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Does Central Vision Loss Impair Visual Search Performance of Adults More Than Children?

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Abstract

Significance—In general, young adults with normal vision show the best visual search performance when compared to children and older adults. Through our study we show that this trend is not observed in individuals with vision impairment. An interaction effect of vision impairment with visual development and aging is observed.

Purpose—Performance in many visual tasks typically shows improvement with age until young adulthood and then declines with aging. Using a visual search task, this study investigated whether a similar age effect on performance is present in people with central vision loss.

Methods—A total of 98 participants, 37 with normal sight (NS) and 61 with visual impairment (VI) searched for targets in 150 real world digital images. Search performance was quantified by an integrated measure combining speed and accuracy. Participant ages ranged from 5 to 74 years, visual acuity (VA) from -0.14 (20/14.5) to 1.16 logMAR (20/290), and log contrast sensitivity (CS) from 0.48 to 2.0. Data analysis was performed with participants divided into 3 age groups: children (aged <14, $n=25$), young adults (aged 14 to 45, $n=47$), and older adults (aged >45, $n=26$).

Results—Regression ($r^2=0.7$) revealed CS ($p<0.001$) and age ($p=0.003$) were significant predictors of search performance. VI participants' performance was normalized to the age matched average performance of NS group. In the VI group it was found that children's normalized performance (52%) was better than both young (39%, $p=0.05$) and older (40%, $p=0.048$) adults.

Conclusions—Unlike NS participants, young adults in VI group may not have search ability superior to children with VI, in spite of having the same level of visual functions (quantified by VA & CS). This could be because of vision impairment limiting the developmental acquisition of the age dividend for peak performance. Older adults in the VI group had the worst performance indicating an interaction of aging.

Keywords

low vision; visual development; aging; visual search

Visual performance typically shows an inverted “U” shaped function with age (Figure 1). The ascending slope of the function indicates improvement due to visual development of the visual system. The peak of the function reveals an age dividend benefit of young adulthood. Finally, the descending slope of the function indicates a decline in visual performance due to aging. Both structural (e.g. biometric changes) and visual functional changes (e.g. contrast acuity) of the ocular and visual system with age contribute for this inverted-U shaped function.¹⁻⁴

Functional vision tasks such as reading and driving gives a measure of visual performance, and are also helpful in understanding the pathological impediments, including age-related visual impairments on these tasks.⁵⁻⁷ Some of these functional vision tasks can only be studied on adults (e.g. driving simulator studies for pedestrian detection⁸). As children cannot be included in such studies, the effect of age has been examined only for a narrow age span. If a functional vision task can cut the age barrier to permit investigation of the effect of visual development and aging on visual performance, then a wider age span can be studied. One such task is visual search.

Visual search performance is known to vary with age. Therefore, results from adult visual search experiments may not be directly extrapolated to children. Studies that have looked at visual search across the life span have included simple images such as circles or squares in a feature/conjunction based search tasks,^{9, 10} and more complex puzzle searches.¹¹ These studies⁹⁻¹¹ also showed that the visual search performance gets better with age with a peak performance in young adulthood and then a decline in visual search performance into late adulthood. Visual search tasks may be better indicators of real life functional vision than visual functions such as visual acuity, which is known to be a poor predictor.¹²⁻¹⁴ Visual search performance has been documented in patients with visual impairment¹⁵⁻¹⁷ and in normally-sighted individuals with simulated condition of visual impairment.¹⁸ These experiments also evaluated rehabilitation interventions, such as image enhancement technology.¹⁶⁻¹⁸ All of these studies have been conducted on adult participants. Visual search studies on children with visual impairment are scarce if not none. The effect of age on visual search performance in individuals with visual impairment is also not known.

The aim of this study is to investigate the effect of age on visual search performance in patients with visual impairment. With children having visual impairment included in the study, the effect of age compounded with visual impairment can be understood more comprehensively from a wider age span.

METHODS

The study protocol adhered to the tenets of declaration of Helsinki and was approved by the institutional review board of L V Prasad Eye institute. All participants were enrolled with informed written consent from them or their parents (for participants less than 18 years of age). Additionally, verbal assent was also obtained from all the participants less than 18 years of age. The study location was L V Prasad Eye Institute, Hyderabad, India.

Participants

Thirty-seven normally-sighted participants and sixty-one participants with visual impairment took part in the study. Visual impairment was defined as the best corrected binocular visual acuity to be logMAR 0.48 (20/60) or worse, similar to established vision standards.¹⁹ Patients with peripheral field loss were excluded. Visual impairment resulted from a variety of ocular diseases (Table 1). Normal vision was defined as visual acuity better than logMAR 0.20 (20/32) in each eye with no ocular pathology. Visual acuity was measured using COMLog (Ver. 1.3.25.0, Bristol, UK). Log contrast sensitivity was measured using COMLog that thresholds contrast with a logMAR 1 (20/200) optotype similar to that of Pelli-Robson contrast sensitivity chart. We also performed luminance measurements for the displayed optotypes in COMLog with a photometer (LS-100 Konica Minolta Photometer, NJ, USA) and developed a look up table for calculating the contrast sensitivity.

In data analysis, the participants were divided into 3 groups: Children (age: 5 to <14 years, n=25), Young Adults (age: 14 to 45 years, n=47) and Older Adults (above 45 years, n=26). There are several different cut-offs for age binning that can be used. We chose the above age criteria based on earlier studies^{9, 11} that showed a steep decline in reaction-time till around age 15 years and an increase in reaction-time from around age 45 years. Our data analysis also showed agreement to such a trimodal age distribution (see Results).

Experimental Procedure

The experimental procedure was similar to our previous visual search studies.^{16–18} Essentially, a real world image (1280 × 1024 pixels) was presented along with a “search target” at upper-left corner on an 18.5” computer screen (HP W1972a monitor) using a desktop computer system (Intel core™ i5-3330 CPU, 3GHz RAM). The search target was taken from within the real world image (Figure 2). The real world images included faces, indoor scenes and collections of objects. Image presentation order was randomized. The average target size was 8.8° for 40 cm viewing distance.

Participants wore their spectacle refractive correction if any, for this experiment. The participant was asked to point to the search target within the image as quickly and as accurately as possible (Figure 2). The examiner clicked the computer mouse on the pointed region, after which the next search trial was presented. As not all participants (especially the older participants) were familiar with using a computer mouse, a single examiner clicked the mouse for all the participants, to minimize this confounding problem. At the start of the next trial the examiner always placed the mouse pointer to the top right corner of the computer screen to maintain uniformity for mouse navigation for all participants in all trials. A delay can be expected between the participant’s touch response and the examiners mouse click. We quantified this delay in a pilot study by video recording participant’s visual search performance. Examiner’s mouse click was delayed on an average by 656 milliseconds. This factor however was not accounted since only relative comparisons were made between the different groups.

Practice trials (n=14) were given to all participants using images not appearing in the main experiment. In the main experiment, a total of 150 trials were presented, with preset breaks

after every 30 trials. When required, ad-hoc breaks could also be taken by informing the examiner who then paused the experiment before beginning a new trial. Time taken to find the search target (reaction time) and the reported target location (to check for accuracy) were recorded for integrated-performance computation. No head or chin restraint was used, to simulate real world viewing conditions (Figure 2). Participants chose their comfortable viewing distance to perform the visual search experiment (Table 1). On average, participants with visual impairment were closer to the screen when compared to their peers with normal vision (30%, 35%, 34% closer for the 3 age groups, respectively).

Integrated Performance

Typically, the median reaction-time and the percentage of correct-response are used to quantify search performance. In our study, median reaction-time was calculated only from those trials that were accurate, like in our previous studies.^{16–18} Correct-response (or accuracy) was determined by checking if the touch response was within the target coordinates with an expanded buffer zone of 5 pixels width. Reaction-time and correct-response are not necessarily independent measures of visual search performance. It is possible that one measure is traded off for the other for any intentional or unintentional reasons. When one has a short response time and a low correct-response rate, the mismatch makes it impossible to conclude whether the subject has a good search performance or not. Ideally, we should take both the measures together into consideration instead of just reporting one at a time.

There were earlier attempts of combining reaction-time and correct-response using an inverse efficiency score, which essentially adds reaction-time penalty according to incorrect response.^{20, 21} The penalty conversion scale was arbitrarily defined but it has been argued the score may not be appropriate for cognitive performance.²² To quantify search performance, we previously proposed an integrated measure as well,¹⁶ which calculates the area under correct-response curve over search time. The end point of the correct-response curve was set at the longest search time among conditions to be compared. The measure is useful for comparing different conditions, but it is not an absolute measure. When a new condition is added, the measure will change because the longest search time is likely to be different. We realized this calculation might not capture the visual search performance ‘trend’ of a person.

In this study, we propose an absolute integrated search performance measure, which can be calculated for single condition without relying on any reference. The absolute measure is important for this study, because multiple groups (by age and vision status) need to be compared with each other. To compute the integrated-performance score, we first sorted the correct trials by reaction-time from the shortest to the longest, and then calculated the accumulative search speed (number of targets found per second) as the rank increases, i.e. the number of targets found from the shortest reaction-time till a given rank, divided by the total reaction-time spent until then. The purpose of such a computation is to capture the trend of slowing down of search speed with increase in target difficulty. Figure 3a shows accumulative search speed versus correct-response for subjects A and B. Observation suggests that their search performances are very similar, as their accumulative search speed

curves were about the same until the first 16 easiest targets. Then because subject B found 4 more targets than A, his final correct-response was higher than A, but his halfway search speed (accumulative search speed when half of the easiest targets were found) is lower. In this example, some non-visual factors might affect reaction-time and correct-response. One possibility is that subject A gives up more easily than subject B. This would result in a shorter reaction-time but lower correct-response. On the other hand, subject B could be more persistent and therefore could find a few more targets, which resulted in a higher correct-response albeit longer reaction-times. Hence one subject is better than the other by one search performance measure, but worse by the other measure. If both subjects A and B had kept trying until they found all targets, or the search time for difficult targets are so long that the accumulative search speed is close to zero, then the influence of persistence on the results could be disregarded. This is important for this study, since subject ages varied widely and attention and motivation may also vary by age. The calculation of integrated-performance is illustrated in Figure 3b. The slowing-down of accumulative search speed is first fitted with a straight line, and the area under the fitted line between 0% and 100% correct response (subject C) or the intercepted correct response rate (subject D) is computed as the integrated-performance score. In this representative example the calculated integrated-performance in Subject D was better than Subject C, whereas applying this method for subjects A and B would result in a similar integrated-performance for each subject.

Data Analysis

Linear regression and one-way ANOVA were used to evaluate performance predictors (median reaction-time, correct-response and integrated-performance). SPSS software (ver 16.0) was used for all statistical analysis. Two-way ANOVA with age and vision status as factors was also performed.

RESULTS

Visual acuity was not significantly different across the age groups within both visual impairment and normally-sighted participants ($p>0.08$, One-way ANOVA). Log contrast sensitivity was not significantly different across age group for participants with visual impairment ($p=0.073$), but was different for normally-sighted participants ($p=0.019$). Post Hoc test showed a significant difference between normally-sighted young and older adults ($p=0.017$), and no difference between normally-sighted children with young ($p>0.99$) or older ($p=0.18$) adults. Figure 4 shows these visual functions of visual-impairment and normally-sighted participants divided by age groups. By comparing every two subjects, we found possible trade-off or ambiguity (i.e. shorter reaction-time but lower correct-response or vice versa) in 41% of the visual impairment group and 25% in normally-sighted group. We also found that for our subjects, reaction-time and correct-response were poorly correlated ($r=-0.37$ for normally-sighted and $r=-0.24$ for visual impairment). This result supports the value for the integrated-performance measure.

Effect of Age on Visual Search

Figure 5 shows visual search performance in terms of median reaction-time, correct-response and integrated-performance. A consistent pattern seen in all these search

performance parameters is that the performance average of the young adult group seemed to be better (shorter reaction-time and higher correct-response) than the other two groups, however, an exception can be seen in median reaction-time for participants with visual-impairment (Figure 5a). As expected a two-way ANOVA showed vision status (normally-sighted or visual-impairment) had significant effects on both reaction-time and correct-response ($p<0.001$). Age factor had a significant effect on reaction-time ($p<0.001$), and the effect approached significance for correct-response ($p=0.074$). The interaction between age and vision status was not significant ($p=0.5$) for correct-response, and approached significance for reaction-time ($p=0.072$).

The two effects with approaching significance here indicate uncertainty about the age effect on search performance. In contrast, the same two-way ANOVA based on integrated-performance showed a clearer picture - both vision status and age were significant factors for integrated-performance ($p<0.001$), and the interaction between vision and age was significant as well ($p=0.004$). The analysis based on integrated-performance suggests a possible age effect specific to visual-impairment. Figure 6 shows the relationship between integrated performance and age. An inverted-U shaped relationship is clearly visible for normally sighted participants. On the contrary, participants with visual impairment appear to have a declining trend with age.

There was a strong correlation between search performance integrated-performance and log contrast sensitivity (Figure 7). Linear regression analysis found that 70% of variation in integrated-performance ($R^2=0.7$) can be explained by log contrast sensitivity ($p<0.001$) and age ($p=0.003$). Inclusion of visual acuity did not help improve the prediction ($p=0.17$).

Because search performance differed by age group, when investigating age effect specific to participants with visual-impairment, their integrated-performance was normalized using the average integrated-performance of their normally-sighted counterpart. Contrast sensitivity was a significant factor for normalized integrated-performance ($p=0.028$). Therefore participants with visual-impairment were further divided into four groups based on their log contrast sensitivity: above 0.9, 0.9 to 0.8, 0.8 to 0.6, and below 0.6. contrast sensitivity grouping enables comparisons among age groups for participants with similar visual function. Figure 8 shows the search integrated-performance and normalized integrated-performance for normally-sighted (group 1) and the four contrast sensitivity groups with visual-impairment (group 2–5) in each age group. As can be seen, normalized integrated-performance (mean: 52%) of children with visual-impairment was better than young adults with visual-impairment (mean: 39%, $p=0.05$) and older adults with visual-impairment (mean: 40%, $p=0.048$).

DISCUSSION

This is the first visual search study to include a wide age range of participants, aged 5 to 74, with both normal vision and visual impairment. Including this wide age range provides two dimensions namely visual development and aging. Visual development, has a positive connotation since development inches towards improved performance eventually revealing an age dividend benefit, that peaks or plateaus after a certain age, depending on the visual

function or functional vision. Post this development phase, a decline in function sets in, commonly referred to as aging. The effect of development and aging on search performance has been investigated before, and a typical inverted-U shaped function has been observed, with young adults exhibiting the peak of the performance.^{9–11} Majority of these studies^{9, 10} used controlled experimental stimuli for Feature search and/or Conjunction search. Interestingly, we were also able to replicate this inverted U-function of development and aging with real world images in our visual search task.

Normally-sighted young adults showed the peak of visual performance in all parameters, this was also true for young adults with visual-impairment except in the speed of target detection, where children with visual-impairment showed a better performance (Figure 5). In addition, we also investigated the normalized visual search performance (integrated-performance) for participants with visual-impairment (Figure 8). Normalization against age-matched normally-sighted participants was needed to compensate for the age effect. Our observation shows that both young adults and older adults with visual-impairment have poorer performance when rescaled to their normally-sighted counterparts. The normalized integrated-performance would have been the same for all visual-impairment age groups, if there were no interaction of visual impairment and aging. Our results therefore potentially reveal an interaction between visual impairment, development and aging. We speculate that there is an attenuating effect in the development of young adults with visual impairment that lowered their performance to a level similar to children with visual-impairment. In other words, although the normally-sighted young adults can develop or demonstrate superior visual search capability than normally-sighted children, this might not be the case for the young adults with visual-impairment, who lack this age dividend. To test this hypothesis a longitudinal study design is needed to investigate the effect of visual development and aging on visual functions and functional vision in patients with visual impairment. Given the heterogeneity of different disease conditions and a myriad of presentations of functional vision and visual functions amidst patients even for the same disease condition, longitudinal study will be better suited than a cross-sectional study. Alternately, one could argue that the children with visual-impairment exhibited better performance due to the early onset of the disease (or congenital) condition giving them an upper hand to adapt better to their visual condition when compared to adults who would have had a late onset of the disease. Our study was not designed to look for these differences. Nevertheless, in the young adult group with visual-impairment in our study population, only 27% of them had acquired vision loss due to eye diseases such as diabetic retinopathy and choroidal neovascular membrane, and the average years of diagnosed visual impairment was 6 years. Understandably, the number of acquired vision loss increased to 80% in older adult group with visual-impairment. To resolve potential interaction with visual impairment onset, age and visual impairment duration requires further studies with larger sample size in each such category.

Better visual search performance of young adults in comparison to children and older adults with normal vision has been attributed to attention differences.^{10, 23} However, we do not know whether our results can be explained due to attention issues. Separate study would be required to look at the role of attention in real world target images and experimental stimuli that have homogenous targets with controlled distractors, as is typical of the classic visual search experiments. Even if attention has played a role in our visual search task, explaining

the poorer performance in normally-sighted children, a similar attenuating effect for children with visual-impairment could then be expected. However, we found the search performance of children with visual-impairment was almost the same as young adults with visual-impairment ($p>0.99$), ruling out attention effect. A potential source of experimenter bias for clicking the mouse differentially for different age groups is nil or minimal in our study since the experimenter (research assistant acknowledged for data collection) was naïve to the purpose of the study and the video recorded pilot study did not show such differential effect.

While contrast sensitivity came out as a significant and strong predictor of search performance (Figure 7), visual search involves perception processes higher than detection of low level contrast stimuli. A parallel can be drawn between visual functions (e.g. visual acuity) improving with vision restoration surgery in congenital cataract, yet these patients have difficulty in visual parsing²⁴ or in face recognition tasks.²⁵ Higher order perception and functioning are needed in complex visual tasks such as visual search. The inconsistency between visual-impairment and normally-sighted groups (normally-sighted children's performance was worse than normally-sighted young adult) cannot be explained by contrast sensitivity, as contrast sensitivity was not significantly different between the children and young adults within both normally-sighted and visual-impairment groups.

In conclusion, our study showed that the typical inverted-U shaped visual search performance as observed in normal development and aging, was not obtained in our cohort of individuals with visual impairment. While the young adults with normal vision had a better visual search performance than children with normal vision, the visual search performance was comparable between the young adults and children with visual impairment. This comparable performance could be because of the lack of age dividend during development and/or could be because of the interaction of age with visual impairment. In addition, aging could take a secondary toll on visual search performance in the older adult group with visual impairment who showed the worst visual search performance amidst all the six groups.

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Figure 1.

A schematic representation of the inverted-U shaped relation between performance and age.

Figure 2. Visual search task used in the experiment. (A) A child participant pointing to the target during the visual search task. Room lights were kept on for the purpose of taking this photograph. The actual experiment was conducted in a dark room. (B) The displayed visual search image in (A) is shown here for more clarity.

Figure 3.

Illustrative representations to calculate integrated performance (IP) in visual search task. **(A)** Examples showing two subjects having similar IP, despite different median reaction time and correct response. **(B)** Computation of IP, which is defined as the area under the accumulative search speed trending line. The area is a triangle if the intercepted correct response is less than 100%, otherwise it is a right trapezoid.

Figure 4. Mean visual functions of the three groups (children, young adults and older adults) of participants: **(A)** Visual acuity **(B)** Log contrast sensitivity. Error bars represent the standard error of mean. Visual functions of the normally sighted participants were better than that of participants with visual impairment category but was comparable between the age groups in a given category except for contrast sensitivity in normally sighted participants.

Figure 5.

Visual search performance parameters for different age groups in both the Visual Impairment and Normally Sighted groups: **(A)** Median reaction time **(B)** Correct Response **(C)** Integrated-performance. Error bars represent standard error of mean. Overall older adults had the worst performance in both the groups. Young adults had better performance in the normally sighted group but had comparable performance to children in the group with visual impairment.

Figure 6. Integrated search performance of all subjects versus age. Dashed lines are polynomial fits for normally sighted participants and participants with visual impairment.

Figure 7.

Scatter plot of integrated-performance versus Log contrast sensitivity. Participants with better log contrast sensitivity showed a better performance.

Figure 8.

Effect of visual impairment and aging on visual search performance. Bars show the visual search integrated-performance (IP) of participants grouped into 5 categories (group 1- NS (normally-sighted) participants, group 2- participants with VI (visual-impairment) with log contrast sensitivity (CS) above 0.9, group 3-VI participants log CS 0.9-0.8, group 4-VI participants with log CS 0.8-0.6 and group 5-VI participants with log CS below 0.6. Connected markers show the IP normalized to the respective age groups of NS participants; for example, children with VI were normalized to children with NS. Based on normalized IP, VI children were better than young and old VI adults.

Table 1

Details of the participants in the study.

	Visual Impairment				Normally Sighted		
	Children	Young Adults	Older Adults	Children	Young Adults	Older Adults	
Number of participants	14	32	15	11	15	11	
LogMAR visual acuity	1.00 to 0.48	1.16 to 0.48	1.00 to 0.48	0.10 to 0.14	0.10 to 0.00	0.14 to −0.02	
Log contrast sensitivity	0.5 to 1.25	0.48 to 1.67	0.48 to 0.91	1.67 to 2.0	1.43 to 2.0	1.0 to 2.0	
Computer viewing distance in centimeters ± standard deviation	29 ± 6.5	36 ± 10.7	37 ± 12.2	41 ± 9.6	55 ± 7.6	56 ± 5.2	
Ocular condition							
Retinal dystrophies	6	13	-				
Status post congenital cataract surgery	3	2	-				
Stargard't's	-	5	1	Within normal limits	Within normal limits	Within normal limits	
Age related macular degeneration	-	-	3				
Diabetic retinopathy	-	-	6				
Other causes (retinoblastoma, coloboma, uveitis, etc.)	5	12	5				