being a salient example. In situations like this, there is a demand on perceptual processing capacity. If the perceptual processing demand is high, the current results show that, for older adults, the FFOV around visual fixation shrinks potentially degrading perception of more peripheral stimuli. When the FFOV shrinks, the observer may be required to make more eye or head movements to perceive all of the relevant items in a display. More eye and head movements may require more integration across fixations, more time required to complete a task, and potentially more errors.

The current results suggest when designing displays that present information in multiple locations, demands on perceptual processing should be minimized, especially if the user must monitor multiple locations of the display. Reducing perceptual processing demands should result in a broader FFOV, which should result in fewer eye and head movements to sample a display. Reducing eye and head movements may be especially important in tasks where it is critically important to remain fixated on a particular location yet be monitoring other areas of the visual field (e.g., driving).

Reducing perceptual processing demands is especially important for older adults because of their reduced perceptual processing capacity. If it is not possible to reduce perceptual processing demands of the foveal task, dual-task performance may be enhanced if the peripheral visual task is perceptual enhanced. This recommendation comes directly from the finding that peripheral sensitivity is reduced under high load conditions. If the signal strength of the peripheral task is enhanced (made brighter or larger) then peripheral sensitivity should improve leading to better dual-task performance.

APPENDIX A

TRIAL CONDITIONS



APPENDIX B

MOUSE PRACTICE INSTRUCTIONS

Before we start the study, we want to make sure that you are comfortable using the mouse. All of your responses in this study will require the mouse. In the following short mouse practice, you will see a solid white box appear on the screen. Use your mouse to move the arrow-shaped pointer over the solid box and use the mouse button to "click" the shape on the screen. The computer will provide feedback.

APPENDIX C

PHASE I EXPERIMENTAL INSTRUCTIONS

In this study, you will be searching for letters presented in the center of the screen. You will be told which letter to search for ahead of time. The letters will flash on the screen very quickly so please pay attention to the center of the computer screen. You will use the computer mouse to make all of your responses. You can use any of the mouse buttons to make your response. Let's look at some sample screens so you know what to expect.

[Participants were then shown a series of self-paced annotated screen captures]

Figure C1. Ready display

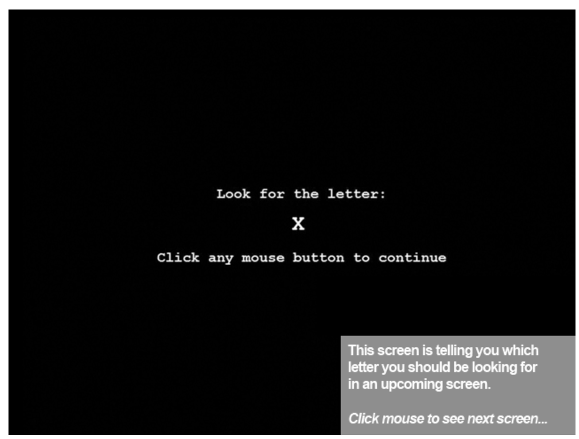


Figure C2. Target notification

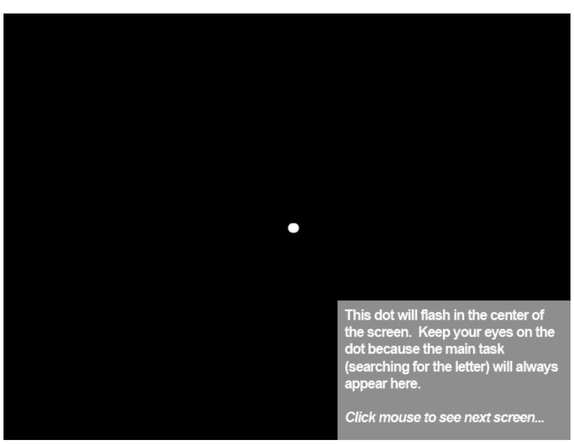


Figure C3. Fixation dot

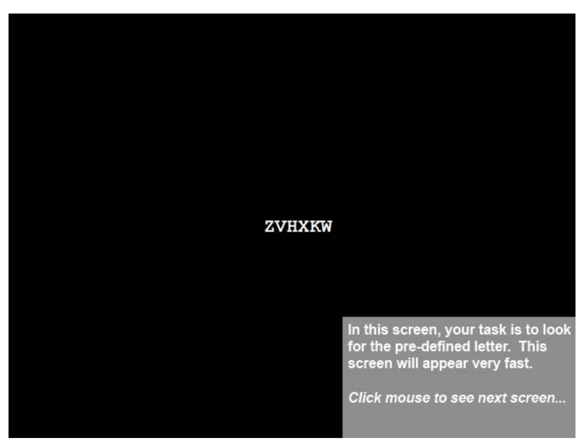


Figure C4. Search task

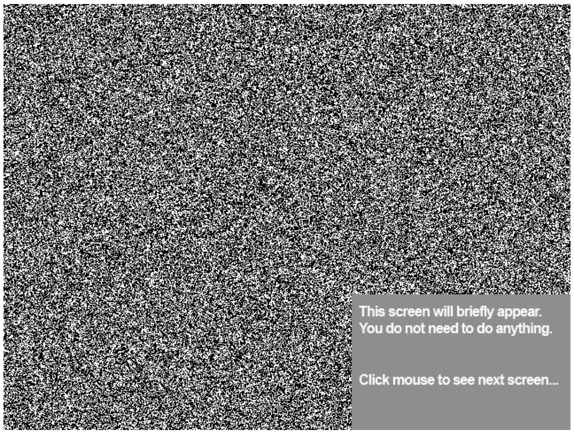


Figure C5. Noise mask

Figure C6. Response display

[after viewing example displays]

Remember, pay attention to the center of the screen. Respond as quickly but accurately as you can. If you are unsure whether the pre-defined letter was presented or not, please just guess. Click a mouse button to start the PRACTICE.

[after 5 trials of practice]

That was the practice. Do you have any questions? The study will now begin. Pay attention to the CENTER of the screen. Respond as quickly but accurately as you can. If you are unsure, please just guess. Please wait for the experimenter.

APPENDIX D

PHASE II EXPERIMENTAL INSTRUCTIONS

Now, you will be trying to do TWO tasks at the same time. Your MAIN task is similar to what you just completed (looking for letters in center of the screen). Just like before, you will be told which letter to look for in the flashed screen. Sometimes, nothing will be presented in the CENTER of the screen. Your SECONDARY task is to determine WHERE you saw a "*" shown elsewhere on the screen. Sometimes, there will not be any star presented. Let's look at some sample screens.

[Participants were then shown a series of self-paced annotated screen captures]

Figure D1. Ready display

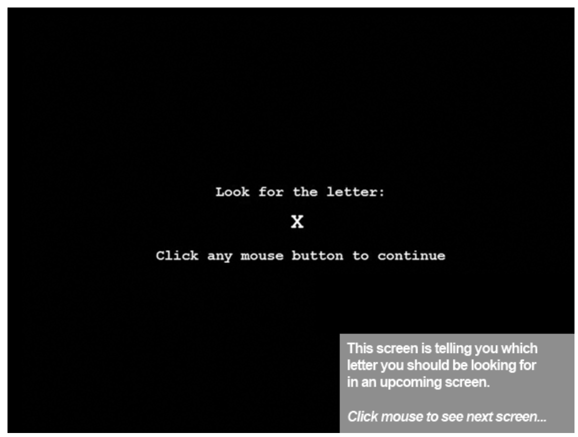


Figure D2. Target notification

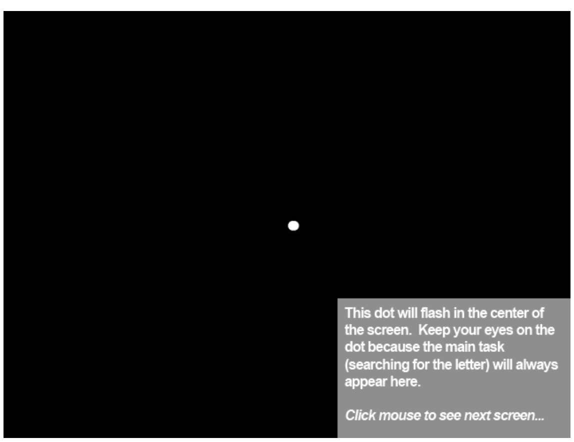


Figure D3. Fixation dot

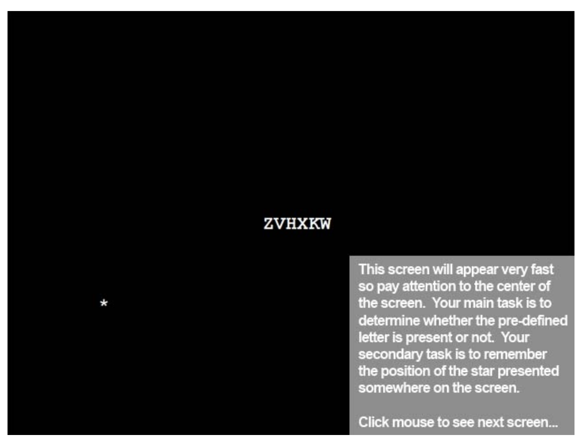


Figure D4. Search task

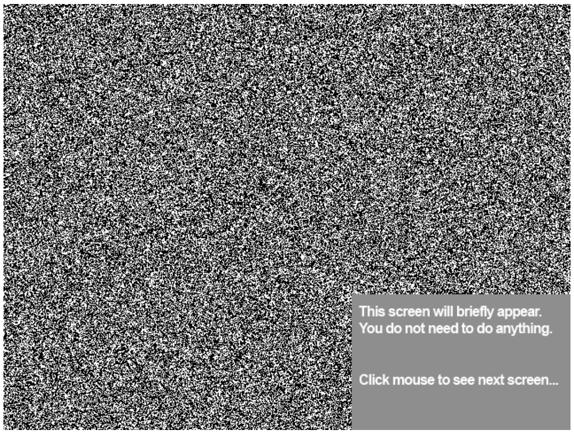


Figure D5. Noise mask

Figure D6. Central task response

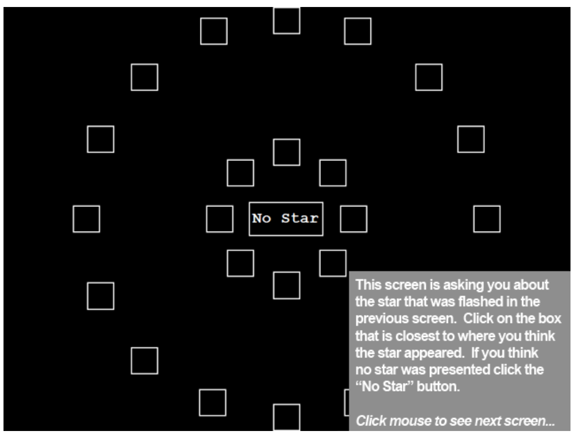


Figure D7. Peripheral task response

[after viewing example displays]

Sometimes, you will find this very easy to do, while at other times you will find it difficult. Remember, your FIRST priority should be the MAIN task of deciding whether the predefined letter was presented in the CENTER of the screen. Your second priority should be looking for where the "*" appeared. You will use the mouse to make all of your responses. We will now try some practice sessions before we start the study. Do you have any questions before we start the practice session?

[after 6 trials of practice]

If you need to take a break, please do so at any time. If you are unsure whether you saw the pre-defined letter in the MAIN central task, please just guess. Also, if you do not know where the "*" appeared in the secondary task please just guess. Remember, focus your efforts on the task in the CENTER of the screen--this is your priority. Do you have any questions?

APPENDIX E

PHASE III EXPERIMENTAL INSTRUCTIONS

In the next phase of the study, you will only be doing one task: The letter search task. This task is the same task you started with. You will be looking for a pre-defined letter presented in the center of the screen. Remember, pay attention to the center of the screen. If you are unsure, please just guess. Click a mouse button to start...

APPENDIX F

GENERAL PROCEDURE

1. Consent form & demographics
2. Vision tests
3. Mouse practice
4. Digit Symbol Substitution
5. Reverse Digit Span
6. Shipley Vocabulary
7. Break
8. Phase 1 (central task only)
    a. Experimental practice (5 trials)
    b. 48 trials
    c. Break
9. Phase 2 (center and peripheral task)
    a. Practice (6 trials)
    b. Block 1 – 54 trials
    c. Break
    d. Block 2 – 54 trials
    e. Break
    f. Block 3 – 54 trials
    g. Break
    h. Block 4 – 54 trials
    i. Break
    j. Block 5 – 54 trials
    k. Break
    l. Block 6 – 54 trials
    m. Break
    n. Block 7 – 54 trials
    o. Break
    p. Block 8 – 54 trials
    q. Break
    r. Block 9 (error trials re-run block) – Number of trials varied
10. Phase 3 (central task only)
    a. 48 trials

APPENDIX G

EQUATIONS USED TO COMPUTE A' AND B'' (STANISLAW & TODOROV, 1999)

$$A' = \begin{cases} 0.5 + \dfrac{(H-F)(1+H-F)}{4H(1-F)} & \text{when } H \geq F \\ 0.5 - \dfrac{(F-H)(1+F-H)}{4F(1-H)} & \text{when } H < F \end{cases}$$

A' is the non-parametric signal detection measure of perceptual sensitivity (cf. *d'*). Two slightly different formulas are used depending on whether hits are greater than or less than the false alarm rate. The values range from .5 (no sensitivity) to 1 (perfect sensitivity)

Figure G1. Formula for A'

$$B'' = \text{sign}\,(H-F)\,\frac{H(1-H)-F(1-F)}{H(1-H)+F(1-F)}$$

Beta double-prime (*B''*) is the non-parametric signal detection measure of response bias (cf. β). The values range from -1 (liberal response bias) to +1 (conservative response bias).

Figure G2. Formula for *B''*

APPENDIX H

MEANS AND STANDARD DEVIATIONS

Table H1

Means and standard deviations of central task *hits and false alarms (proportions) by central task condition and age group.*

	Younger (n = 19)				Older (n = 17)			
	Hits	SD	False alarms	SD	Hits	SD	False alarms	SD
Lower load	0.9	0.06	0.15	0.06	0.81	0.02	0.41	0.03
Higher load	0.9	0.07	0.28	0.19	0.88	0.02	0.57	0.04

Note. Perfect performance is 1.0 while .33 is chance performance.

Table H2

Means and standard deviations of peripheral *task hits and false alarms (proportions) by central task condition and age group.*

	Younger (n = 19)				Older (n = 17)			
Peripheral task eccentricity/Load	Hits	SD	False alarms	SD	Hits	SD	False alarms	SD
Near								
No load	0.97	0.03	0.01	0.01	0.80	0.13	0.01	0.01
Lower load	0.96	0.03	0.02	0.02	0.77	0.12	0.04	0.05
Higher load	0.96	0.03	0.03	0.03	0.76	0.13	0.06	0.05
Far								
No load	0.97	0.03	0.02	0.03	0.84	0.11	0.10	0.08
Lower load	0.95	0.04	0.02	0.02	0.71	0.21	0.12	0.08
Higher load	0.93	0.07	0.02	0.02	0.72	0.20	0.13	0.10

Note. Perfect performance is 1.0 while chance performance is .50

Table H3

Means and standard deviations of central task *signal detection statistics (A' and B'').*

	Younger (n = 19)				Older (n = 17)			
Central task load	A'	SD	B''	SD	A'	SD	B''	SD
Lower load	0.93	0.03	-0.22	0.34	0.78	0.08	-0.20	0.16
Higher load	0.84	0.06	-0.38	0.27	0.75	0.06	-0.35	0.14

Note. The value of A' ranges from 0 to 1; 0 indicates no sensitivity while 1 indicates perfect sensitivity. The value of B'' ranges from -1 to 1 with -1 indicating a liberal bias while 1 indicates a conservative bias and 0 represents no bias.

Table H4

Means and standard deviations of peripheral *task signal detection statistics (A' and B'').*

Central task load/ Second task eccentricity	Younger (n = 19)				Older (n = 17)			
	A'	SD	B''	SD	A'	SD	B''	SD
Near								
No load	0.99	0.01	0.48	0.33	0.95	0.03	0.88	0.06
Lower load	0.98	0.01	0.38	0.39	0.92	0.04	0.64	0.28
Higher load	0.98	0.01	0.24	0.5	0.91	0.05	0.54	0.27
Far								
No load	0.99	0.01	0.36	0.35	0.92	0.05	0.15	0.41
Lower load	0.98	0.01	0.42	0.48	0.88	0.07	0.21	0.04
Higher load	0.98	0.02	0.54	0.41	0.88	0.07	0.19	0.46

Note. The value of A' ranges from 0 to 1; 0 indicates no sensitivity while 1 indicates perfect sensitivity. The value of B'' ranges from -1 to 1 with -1 indicating a liberal bias while 1 indicates a conservative bias and 0 represents no bias.

APPENDIX I

ANOVA TABLES

Table I1

Central task hit rate (arc-sine of proportion) ANOVA

Source	SS	df	MS	*F*	*p*
		Between subjects			
Age group (A)*	.15	1	.15	15.86	.00
		Within subjects			
Load (L)*	.03	1	.03	6.73	.01
L × A*	.03	1	.03	6.50	.02

Note. * indicates significance at p < .05

Table I2

Central task false alarms (arc-sine of proportion) ANOVA

Source	SS	df	MS	*F*	*p*
		Between subjects			
Age group (A)*	.83	1	.83	52.91	.00
		Within subjects			
Load (L)*	.49	1	.49	24.95	.00
L × A	.00	1	.00	.14	.71

Note. * indicates significance at p < .05

Table I3

Peripheral task hit rate (arc-sine of proportion) ANOVA

Source	SS	df	MS	*F*	*p*
		Between subjects			
Age group (A)*	.72	1	.72	62.70	.00
		Within subjects			
Load (L)*	.27	2	.14	9.06	.00
Eccentricity (E)	.01	1	.01	.53	.47
E × A	.01	1	.01	.25	.62
L × A	.03	2	.01	.94	.40
L × E*	.06	2	.03	5.23	.01
L × A × E	.02	2	.01	1.72	.19

Note. * indicates significance at p < .05

Table I4

Peripheral false alarm (arc-sine of proportion) ANOVA

Source	SS	df	MS	*F*	*p*
		Between subjects			
Age group (A)*	.15	1	.15	40.34	.00
		Within subjects			
Load (L)*	.15	2	.07	16.32	.00
Eccentricity (E)*	.33	1	.33	30.59	.00
E × A*	.33	1	.33	31.05	.00
L × A	.03	2	.01	3.03	.06
L × E*	.06	2	.03	4.72	.01
L × A × E	.01	2	.00	.49	.61

Note. * indicates significance at p < .05

Table I5

Central task sensitivity (A’) ANOVA

Source	SS	df	MS	*F*	*p*
		Between subjects			
Age group (A)*	.23	1	.23	52.92	.00
		Within subjects			
Load (L)*	.07	1	.07	22.49	.00
L × A*	.02	1	.02	6.26	.02
Note. * indicates significance at p < .05					

Table I6

Central task bias (B’’) ANOVA

Source	SS	df	MS	*F*	*p*
		Between subjects			
Age group (A)*	.04	1	.04	.56	.46
		Within subjects			
Load (L)*	.46	1	.46	9.79	.00
L × A	.00	1	.00	.01	.91
Note. * indicates significance at p < .05					

Table I7

Peripheral task sensitivity (A') ANOVA

Source	SS	df	MS	*F*	*p*
		Between subjects			
Age group (A)*	.05	1	05	51.30	.00
		Within subjects			
Load (L)*	.03	2	.01	11.35	.00
Eccentricity (E)*	.02	1	.02	20.24	.00
E × A*	.02	1	.02	13.90	.00
L × A*	.01	2	.01	5.08	.00
L × E*	.00	2	.00	4.20	.02
L × A × E*	.00	2	.00	3.95	.02

Note. * indicates significance at p < .05

Table I8

Peripheral task bias (B'') ANOVA

Source	SS	df	MS	*F*	*p*
		Between subjects			
Age group (A)	.01	1	.01	.43	.52
		Within subjects			
Load (L)	.27	2	.13	1.52	.23
Eccentricity (E)*	2.5	1	2.50	8.06	.01
E × A*	4.89	1	4.89	14.41	.00
L × A	.13	2	.07	.75	.48
L × E*	1.48	2	.74	6.07	.00
L × A × E	.09	2	.04	.35	.71

Note. * indicates significance at p < .05

APPENDIX J

OVERALL ACCURACY FOR CENTER AND PERIPHERAL TASK

Central task

Figure J1 (ANOVA Table J1) illustrates the overall central task accuracy by central task load and age group. Overall central task accuracy is the average proportion of items participants responded correctly (e.g., target letter was present in display and response was "present"). The main effect of load on central task accuracy was significant, $F(2,72) = 112.44$, $MSE = 1.25$, indicating that increasing load resulted in decreased central task accuracy.

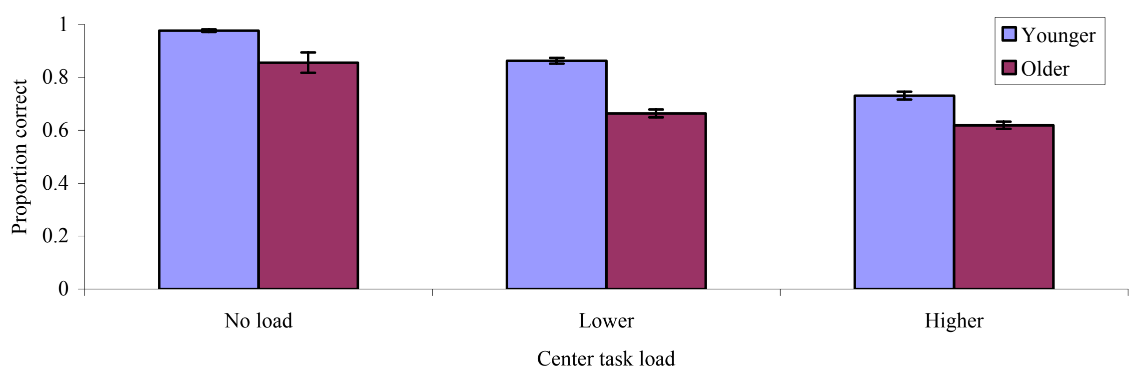


Figure J1. Central task overall accuracy (proportion correct) by central task load and age group.

This showed that the central task manipulation of load did indeed have an effect on performance. The interaction between load and age group was marginally significant, $p = .052$, indicating that varying load had different effects in each age group. The effect of load on central task performance was greater for the younger adults compared to the older adults.

Table J1.

Center task overall accuracy (arc-sine of proportion correct) ANOVA

Source	SS	df	MS	*F*	*p*
		Between subjects			
Age group (A)*	1.04	1	1.04	72.97	.00
		Within subjects			
Load (L)*	2.55	1	2.55	148.08	.00
L × A	.04	1	.04	2.01	.165

Note. * indicates significance at p < .05

Peripheral Task

Figure J2 illustrates the overall accuracy in the peripheral task by central task load, eccentricity, and age group. The *no load* condition refers to the case when no central task was displayed. The *no star* condition refers to the case when no star was presented. The no-load/no star condition (the first two bars) was a blank screen. In this case, proportion correct is whether the participant correctly indicated that the center and peripheral task was "blank."

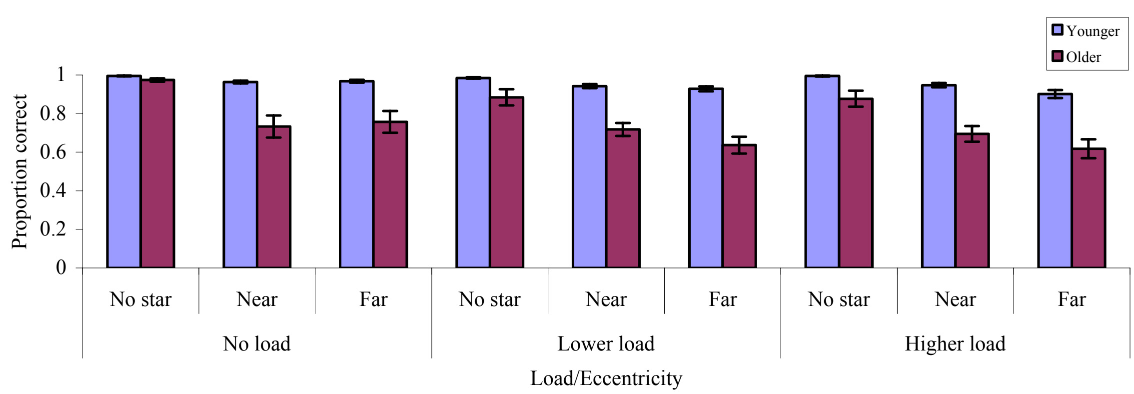


Figure J2. Peripheral task overall task accuracy (proportion correct) by central task load, eccentricity, and age group.

These proportion data were arc-sine transformed and submitted to a repeated-measures ANOVA (Table J2). The main effect of load was significant, $F(2,72) = 5.28$, $MSE = .20$, indicating that increasing load resulted in decreasing peripheral task accuracy. No load versus lower load was significant different in terms of the effect on peripheral task performance. However, the difference between lower load and higher load was not significant. The interaction between load and eccentricity was also significant, $F(2,72) = 5.00$, $MSE = .05$, indicating that varying load had different effects at each eccentricity. In the near eccentricity, increasing load had no effect on peripheral task accuracy, however, in the far eccentricity, increasing load from no load to lower load had a significant effect on peripheral task accuracy.

Table J2.

Peripheral task overall accuracy (arc-sine of proportion correct) ANOVA

Source	SS	df	MS	*F*	*p*
Between subjects					
Age group (A)*	1.27	1	1.27	63.38	.00
Within subjects					
Load (L)*	.39	2	.32	5.28	.02
Eccentricity (E)	.09	1	.09	2.90	.10
E × A	.09	1	.09	2.90	.10
L × A	.00	2	.00	.06	.95
L × E*	.11	1.57	.07	4.98	.02
L × A × E	.02	1.57	.01	.69	.48

Note. * indicates significance at $p < .05$

APPENDIX K

HIT RATE BY SPOKE

To determine if participants preferentially allocated their attention to a particular area of the screen, hit rate was individually computed for each spoke (north, south, east, west, northwest, northeast, southeast, southwest) in which the peripheral star task could have appeared. A hit was when a star was presented in a particular spoke and the participant responded with that spoke. Only the trials in which participants correctly responded to the *central task* were included in the hit rate calculation. This was to ensure that participants were not ignoring the central task and focusing attention preferentially to a particular location (e.g., north). Figure K1 illustrates hit rate for younger and older adults by spoke (across all load conditions).

While there was a main effect of age on hit rate by spoke (older adults had an

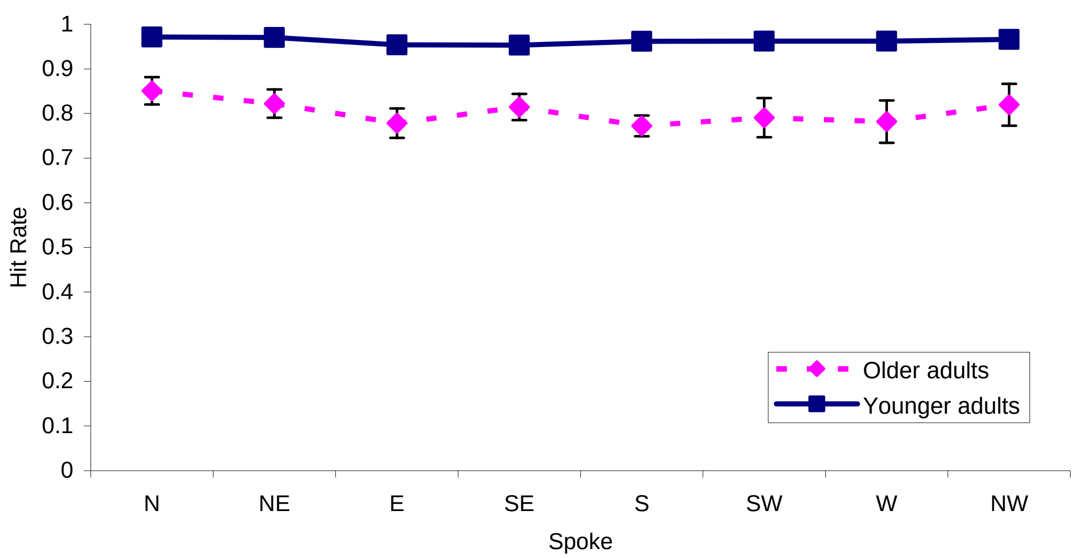


Figure K1. Older and younger adult peripheral task hit rate by spoke. A hit was when the participant responded in the correct spoke. Younger adults standard error was smaller than the indicator symbol and was thus occluded. The spokes are indicated by the abbreviations of the cardinal directions and obliques.

overall lower hit rate than younger adults at each spoke), the main effect of spoke was not significant (participants of both age groups did not have different hit rates for any one spoke). Because the hit rate was not significantly different by spoke, performance was collapsed over spokes and analyzed in terms of near ring or far ring. The results of the ANOVA are illustrated in Table K1.

Table K1.

Peripheral task hit rate by age and spoke (arc-sine of proportion) ANOVA

Source	SS	df	MS	*F*	*p*
	Between subjects				
Age group (A)*	.70	1	59.3	93.47	.00
	Within subjects				
Spoke (S)	.25	7	.04	1.38	.22
A × S	.06	7	.01	.32	.94

Note. * indicates significance at p < .05

APPENDIX L

ALTERNATE COMPUTATIONS OF PERIPHERAL TASK FALSE ALARM RATE, SENSITIVITY, AND BIAS

Hits and False Alarms

Peripheral task hit rate and false alarm are illustrated in Figure L1 as a function of central task load (no load, lower, or higher), eccentricity (near or far ring), and age group (younger, older). A response was considered a 'hit' in a particular ring if the star appeared and that ring and participants responded with that ring. A response was

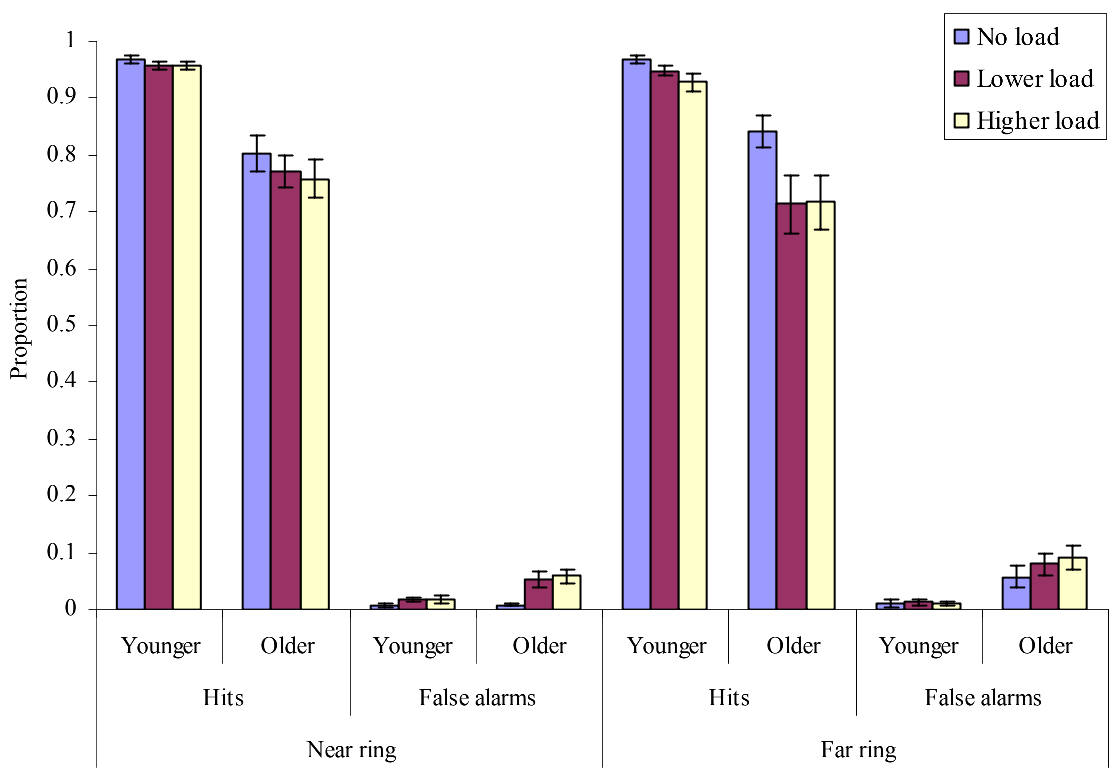


Figure L1. Peripheral task hits and false alarms by central task condition (no load, lower load, higher load) and age group (young, old). Error bars represent the standard error.

considered a ‘false alarm’ for a particular ring when participants made a response in a ring where a star either did not occur at all or it was actually presented in the other ring. Thus, the false alarm rate for the near ring was the total number of times the participant responded “near” divided by the total number of times the star was actually in the far ring or there was no star.

The proportion data were transformed and submitted to a repeated-measures ANOVA (Table L1). Because hit rate was computed the same way as that presented in the results section, I will only discuss the false alarm data and whether any differences existed by re-calculating false alarm rate.

Table L1

Peripheral task false alarm rate (arc-sine of proportion) ANOVA

Source	SS	df	MS	*F*	*p*
Between subjects					
Age group (A)*	.11	1	.11	33.31	.00
Within subjects					
Load (L)*	.08	2	.08	26.19	.00
Eccentricity (E)*	.09	1	.09	33.31	.00
E × A*	.13	1	.13	24.33	.00
L × A*	.06	2	.03	9.25	.00
L × E*	.04	2	.02	5.59	.01
L × A × E	.01	2	.00	.98	.38

Note. * indicates significance at $p < .05$

For false alarm rate, the main effects of age, $F(1,34) = 33.31$, $MSE = .11$, load, $F(2,68) = 26.19$, $MSE = .08$, and eccentricity, $F(1,34) = 16.23$, $MSE = .09$, were significant. However, the interaction between age group and eccentricity was significant, $F(1,34) = 24.33$, $MSE = .13$, because for younger adults increasing eccentricity had no effect on false alarm rates but for the older adults, increasing eccentricity resulted in a significant increase in false alarm rate. The interaction between load and eccentricity on false alarm rate was also significant, $F(2, 34) = 5.59$, $MSE = .02$, indicating that varying central task load significantly affected peripheral task false alarm rates in the *near* position but not in the *far* position.

The only change in significance from re-computing false alarms was an additional load × age interaction (which was previously marginally significant, $p=.06$) suggesting that load had different effects for each age group. For younger adults, increasing load did not result in increasing false alarm rates (pairwise comparisons of load were not significant) whereas for older adults, increasing load resulted in a higher false alarm rate. The pairwise comparisons of older adults' false alarm rate showed significant differences between "no load"/"lower load", and "no load"/"higher load". Additionally, the difference between "lower load" and "higher load" on older adults' false alarm rate was marginally significant ($p=.055$).

To summarize, re-calculating the false alarm rate showed that including the trials in which no peripheral task was present resulted in a very similar pattern of results compared to when the blank peripheral task trials were not included. The only difference was a significant load × age interaction when blank trials were included in the calculation of false alarm rate. When the false alarm rates were computed only with peripheral-task-present trials, I was strictly examining how age, eccentricity, and load would affect stimulus *localization*, not detection—detection was assumed. By including the blank peripheral task trials into the calculation of false alarms, detection was not assumed. The finding of no major differences in the patterns of hits and false alarms suggest that my initial assumption that participants, older and younger, were able to initially detect the peripheral task before being able to localize it is a valid assumption.

Signal Detection Analyses

Sensitivity

Sensitivity (Figure L2) was computed using the hit and false alarm rates for each participant. Because false alarm rate was re-computed, the sensitivity and bias measures were re-computed as well. When sensitivity was re-computed using the new definition of false alarm rate, the only change from the sensitivity analyses presented in the results section was that the three-way interaction became only marginally significant ($p=.072$). Even though the three-way interaction was only marginally significant, pairwise comparisons showed that the pattern was essentially the same as the previous analyses. Older adults experienced a greater effect of load on sensitivity in the far ring compared to the near ring while younger adults did not show any sensitivity change. For older adults, pairwise comparisons of sensitivity by ring showed that in the no load condition, there was no significant difference in sensitivity between the near and far rings.
However, in the lower and higher loads, sensitivity was significantly lower in the far ring compared to the near ring.

The interaction between load and eccentricity was still significant, indicating that the effect of load was greater in the far ring than the near ring. For older adults, pairwise

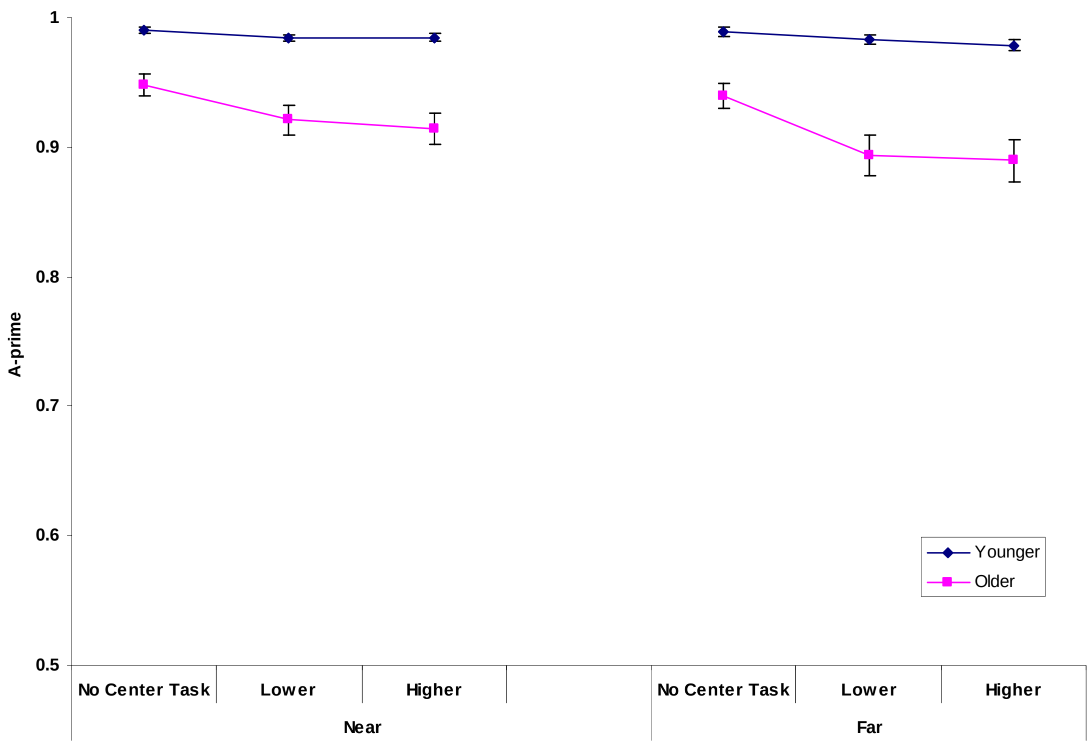


Figure L2. Peripheral task signal detection analysis: Sensitivity as a function of peripheral task position, central task load, and age group (A'). Perfect sensitivity is equal to 1.0 while no sensitivity is 0.5.

comparison of sensitivity showed that sensitivity significantly decreased from "no load" to "lower load" and "no load" to "higher load" in both rings. There was no significant sensitivity change between "lower load" to "higher load" in either the near or far ring. For younger adults, pairwise comparisons of sensitivity in the near and far rings showed no significant differences between loads in the near or far rings.

To summarize, the major difference when false alarms were re-computed was that the interaction between age × load × and eccentricity was only marginally significant, however, the general pattern (older adults sensitivity more reduced in the far ring with increasing load) was identical to the previous analyses. The summary of the ANOVA of sensitivity is shown in Table L2.

Table L2

Peripheral task sensitivity (A') ANOVA

Source	SS	df	MS	*F*	*p*
		Between subjects			
Age group (A)*	.041	1	.041	48.43	.00
		Within subjects			
Load (L)*	.03	2	.01	13.5	.00
Eccentricity (E)*	.01	1	.01	9.84	.00
E × A*	.00	1	.00	5.70	.02
L × A*	.01	2	.01	6.61	.00
L × E*	.00	2	.00	4.27	.02
L × A × E	.00	2	.00	2.74	.07

Note. * indicates significance at p < .05

<u>Bias</u>

Response bias was re-computed using the new false alarm rates (illustrated in Figure L3, ANOVA summary in Table L3). When the measures of bias were re-computed, the major change was that the main effect of eccentricity was no longer significant, however, the eccentricity × age, and load × eccentricity interactions were still significant. The eccentricity × age interaction shows that older adult's bias was significantly affected by eccentricity (they were more liberal in the far ring) whereas younger adult's bias was unaffected by eccentricity. The interaction between load and eccentricity was also significant indicating that in the near ring (closest to fixation) increasing central task load resulted in an increasingly neutral response bias (pairwise

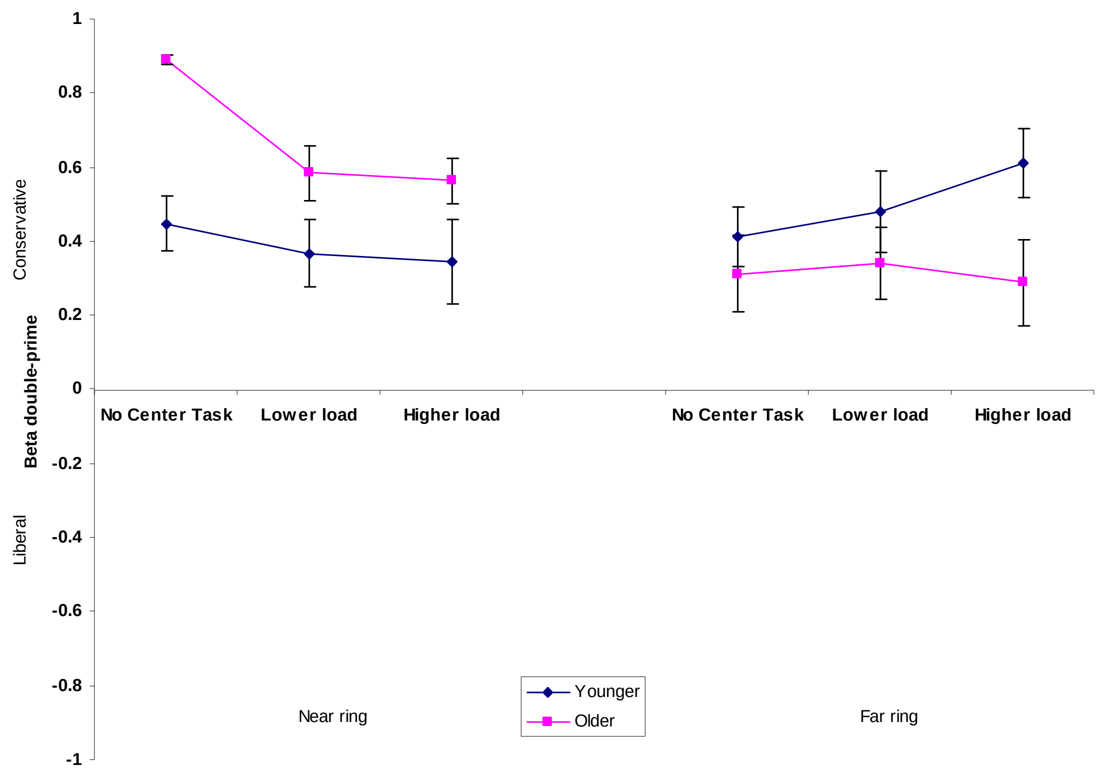


Figure L3. Peripheral task signal detection analysis: Bias as a function of peripheral task position, central task load, and age group (B''). Positive values indicate conservative bias, negative values indicate liberal bias while zero is no bias.

comparisons of no load/lower and no load/higher were significant only for older adults). However, in the far ring, increasing load had no significant effect on response bias for either age group. The three-way interaction between age, load, and eccentricity was not significant.

To summarize, including the blank peripheral trials into the calculation of false alarms (and thus computing a detection/localization false alarm versus a localization only false alarm) resulted in minor changes to the significance levels of some of the major effects, however, the interpretation remains unchanged from that presented in the main results section.

Table L3

Peripheral task bias (B'') ANOVA

Source	SS	df	MS	*F*	*p*
		Between subjects			
Age group (A)	.03	1	.03	.86	.36
		Within subjects			
Load (L)	.23	2	.11	1.15	.32
Eccentricity (E)	.85	1	.85	3.23	.08
E × A*	3.10	1	3.10	11.80	.00
L × A	.45	2	.22	2.26	.11
L × E*	.91	2	.45	4.75	.01
L × A × E	.10	2	.05	.94	.59

Note. * indicates significance at p < .05

REFERENCES

Artal, P., Ferro, M., Miranda, I., & Navarro, R. (1993). Effects of aging on retinal image quality. *Journal of the Optical Society of America, 10*, 1656-1662.

Ball, K. K., Beard, B. L., Roenker, D. L., Miller, R. L., & Griggs, D. S. (1988). Age and visual search: expanding the useful field of view. *Journal of the Optical Society of America, 5(12),* 2210-2219.

Batsakes, P. B., & Fisk, A. D. (2000). Age-related differences in dual-task visual search. *The Journals of Gerontology Series B: Psychological and Social Sciences, 55,* 332-342.

Carrasco, M., McElree, B., Denisova, K., & Giordano, A. M. (2003). Speed of visual processing increases with eccentricity. *Nature Neuroscience, 6,* 699-700.

Chan, H. S., & Courtney, A. J. (1993). Effects of cognitive foveal load on a peripheral single-target detection task. *Perceptual and Motor Skills, 77(2),* 515-533.

Chan, H. S., & Courtney, A. J. (1998). Stimulus size scaling and foveal load as determinants of peripheral target detection. *Ergonomics, 41(10),* 1433-1452.

Crossley, M., & Hiscock, M. (1992). Age-related differences in concurrent-task performance of normal adults: Evidence for a decline in processing resources. *Psychology and Aging, 7,* 499-506.

Duncan, J., & Hymphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review, 96(3),* 433-458.

Eriksen, C. W., & St. James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception and Psychophysics, 40,* 225-240.

Eriksen, C. W., Yeh, Y-Y. (1985). Allocation of attention in the visual field. *Journal of Experimental Psychology: Human Perception and Performance, 11(5),* 583-597.

Green, E. M., & Swets, J. A. (1988). *Signal detection theory and psychophysics*. New York: Wiley.

Grier, J. B. (1971). Nonparametric indexes for sensitivity and bias: Computing formulas. *Psychological Bulletin, 75,* 424-429.

Hahn, S., & Kramer, A. F. (1995). Attentional flexibility and aging: You don't need to be 20 years of age to split the beam. *Psychology and Aging, 10(4),* 597-609.

Henderson, J. M., & Ferreira, F. (1990). Effects of foveal processing difficulty on the perceptual span in reading: Implications for attention and eye movement control. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16(3),* 417-429.

Horrey, W. J., & Wickens, C. D. (2004). Driving and side task performance: The effects of display clutter, separation, and modality. *Human Factors, 46(4),* 611-624.

Ikeda, M., & Takeuchi, T. (1975). Influence of foveal load on the functional visual field. *Perception and Psychophysics, 22*, 571-577.

LaBerge, D., & Brown, V. (1989). Theory of attentional operations in shape identification. *Psychological Review, 96,* 101-124.

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 21(3),* 451-468.

Lavie, N. (2005). Distracted and confused?: Selective attention under load. *Trends in Cognitive Sciences, 9,* 75-82.

Lavie, N., & Cox, S. (1997). On the efficiency of visual selective attention: Efficient visual search leads to inefficient distractor rejection. *Psychological Science, 8(5),* 395-398.

Lavie, N., Hirst, A., de Fockert, J. W., & Viding, E. (2004). Load theory of selective attention and cognitive control. *Journal of Experimental Psychology: General, 133(3),* 339-354.

Lavie, N., Ro, T., & Russell, C. (2003). The role of perceptual load in processing distractor faces. *Psychological Science, 14(5),* 510-515.

Leibowitz, H. W., & Appelle, S. (1969). The effect of a central task on luminance thresholds for peripherally-presented stimuli. *Human Factors, 11,* 387-392.

Mackworth, N. H. (1965). Visual noise causes tunnel vision. *Psychonomic Science, 3,* 67-68.

Mackworth, N. H. (1976). Stimulus density limits the useful field of view. In R. A. Monty and J. W. Senders (Eds.), *Eye movements and psychological processes*. New York: John Wiley & Sons, 307-321.

Maylor, E. A., & Lavie, N. (1998). The influence of load on age differences in selective attention. *Psychology and Aging, 13(4),* 563-573.

McCarley, J. S., Mounts, J. R. W., Kramer, A. F. (2004). Age-related differences in localized attentional interference. *Psychology and Aging, 19(1),* 203-210.

Navon, D., & Gopher, D. (1979). On the economy of the human processing system. *Psychological Review, 86*, 214-255.

Pollack, I., & Norman, D. A. (1964). A nonparametric analysis of recognition experiments. *Psychonomic Science, 1,* 125-126.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32,* 3-25.

Pringle, H. L., Irwin, D. E., Kramer, A. F., & Atchley, P. (2001). The role of attentional breadth in perceptual change detection. *Psychonomic bulletin & review,* 8(1), 89-95.

Rantanen, E. M., & Goldberg, J. H. (1999). The effect of mental load on the visual field size and shape. *Ergonomics, 42 (6),* 816-834.

Raz, N. (2000). Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (2nd ed.,pp. 1–90). Mahwah, NJ: Erlbaum.

Rovamo, J. & Virsu, V. (1979). An estimation and application of the human cortical magnification factor, *Experimental Brain Research, 37,* 495-510.

Sanders, A. F. (1970). Some aspects of the selective process in the functional visual field. *Ergonomics, 13(1),* 101-117.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Review, 84,* 1-66.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime Reference Guide*. Pittsburgh: Psychology Software Tools Inc.

Scialfa, C. T., Kline, D. W., & Lyman, B. J. (1987). Age differences in target identification as a function of retinal location and noise level: examination of the useful field of view. *Psychology and Aging, 2(1),* 14-19.

Scialfa, C. T., Thomas, D. M., & Joffe, K. M. (1994). Age differences in the useful field of view: An eye movement analysis. *Optometry and Vision Science, 71,* 736-742.

Seiple, W., Szlyk, J. P., Yang, S., & Holopigian, K. (1996). Age-related functional field losses are not eccentricity dependent. *Vision Research, 26(12),* 1859-1866.

Sekuler, R., & Ball, K. (1986). Visual localization: age and practice. *Journal of the Optical Society of America, 3(6),* 864-867.

Shipley, W. C. (1940). A self-administering scale for measuring intellectual impairment and deterioration. *Journal of Psychology, 9,* 371-377.

Stanislaw, H., & Todorov, N. (1999). Calculation of signal detection theory measures. *Behavior Research Methods, Instruments, & Computers, 31(1),* 137-149.

Sternberg, S. (1975). Memory scanning: New findings and current controversies. *Quarterly Journal of Experimental Psychology, 27,* 1-32.

Tsang, P. S., & Shaner, T. L. (1998). Age, attention, expertise, and time-sharing performance. *Psychology and aging, 13(2)*, 323-347.

Wechsler, D. (1981). *The Digit Symbol Substitution Test. Wechsler Adult Intelligence Scale-Revised*. New York: Psychological Corporation/Harcourt Brace Jovanovich.

Wechsler, D. (1997). *Wechsler Memory Scale III, (3rd Ed.).* San Antonio, TX: The Psychological Corporation.

Weinstein, L. F., & Wickens, C. D. (1992). Use of nontraditional flight displays for the reduction of central visual overload in the cockpit. *The International Journal of Aviation Psychology, 2(2),* 121-142.

Wickens, C. D. (2002). Multiple resource and performance prediction. *Theoretical Issues in Ergonomic Science, 2(2),* 159-177.

Williams, L. J. (1982). Cognitive load and the functional field of view. *Human Factors, 24,* 683-692.

Williams, L. J. (1989). Foveal load affects the functional field of view. *Human Performance, 2(1),* 1-28.

Williams, L. J. (1995). Visual field tunneling in aviators induced by memory demands. *Journal of General Psychology, 122(2),* 225-236.

Wixted, J., & Lee, K. (2005). Signal detection theory. Retrieved July 2005, from http://psy.ucsd.edu/~kang/sdt/sdt.htm