Perceptual processing deficits underlying reduced FFOV efficiency in older adults

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Older adults are known to perform more poorly on measures of the functional field of view (FFOV) than younger adults. Specific contributions by poor bottom-up and or top-down control of visual attention to the reduced FFOV of older adults were investigated. Error rates of older and younger adults were compared on a FFOV task in which a central identification task, peripheral localization task, and peripheral distractors were presented in high and low contrast. Older adults made more errors in all conditions. The effect of age was independent of the contrast of the peripheral target or distractors. The performance cost of including the central task was measured and found to be negligible for younger adults. For older adults performance costs were present in all conditions, greater with distractors than without, and greater for a low rather than high contrast central stimulus when the peripheral target was high contrast. These results are consistent with older adults compensating for reduced sensory input or bottom-up capture of attention by relying more heavily on top-down control for which they are resource limited.

Introduction

Older adults have a less efficient functional field of view (FFOV, also referred to as the useful field of view) than younger adults: They are slower and less accurate when identifying the location of a peripheral target when required to perform a simultaneous task presented at fixation, and particularly so if peripheral distractors are present (Ball, Bruni, & Roenker, 1990; Fiorentino, 2008; Owsley, 2013; Seiple, Szlyk, Yang, & Holopigian, 1996; Sekuler, Bennett, & Mamelak, 2000). FFOV tasks have been used to successfully identify older adults at greater risk of falls (Owsley & McGwin, 2004) and driving accidents (Ball et al., 2006; Hoffman, McDowd, Atchley, & Dubinsky, 2005; Wood, 2002). However, the perceptual processes that explain poorer FFOV efficiency in older adults have not been clearly established.

The FFOV is an index of an individual's capacity to efficiently deploy visual attention in that it requires dividing attention between central and peripheral vision, and when distractors are added to the task, the capacity to selectively attend to a target and ignore distractors (Owsley, 2013). However, the deployment of visual attention relies on a complex process broadly understood as comprising two distinct but interacting mechanisms: bottom-up attention that involves automatically attending to the most salient input, and top-down control of attention in which the observer intentionally deploys attention to the most relevant feature or location (Buschman & Miller, 2007; Pinto, van der Leij, Sligte, Lamme, & Scholte, 2013).

Bottom-up and top-down attention are likely to play a role in the efficient performance of FFOV tasks. FFOV is typically assessed by measuring accuracy or speed of processing when observers are simultaneously given an object identification task presented centrally, and an object localization task presented peripherally, with or without peripheral distractors. Both dividing attention between central and peripheral vision, and selectively attending to targets amid distractors, require top-down control of attention. At the same time, the peripheral target will be detected most efficiently if it is able to capture attention automatically in a sensory-driven, bottom-up manner (Itti & Koch, 2000; Wolfe & Horowitz, 2004).

Increasing the attentional demands of the FFOV task increases the differences between older and younger groups. Relative to younger groups, older groups are less accurate when no distractors are

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present, and the difference between age-groups is increased when distractors are added (Ball, Beard, Roenker, Miller, & Griggs, 1988; Seiple et al., 1996; Sekuler & Ball, 1986). However, whether the reduced efficiency of the FFOV of older adults reflects poor top-down control or reduced capacity for bottom-up attention, or is independent of these mechanisms and attributable to some other factor such as general cognitive slowing (Salthouse, 1996; Yamani, McCarley, & Kramer, 2015), has not been fully determined. The current study therefore used a modified version of the standard FFOV paradigm to investigate the impact of varying the attentional demands of the task (increasing or decreasing the salience of the central and peripheral stimuli, and removing the central task) on FFOV performance in younger and older adults. The aim was to identify whether reduced FFOV efficiency in older adults could be attributed to a reduced capacity for either bottom-up or top-down attentional processes.

Normal aging is associated with a decline in the efficient deployment of visual attention, but the decline is not consistent across all aspects of visual attention (Madden, 2007; McAvinue et al., 2012). Whether top-down control or bottom-up capture of attention is more prone to age-related decline is unclear (Zanto & Gazzaley, 2014). Older adults have been shown to exercise top-down attention just as effectively as younger adults when attending to a predictable target feature (Madden, Whiting, Cabeza, & Huettel, 2004), and when using a cue to avoid bottom-up capture by irrelevant distractors (Muller-Oehring, Schulte, Rohlfing, Pfefferbaum, & Sullivan, 2013; Whiting, Madden, & Babcock, 2007). It has been argued that older adults have a reduced capacity for bottom-up attention due to poorer sensory input or increased internal neural noise, and compensate by relying more heavily on top-down attentional mechanisms (Madden et al., 2002; Whiting, Sample, & Hagan, 2014). However, bottom-up capture of attention has been shown to be equivalent in older and younger adults when searching for a target defined by a single feature (Muller-Oehring et al., 2013; Plude & Doussard-Roosevelt, 1989), or when irrelevant salient distractors disrupt visual search (Kramer, Hahn, Irwin, & Theeuwes, 1999).

More reliable differences between older and younger adults have been found when performing more complex visual search tasks. Searching for a target defined by the conjunction of two features among distractors that share one of the target-defining features is a more complex task than search for a target defined by a single feature. Searching for a conjunction of two features produces longer search durations as the number of items to be searched increases, known as a set size effect. These effects are greater in older adults than in younger adults, suggesting that older adults have more difficulty with the increased attentional demands of the conjunction search. However set size effects are likely to reflect top-down serial deployment of attention and bottom-up response to pre-attentive processing of signal in noise (Eckstein, 2011; Liesefeld, Moran, Usher, Müller, & Zehetleitner, 2016; Wolfe, 2003). Creating conditions that manipulate the extent to which performance is determined by bottom-up and top-down processes is one way to determine how the different forms of attention contribute to age differences in perception.

Older adults may also be more resource limited in their capacity for top-down control of attention. This group is able to ignore inconspicuous distractors (equiluminant with targets), which exert relatively little bottom-up capture, but are less effective than younger adults at using top-down control of attention to overcome bottom-up attentional capture by highly conspicuous (higher luminance) distractors (Kramer, Hahn, Irwin, & Theeuwes, 2000). Older adults are also less able to take advantage of additional sources of top-down guidance. Whiting and colleagues varied multiple sources of top-down guidance: a consistent versus an inconsistent cue feature, and knowledge of whether the cue would be informative or not (Whiting et al., 2007). They found younger adults could gain additional advantage in search reaction times from combining both sources of top-down guidance relative to gains from one source, whereas older adults improved with one source of guidance but gained no further advantage from a second source. This may be a result of older adults having more limited resources for top-down attention or their need to use greater top-down control to compensate for a poorer bottom-up response, leaving insufficient additional resources to take advantage of a second source of top-down control (Whiting et al., 2007; Zanto & Gazzaley, 2014).

The specific contributions of reduced capacity for top-down or bottom-up attentional mechanisms to the reduced efficiency of the FFOV of older adults have not yet been systematically investigated. There is evidence that the FFOV of older adults deteriorates more than that of younger adults when the attentional demands of the central task are increased (Coeckelbergh, Cornelissen, Brouwer, & Kooijman, 2004). It has also been argued that those older adults who are poorer at a demanding FFOV task also have more difficulty disengaging attention from one location (i.e., the central task) in order to attend another (Cosman, Lees, Lee, Rizzo, & Vecera, 2012). Both of these findings suggest the poor FFOV of older adults is linked to reduced capacity to control top-down attention. However, they are also consistent with older adults having an increased reliance on top-down attention to compensate for reduced bottom-up response to the stimuli as suggested by Whiting and colleagues (2007). This would lead to a greater impact on already stretched top-down control when the central task is made more demanding and to more effortful reorientation of attention if it is being directed by top-down rather than bottom-up mechanisms.

The goal of the current study was to investigate whether the reduced FFOV in older adults was due to poor bottom-up attentional capture by the peripheral target or poor top-down control when dividing attention between the central and peripheral stimulus. We manipulated the bottom-up attentional component of the FFOV by varying the contrast of the peripheral target and distractors across trials. High contrast elements should capture bottom-up attention more effectively than low contrast elements (Wolfe & Horowitz, 2004). Bottom-up attention should therefore improve performance when the peripheral target is high contrast and the distractors low contrast, and impair performance when the target is low contrast and the distractors high contrast. If older adults have a reduced capacity to deploy bottom-up attention, the advantage of a high contrast peripheral target among low contrast distractors should be diminished for older compared with younger adults, as should the difficulty presented by a low contrast peripheral target among high contrast distractors. Top-down control of attention will be required to ignore high contrast distractors and attend to low contrast peripheral targets. Any deficit in top-down control in the older group will result in a greater difference in error rates between the younger and older groups in this condition compared with conditions requiring less top-down control.

The need to divide attention is the major top-down control required in the FFOV task. Investigation of performance costs of the inclusion of the central task by comparing error rates when both the peripheral and central tasks are presented simultaneously to error rates on the peripheral localization task presented alone allows the impact of dividing attention on the FFOV to be evaluated. Previous research has demonstrated that the cost of adding the central task is greater for older than for younger adults (Sekuler et al., 2000). In the current study, the interaction of top-down and bottom-up attentional mechanisms can be investigated by comparing performance costs in conditions with different bottom-up characteristics provided by different combinations of high and low contrast central and peripheral stimuli. The inclusion of a low contrast central stimulus will require more effortful top-down allocation of attention to central vision than the inclusion of a high contrast central stimulus, particularly for older adults if they use top-down control of attention to compensate for reduced sensory input or bottom-up attention. This will result in increased performance costs of the central task for older adults whose top-down attentional resources are thought to be more limited (Whiting et al., 2007).

Method

Participants

Participants were 42 younger (Mean = 27.38 years of age, *SD* = 5.41 years, 21 men, 21 women) and 42 older (Mean = 72.11 years of age, *SD* = 5.92 years, 19 men, 23 women) adults who reported they were free from ocular pathologies such as cataracts, glaucoma, or macular degeneration. All participants were screened for visual acuity and contrast sensitivity. Participants wore their preferred corrective lenses for screening and all testing. No participant had poorer than 6/9 (20/40) corrected visual acuity, or contrast sensitivity as measured by the Pelli–Robson chart that was poorer than 1.65 Db. The younger group was comprised of first-year psychology students who received course credit for participation, and the older group consisted of volunteers recruited from the local community. To meet the requirements of a larger project, all participants were currently licensed drivers with a minimum of three years' driving experience. This study had University Human Research Ethics Committee approval with all volunteers providing written informed consent.

Stimuli

Screening of participants was conducted using the Pelli–Robson Contrast Sensitivity (Pelli, Robson, & Wilkins, 1988) and Snellen visual acuity charts. The Pelli–Robson chart presents triplets of letters at decreasing contrast with contrast sensitivity determined by the lowest contrast at which two out of three letters can be correctly identified. The chart was presented at a luminance of 100 cd/m^2 and viewed at a distance of 1 meter. Stimuli for the FFOV were produced using Director MX (Macromedia, 2004) and displayed by a NEC NP 500WS data projector (NEC, Tokyo, Japan) controlled by a Dell Optiplex 980 computer (Dell, Round Rock, TX) running at 3.2 Ghz and a screen refresh rate of 60 Hz. Viewing distance was 110 cm, and this was monitored by the experimenter. All elements were presented in either high (90 cd/m^2) or low (6 cd/m^2) luminance (and therefore contrast) against a dark (2 cd/m^2) background in a room where the display was the only light source. FFOV performance was measured as the proportion of errors made on the peripheral task when the central task (if present) received a correct response. On trials where the peripheral target and central task were included, only responses in which the center target was correctly identified were considered valid trials. Invalid trials were excluded from the data analysis.

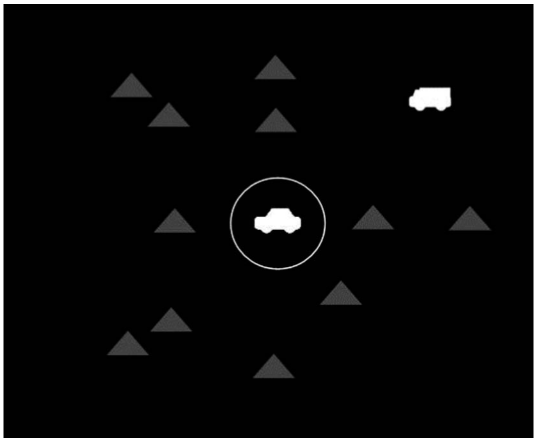

Figure 1. FFOV stimulus showing all elements present with central stimulus and peripheral target in high contrast and peripheral distractors in low contrast.

The display consisted of varying combinations of three stimuli: a central stimulus, a peripheral target, and distractors (noise elements). The central stimulus was a solid 3° by 5° car shape (see Figure 1) presented at fixation which was present or absent, with the stimulus present in 50% of randomly chosen trials. The peripheral target stimulus was a solid 3° by 5° car or truck shape placed at one of eight evenly spaced radial points around an imaginary circle with a radius of 30° centered on the central fixation point at a viewing distance of 110 cm. Participants were required to report the location of the peripheral target by choosing the appropriate number on a subsequent response screen, with possible target locations numbered 1 through 8. Distractors were 3° by 5° triangles placed in 11 positions randomly chosen from the 23 available locations at 10°, 20°, or 30° from fixation on the same eight evenly spaced radians as the peripheral target. In conditions with no distractors, based on Wood (2002), the stimulus duration was 90 ms. The stimulus duration for conditions in which distractors were present was 240 ms due to high numbers of older adults performing no better than chance level in pilot testing with 90 ms stimulus durations.

Procedure

Participants were first screened for age appropriate contrast sensitivity and visual acuity using the Pelli–Robson and Snellen charts. This was followed by two sessions of FFOV testing: One session included the central task in all blocks, the other included blocks without the central task. The session including the central task was arranged in three blocks of trials. The first block presented the central task alone, the second block included the center task and peripheral target without distractors, and the third block added distractors to the stimulus from the second block. The session without the central task in the stimulus comprised two blocks: The first presented only the peripheral target, and the second presented the peripheral target with distractors. The order of sessions was counterbalanced across participants, and the two sessions were separated by at least a 10-min break. Testing was conducted in a darkened room after participants dark adapted for 10 min. Each block began with 10 practice trials in which stimulus duration was 3000 ms for the first trial and was halved on successive trials until reaching the test duration.

Each trial began with presentation of a fixation cross for 750 ms in the center of the display. A white circle 12° in diameter at the center of the display surrounded the fixation cross and remained on the screen for the full duration of the trial. Following presentation of the FFOV stimulus a mask containing a crosshatch pattern covering all possible target and distractor locations was presented with the same duration as the FFOV stimulus. This was replaced by a response screen with options to indicate whether the central stimulus was present or absent, and numbers 1 to 8 at each of the possible peripheral target locations. Participants stated their response to the experimenter who then entered responses into the computer. No feedback was provided about response accuracy.

When both the central task and peripheral target were included, a trial was only considered valid if the central task was performed correctly. Replacement trials were added to the end of each block to ensure six valid trials were recorded for each combination. Each block terminated after six valid trials for each possible combination of high and low contrast presentations of the included element(s) (central stimulus, peripheral target, and distractors). Therefore, there were 12 valid trials required to complete a block for a single element (either central stimulus or peripheral target presented alone), 24 valid trials per block for the combination of two elements (either central stimulus and peripheral target without distractors, or peripheral target and distractors without the central task), and 48 valid trials required for the block combining all three elements. Within each block the order of presentation for the possible combinations of high and low contrast elements was random. An additional short break was provided at the midpoint of the longest block to ensure participants did not become fatigued.

Results

Prior to analysis, the FFOV data was arcsine transformed to reduce the impact of floor effects commonly found in such data (Sekuler et al., 2000).

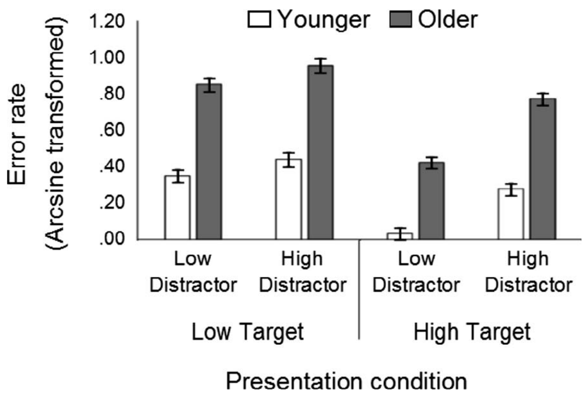

Figure 2. FFOV performance (errors as proportion of valid trials arcsine transformed: 0 = 0%, 1.57 = 100% error) showing each combination of peripheral target contrast and peripheral distractor contrast. Error bars represent ±1 *SE*.

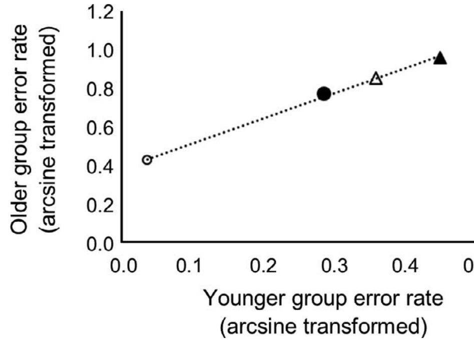

Figure 3. Relationship between the mean proportion of errors made by the younger and older groups across conditions. Triangles and circles represent high and low contrast peripheral targets, respectively; filled and unfilled symbols represent high and low contrast distractors, respectively.

Floor effects in the younger group were further controlled by combining data for the high and low contrast center stimulus conditions for analyses comparing younger and older groups, and eliminating the no distractor condition from the analysis. No floor or ceiling effects were found in the older group for any condition. All other assumptions of the analyses were met. Error rates were also examined for detection of the central stimulus alone to ensure the center stimulus could be detected. Few errors were made across trials in either the younger (2.4% errors: 1/42) or older (9.5% errors: 4/42) groups. No further analyses were conducted on these data.

Age group differences in FFOV performance

The first analysis evaluated age group differences in FFOV performance across presentation conditions when the center and peripheral tasks were presented simultaneously together with peripheral distractors. The distractors and peripheral targets were of either high or low contrast (see Figure 2). The dependant variable was the arcsine transformed proportion of errors made across 12 trials per condition, with a score of 1.2 reflecting chance performance.

Results of a mixed factorial analysis of variance (ANOVA) showed that regardless of condition significantly more errors were made by the older than the younger group, $F(1, 82) = 195.53$, $MSE = 0.10$, $p < 0.001$, $\eta_p^2 = 0.71$, confirming previous findings that older adults have a less efficient FFOV than younger adults. There were no significant interactions with age group, all Fs $(1, 82) < 2.39$, all ps > 0.126, indicating the effect of target and distractor contrast, and their interaction, were similar for younger and older groups. For both age groups significantly fewer errors were made when the peripheral target was presented in high compared with low contrast, $F(1, 82) = 142.76$, $MSE = 0.04$, $p < 0.001$, $\eta_p^2 = 0.64$, and when distractors were low relative to high contrast, $F(1, 82) = 105.13$, $MSE = 0.03$, $p < 0.001$, $\eta_p^2 = 0.56$. There was a significant interaction between peripheral target contrast and distractor contrast, $F(1, 82) = 24.99$, $MSE = 0.03$, $p < 0.001$, $\eta_p^2 = 0.23$. The difference between high and low contrast peripheral targets was greater when presented among low contrast distractors, $F(1, 82) = 161.58$, $p < 0.001$, $\eta_p^2 = 0.66$, than among high contrast distractors, $F(1, 82) = 30.03$, $p < 0.001$, $\eta_p^2 = 0.27$. Also, as can be seen in Figure 2, regardless of age group the difference in error rates between the high and low contrast distractor conditions was greater when the peripheral target was high contrast, $F(1, 82) = 113.84$, $p < 0.001$, $\eta_p^2 = 0.58$, than when the peripheral target was low contrast, $F(1, 82) = 12.10$, $p = 0.001$, $\eta_p^2 = 0.13$. Figure 2 shows that presentation of a high contrast peripheral target among low contrast distractors resulted in fewer errors compared with all other conditions. This reflects the bottom-up capture of attention by a high contrast target among low contrast distractors. In the other conditions, the peripheral target was either the same or of lower contrast than the distractors, resulting in less bottom-up attentional capture. This pattern of results also demonstrates that high contrast distractors are harder to ignore than low contrast distractors, requiring greater top-down control of attention. The consistency of the effect of age group across conditions, indicated by the lack of any interaction between age group and any other variable, shows that the proportion of errors made in the older group is a simple linear function of the proportion of errors made by the younger group (see Figure 3).

Effect of dividing attention on older adults

The effect of dividing attention was examined by comparing error rates for the peripheral localization task with and without simultaneous presentation of the central identification task. The performance cost of including the central task was calculated by subtracting error rates when only the peripheral target localization task was included from error rates for the dual task FFOV (central and peripheral task presented simultaneously). Performance costs were calculated separately for each unique combination of high and low contrast center task stimulus, high and low contrast peripheral target, and peripheral distractor condition (none, low contrast, and high contrast). For the younger group performance costs were negligible in all conditions although significantly different from zero in two conditions: the high ($M = 0.15$, $SD = 0.34$, $t_{(41)} = 2.84$, $p < 0.007$) and low ($M = 0.04$, $SD = 0.12$, $t(41) = 2.07$, $p = 0.044$) contrast distractor conditions when both the central stimulus and peripheral target were high contrast. This indicates that the requirement to divide attention between central and peripheral vision had almost no impact on the ability of the younger group to locate the peripheral target. Consequently, the performance cost of the central task for the younger adults was not further analyzed. For the older group, all conditions with distractors present had costs significantly different from zero (all ts > 2.57, all ps < 0.014), indicating the requirement to divide attention did reduce their ability to locate the peripheral target, especially when distractors were present (see Figure 4). The impact of varying the contrast of the components of the stimulus on performance cost of including the central task was examined by comparing costs across experimental conditions.

The performance cost of the central task for the older group was analyzed using a fully-repeated-measures ANOVA with performance costs as the dependent variable, and center stimulus contrast (low and high), peripheral target contrast (low and high), and distractor condition (none, low, and high contrast) as the independent variables. All assumptions of the analysis were met. The only significant main effect was for distractor condition, $F(2, 82) = 5.23$, $MSE = 0.17$, $p = 0.007$, $\eta_p^2 = 0.11$. Pairwise comparisons revealed that, compared with the no distractor condition, the performance cost of adding the central task was greater when distractors were present at both high, $p = 0.014$, and low, $p = 0.008$ contrast. There was no significant difference to the cost of including the central task between high and low contrast distractor conditions, $p = 0.967$, indicating the performance cost of adding the central task was independent of the contrast of the distractors (see Figure 4).

The only significant interaction was between center stimulus contrast and peripheral target contrast, $F(1, 41) = 5.29$, $MSE = 2.45$, $p = 0.027$, $\eta_p^2 = 0.11$. It was expected that a low contrast central stimulus would result in greater performance costs of the central task for older adults. Simple effects analysis indicated that when a high contrast peripheral target was used, the performance cost of adding a high contrast central stimulus was less than the performance cost of adding a low contrast central stimulus, $F = 8.03$, $p = 0.007$, $\eta_p^2 = 0.16$. When the peripheral target was low contrast, the contrast of the central stimulus (high or low) had no effect on the performance cost of adding the central task, $F = 0.42$, $p = 0.521$, $\eta_p^2 = 0.01$. In sum, for the older adults, when the peripheral target was low contrast, the contrast of the added central task made no difference to its performance cost. However, when the peripheral target was high contrast, the performance cost of including the central stimulus was influenced by the contrast of the central stimulus: The central task had a lower performance cost when it was high contrast and a greater performance cost when a low contrast central stimulus was used.

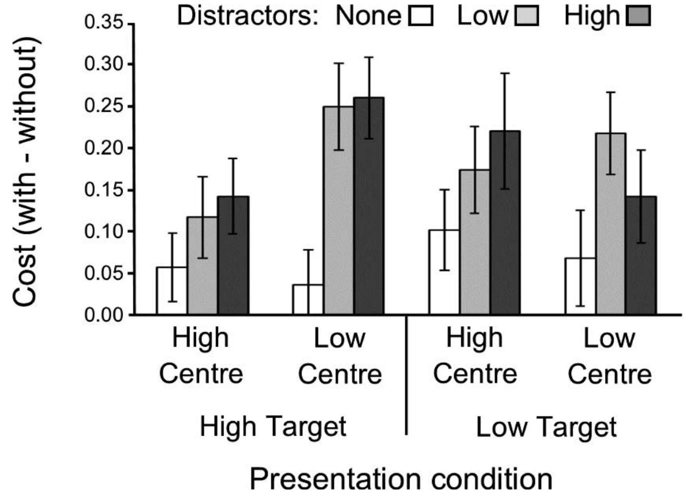

Figure 4. Cost of dividing attention for the older adult group across conditions formed by combining distractor (none, low contrast, high contrast), peripheral target contrast, and center stimulus contrast conditions. Cost calculated by subtracting FFOV error rates (arcsine transformed) made without the center task included from those made with the center task included. Error bars represent ±1 *SE*.

Discussion

The main aim of the current study was to determine whether the reduced efficiency in the FFOV of older adults reflected a reduction specific to the capacity for either top-down or bottom-up allocation of visual attention. We hypothesized that a high contrast peripheral target presented among low contrast distractors would reduce difficulties older adults experience in deploying bottom-up attention, whereas attending to a low contrast peripheral target among high contrast distractors would exacerbate difficulties in the allocation of top-down attention. We also hypothesized that older adults would have greater reliance on top-down rather than bottom-up control of attention. As a result, we anticipated that the performance cost of dividing attention between the central and peripheral tasks would be greater for the older adults when a low contrast central stimulus was used, because this condition would require more top-down focus of attention to central vision. In the following sections, each of these hypotheses will be addressed and the theoretical implications discussed.

Effect of age on FFOV errors

As expected, older adults made more errors in all conditions on the FFOV task than younger adults, replicating previous research (Ball et al., 1988; Coeckelbergh et al., 2004; Scialfa, Kline, & Lyman, 1987; Seiple et al., 1996; Sekuler et al., 2000). However, as expected, older and younger groups made fewer errors when a high contrast peripheral target was presented among low contrast distractors, demonstrating both groups were able to use bottom-up capture by a salient target to improve accuracy. Both age groups also found high contrast distractors more difficult to ignore than low contrast distractors. The difference in the proportion of errors made between high and low contrast distractors was less for the low contrast peripheral targets than for the high contrast peripheral targets. For low contrast peripheral targets, top-down attention is required to attend to the target for high and low contrast distractors because in neither condition is the target salient. Low contrast distractors were presented at the same contrast as the low contrast target, increasing target–distractor similarity, which limits bottom-up capture by the peripheral target and requires top-down attention to ignore the distractors. With a low contrast peripheral target, high contrast distractors were particularly difficult to ignore because they—and not the target—exert bottom-up capture of attention, which must be overcome by top-down control. For high contrast peripheral targets, low contrast distractors were much easier to ignore than high contrast distractors. The low contrast distractors were less salient than the high contrast peripheral target, allowing bottom-up attentional capture by the target and a reduced need for top-down control. When the peripheral target and the distractors were of high contrast, the target and distractor were more similar, and, therefore, less bottom-up attentional capture was exerted by the target, resulting in increased error rates in both age groups.

The differences among these conditions therefore reflect the interaction of bottom-up and top-down attention. Neither facilitation by bottom-up attention to a peripheral target of higher contrast than the distractors nor increased need for top-down attention to ignore distractors of equal or higher contrast than the peripheral target produced a change in the effect of age: The difference between the age groups remained constant across all conditions in which both the central task and distractors were included. This surprising result suggests the effect of age on the FFOV is not a simple result of poorer bottom-up or top-down control of attention when locating the peripheral target.

When interpreted from the perspective of signal detection theory, the localization of the peripheral target among distractors is a signal in noise task. A high contrast target presented among low contrast distractors will produce a high signal-to-noise ratio, which attracts bottom-up attention. A low contrast target presented among high contrast distractors produces a low signal-to-noise ratio and requires top-down attention to either reduce response to noise or enhance response to the signal (Lu & Dosher, 1999). The difference between the age groups did not change across conditions even though the relative strength of the signal and noise components varied. The effect of age is therefore independent of the signal-to-noise ratio inherent in the stimulus. Older adults have been found to have higher levels of internal neural noise, which diminishes their capacity on signal in noise tasks (Bower & Andersen, 2012; Conlon, Brown, Power, & Bradbury, 2015). Increased internal neural noise can impair perception by reducing the signal-to-noise ratio independent of the external stimulus characteristics, depending on whether the internal noise is additive or multiplicative (Lu & Dosher, 1999). Therefore, increased internal neural noise in older adults may explain the consistent effect of age found across conditions.

Performance costs of dividing attention in the older group

For the older adults, the cost of a more demanding (low contrast) central task was greater than that for a less demanding central task (high contrast) when the peripheral target was more easily detected (high contrast). This was not the case when the peripheral target was low contrast. This suggests that when greater top-down control of attention was required to focus centrally and detect a low contrast central stimulus, the capacity for a salient peripheral target to pop out due to bottom-up attentional capture was reduced.

Previously, two explanations have been offered as to why older adults perform more poorly on the FFOV: generalized slowing (Owsley, 2013) and reduced efficiency when shifting attention from central to peripheral targets (Cosman et al., 2012). Although these accounts can explain the cost of the central task being greater when it is more perceptually demanding (i.e., low contrast), they would not anticipate the difference being present only for high contrast peripheral targets. The current results are best explained by a narrowing of attentional focus effectively inhibiting processing of the peripheral stimulus in order to allow processing of a perceptually demanding central task. This is consistent with a FFOV study that allowed eye movements and found older adults had a narrower FFOV and employed more eye movements than younger adults when the eccentricity at which the peripheral target was presented increased (Coeckelbergh et al., 2004).

This explanation of the reduced FFOV in older adults is consistent with the finding that older adults exert more top-down control of attention in order to compensate for reduced sensory input or a poor bottom-up attentional response (Madden, 2007), something that would be exacerbated by a low contrast central stimulus. The cost of including the central task was also greater when distractors were present than when no distractors were present, but the performance cost did not vary between high and low contrast distractor conditions. This suggests the cost of using top-down control to divide attention between central and peripheral vision was increased by the need to also use top-down attentional control to ignore distractors. This is consistent with older adults being more resource-limited in terms of their capacity for using multiple sources of top-down attentional control simultaneously (Whiting et al., 2007).

Part of the evidence for greater reliance on top-down control in older adults comes from studies of the neural areas engaged during visual search by younger and older adults. Relative to younger adults, older adults performing visual search tasks recruit more frontal areas, associated with cognitive and therefore top-down control, and show less activity in occipital and parietal areas from which bottom-up attention arises (Buschman & Miller, 2007; Cabeza, Daselaar, Dolcos, Budde, & Nyberg, 2004; Lorenzo-López, Amenedo, & Cadaveira, 2008). It is understood that this pattern, known as posterior–anterior shift in aging (PASA) allows older adults to recruit frontal regions to compensate for declines in posterior neural processing (Davis, Dennis, Daselaar, Fleck, & Cabeza, 2008), and that this phenomenon is stronger when older adults perform more complex tasks (Ansado, Monchi, Ennabil, Faure, & Joanette, 2012). In attentionally demanding visual search tasks, older adults increase top-down control intentionally and reflexively through greater activation of the dorsal component of the frontoparietal attention network (dorsal attention network or DAN) and related areas that reduce bottom-up capture by salient peripheral signals arising from the ventral component of the frontoparietal attention network (Geerligs, Saliasi, Maurits, Renken, & Lorist, 2014). When focused attention is required, the DAN can block the capacity of the ventral attention network to draw attention to salient stimuli outside the current focus of attention (Corbetta, Patel, & Shulman, 2008; Corbetta & Shulman, 2002). This phenomenon would account for the pattern of results seen in the current study if older adults use top-down attention to narrow the focus of attention around a low contrast central target more than a high contrast central stimulus, and, in doing so, block some of the capacity of the high contrast peripheral target to capture bottom-up attention more effectively than a low contrast peripheral target.

Conclusion

The current results indicate that when selectively attending to the peripheral target among peripheral distractors, older adults can use bottom-up and top-down control of attention as effectively as younger adults. Although older adults make more errors, varying the bottom-up and top-down requirements of the peripheral task had no impact on the age group difference. We explored how older adults cope with the requirement to divide attention in the FFOV task by investigating the performance cost of including the central task. The results suggested older adults use top-down attention to focus available resources centrally, at the expense of reduced processing capacity for peripheral vision. The cost of narrowing the focus to central vision was found to be greater when the central stimulus was perceptually more difficult (low contrast) and the peripheral target was more salient. This suggests focussing centrally reduces the ability of salient peripheral objects to exert bottom-up attentional capture. This appears to be a compensatory strategy due to some more fundamental processing deficit exacerbated by a low contrast central stimulus. The current study cannot determine what this more fundamental deficit is. Previous research has suggested poor sensory input (Madden, 2007), increased internal neural noise (Whiting et al., 2014), or general cognitive slowing (Yamani et al., 2015) as possible general deficits for which older adults could use top-down attention to compensate. However, the use of a narrowed focus of attention to compensate for a general decline in perception may have implications for everyday tasks. For example, older drivers have been found to engage in a more active or serial search strategy, shown by a greater number of eye movements than younger drivers, when identifying other vehicles on the road, (Maltz & Shinar, 1999). Older drivers also have more accidents involving other vehicles approaching from outside their current focus of attention at uncontrolled intersections (Langford & Koppel, 2006). More research is needed to identify the underlying deficit that requires older adults to adjust their attentional priorities toward central vision in complex visual environments.

Keywords: aging, top-down attention, bottom-up attention, FFOV

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