Journal of Optometry 15 (2022) 299–304

Journal of Optometry

www.journalofoptometry.org

ORIGINAL ARTICLE

Role of reading medium and audio distractors on visual search

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Received 13 October 2021; accepted 27 December 2021
Available online 4 July 2022

KEYWORDS
Visual search;
Attention;
Distractor;
Word search;
Directionality;
Familiarity;
Digital medium

Abstract
Purpose: Visual search is an active perceptual task influenced by objective factors and subjective factors such as task difficulty, distractors, attention and familiarity respectively. We studied the effect of different search directions, task medium and presence or absence of audio distractors on visual search time in young normal subjects
Methods: Twenty-four young (19–27 years) subjects with normal ocular health (except refractive error) participated in the study after obtaining informed consent. Subjects performed a word search task of ten 7-letter words of medium difficulty level. It was performed by each subject in Up-down, Down-Up, Left-Right, Right-Left, Diagonal and Random directions, with equal number of distractors. The task was performed in paper and digital medium, with or without audio distractors. The conditions were performed in random order by each subject and the time taken to accurately complete the word search was documented for each condition.
Result: The visual search time (VST) was significantly different with different search directions (ANOVA $p<0.0001$, df=5), considering both digital and non-digital medium, with or without audio distractors. The average VST was the least for left-right search direction (100±7.2 s) and was highest for random search direction (291±19 s), on a digital medium ($VST_{digital}$: 183±77 s) and in presence of an audio distractor (VST_{audio}: 184±77 s). The VST scores were not correlated with the age (r=-0.14, p = 0.25).
Conclusion: The visual search time is significantly delayed for search direction other than left-right direction and in presence of an audio distractor on a digital medium. These factors could play a significant role in visual orientation and specific tasks such as reading.

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https://doi.org/10.1016/j.optom.2021.12.004

Introduction

Visual search is a perceptual task that requires detection of a particular stimulus called target from a visual array of other stimuli called distractors [1]. Feature integration and combination theories regarding visual search suggest [2, 3] that visual search involves parallel processing and is significantly influenced by visual attention. Previous studies also reported that visual search process is faster for previously recognized target, distractors of similar visual quality, distractors with unique visual feature such as color, shape, orientation, or size by efficient feature search [3–5].

Wolfe, Friedman-Hill [3] assessed the role of categorization and orientation in visual search using straight target and distractors tilted to the left or right or tilted targets and tilted distractors. It was established that orientation of the target and distractors enhances the visual search when the distractors are homogeneous. Furthermore, studies show that the visual search for a moving target and popped out target were faster due to simultaneous processing of movement and form [6, 7] Familiarity helped visual search if the familiarity confined to the background and studies show target-background similarity and background uniformity adversely influenced visual search time [8].

Visual search is conventionally quantified in terms of reaction time or error rates. Brussee, van Nispen [9] reported that age and educational level played a significant role visual search and that better contrast sensitivity was associated with higher reading speed. The error rates in word detection was studied by Henderson and Chard [10] . The targets and the distractors were semantically similar, different or random. They found that the error rate was less for the different semantic condition. Smilek, Frischen [11] assessed the influence of memory and attention on visual search. Subjects performed a dual task of memorizing the test display item or by ignoring it. The shallower reaction time for dual task condition indicated that memory influenced the efficiency of search.

Several factors [12] such as heterogeneity of the distractors, familiarity of the target, attention, number of targets and distractors, set size and orientation of the target with respect to the distractors affect visual search. The efficiency of a search was found to be influenced by the distribution of items across the visual field and other confounders to visual processing such as binocularity [13]. In general, search efficiency decreased as the similarity between target and distractors increased.

With an increasing use of digital medium for various visual tasks, the observers encounter an unfamiliar visual environment. While most visual search studies are performed on an electronic or digital medium, there is a lack of information of how the medium of visual search influences visual search time. In this study, we assessed the visual reaction time with different visual search directions using digital and non-digital medium, in presence and absence of an audio input as a distractor.

Methods

Participants

A total of twenty four undergraduate students from the SRM Medical College and Research Center participated this study. All subjects underwent a preliminary ophthalmic evaluation. The mean age of the participants was 20.6 $\pm$ 1.7years (Range: 19 to 27 years). The mean spherical equivalent was $-0.47D \pm 0.97D$. Subjects had normal ocular health and those with high refractive errors were excluded from the study. Subjects were screened for cognitive impairment using MoCA (Montreal Cognitive Assessment) questionnaire [14] and the scores were normal. All subjects provided a written informed consent before beginning the measurements.

The study protocol was approved by the Scientific Committee and the Institutional Ethics committee of institutional ethics committee of SRM Medical College Hospital and Research Center. All subjects provided a signed informed consent.

Visual search task

Fig. 1 shows the overall experimental protocol. The subjective task was to perform word search in 6 different directions (Right to left, left to right, up to down, down to up, diagonal and random). Word search task was constructed for 10 words in a 14×14 grid using 7 letter words of medium difficulty [15].

The task was performed both on a digital medium (on iPAD2) and paper medium with and without audio distractor. Audio distraction was introduced by loud music played through generic noise cancelling headphones. In total 24 conditions were assessed (6 directions x 2 medium x 2 audio conditions) and all the sets had the same set size. The order of testing was randomized and the experimental protocol was approved by the institutional ethics committee of SRM Medical College Hospital and Research Center.

The time taken to accurately complete the word search was recorded as visual search time (in seconds). The difference in visual search time between the testing conditions were analysed. All the data were entered and the difference in visual reaction time (a) with different directions of visual search; (b) with digital and paper medium and; (c) with and without audio distractors was analysed.

Results

Intersubject variability was observed in visual search time, on an average across conditions. As seen from Fig. 2 the mean visual search time varied over a range of 70 s to 235 s. No significant correlation was found between the age of the participant and the mean visual search time ($r = -0.14$, $p = 0.25$). All subjects had normal MoCA score, yet a significant correlation was found between the MoCA scores and the average visual search times ($r = -0.51$, $p < 0.01$).

Fig. 3 shows the visual search time for different search directions. On an average across both the media and presence or absence of audio distractors, the mean visual search time was significantly different between conditions ($p < 0.001$). The visual search time was consistently minimum for Left-Right search direction (Mean VST 100$\pm$7 s) and was consistently the highest for the random search direction (Mean VST 291$\pm$19 s). Fig. 3 also shows the standard deviation to be highest for the search direction Up-Down (Mean VST 144$\pm$19 s), emphasizing the subjective differences in that particular search direction.

Fig. 4A shows the difference in visual search time because of presence of an audio distractors. The values are averaged

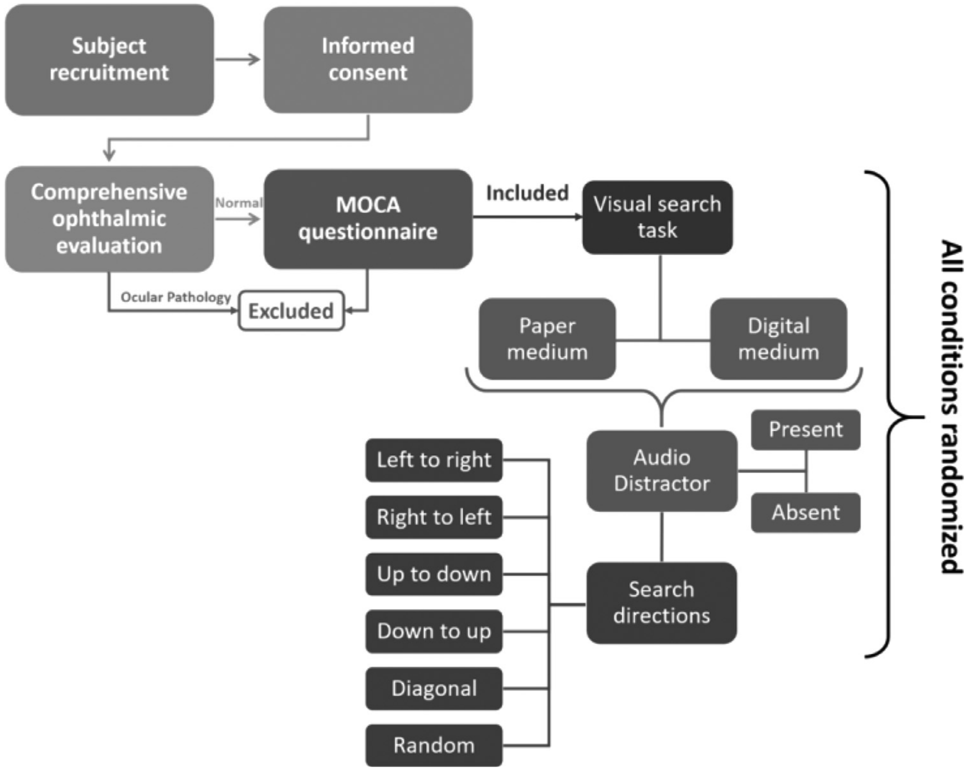

Fig. 1 Experimental protocol.

across different subjects, medium and search conditions. The presence of an audio distractor increased the visual search time significantly (VSTaudio: 184±77 s, VSTnoaudio: 173±75 s, $p<0.05$). The role of the search medium is shown in Fig. 4B. The mean visual search time for the task performed on a digital medium (using iPAD2) was significantly higher than that performed on a paper medium (VSTdigital: 183±77 s, VSTpaper:175±77 s, $p<0.01$).

Few subjects performed better with a digital medium and/or in presence of an audio distractor. The mean age of participants (*N*=, 20±1.5 years) who performed better with an audio distractor was which was slightly less than those participants (*N*=, 20.9 ± 2.4 years) who performed better without an audio distractor (p = 0.96). Similarly subjects who performed better with a digital medium had a lesser (*N*=, 20.3 ± 2.5 years) age than those who performed better with paper medium (*N*=, 21.4 ± 1.9 years), and this difference was statistically insignificant (p = 0.72).

Considering all conditions, fastest visual search was observed for the search direction Left-Right on a paper medium without the presence of an audio distractor (Mean VST 91±13 s). Even in presence of an audio distractor and using a digital medium, the visual search time with the Left-Right search direction remained lesser compared to any other condition of visual search. The highest visual search time was observed for random search direction on a paper medium with audio distractors present (Mean VST 292± 28 s). The results are summarized in Fig. 4.

ANOVA showed significant differences in the mean visual search time between conditions (df=5, $p<0.0001$). All the three factors such as the direction of search, the medium of search and the presence or absence of an audio distractor had significant influence on the visual search times. There

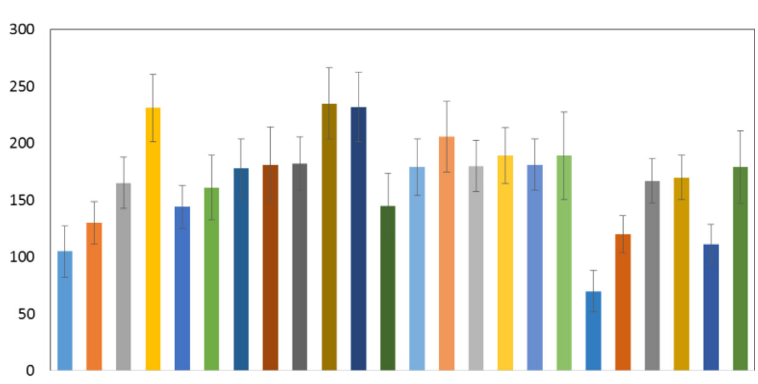

Fig. 2 Intersubject differences in Visual Search Time. Values are averaged across conditions.

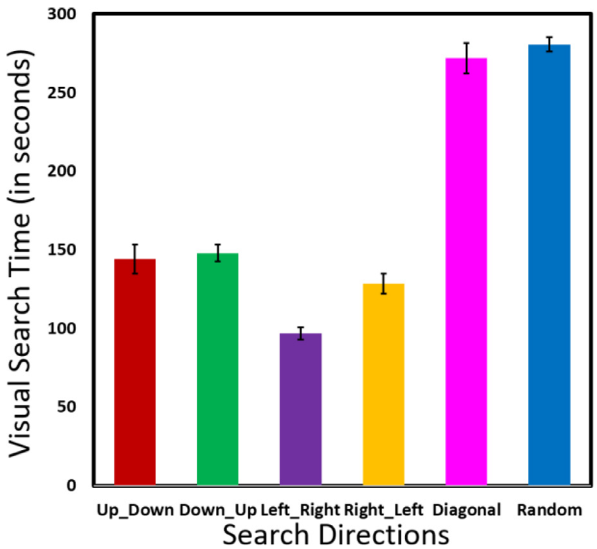

Fig. 3 Visual Search Time across different directions. Values are averaged across subjects, search medium and distractors.

was no significant correlation between the order of testing and the visual search time ($r = 0.0036$, $p = 0.42$), (Fig. 5).

Discussion

In this study, visual search was measured as a function of direction of search in a digital medium and paper medium in presence or absence of audio distractors. We reported that the direction of visual search had significant impact on the visual search time and that presence of audio distractors and the use digital medium delayed the visual search time.

Malinowsky and Hubner [16] studied the effect of familiarity on visual search and found that a search for familiar target among familiar distractor had a better search outcome. In our study, the visual search task involved looking for familiar words of equal difficulty, among a set of similar distractors. The difficulty of the word and the number and similarity of the letters were the same for all the 24 conditions tested (8 directors, 2 media and 2 audio distractor conditions). Thus, it is unlikely that the word familiarity could have affected the outcome of the current study.

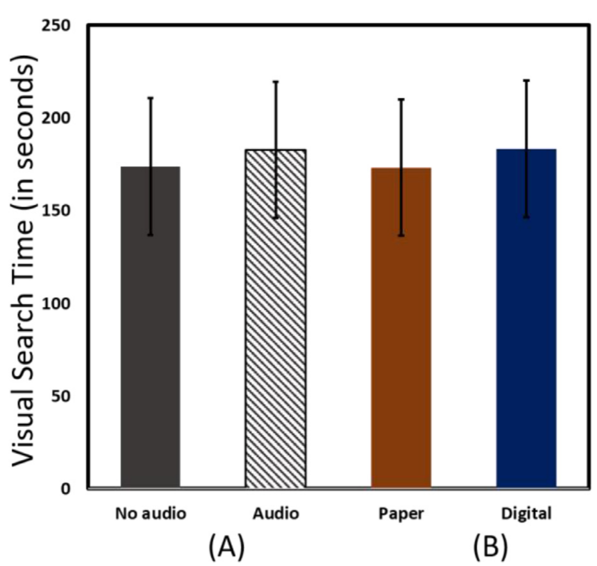

Fig. 4 (A) Effect of audio distractor on VST. Values are averaged across subjects, search directions and media (B) Effect of medium on VST. Values are averaged across subjects, search directions and distractor status.

However, as shown by previous works by Wolfe et al. [2], visual search is also affected by memory and task familiarity. Word search is a common task applied in reading related activities. The fact that the participants were a heterogeneous group of students with a variety of reading activity and the word search task itself could be a familiar task for few subjects that could have led to the intersubject differences.

In the population studied, conventionally paper is used as the medium of reading or writing and in most ethnic groups the direction of reading is from left to right. These factors could have contributed towards faster visual search time compared to other conditions [17]. While reading direction itself could be formed as a result of familiarity the effect seen in this study could show that the bias to reading direction is task specific and could reflect cerebral dominance [18]. Moreover, parameters like set size and the size of the search grid was similar on the digital and paper medium and are unlikely to have influenced the results.

As reported by previous studies [19], visual search is influenced by target orientation. In the current study, the horizontal search direction had better performance. While, this is not target specific orientation, the general search direction can also be influenced by orientation. In addition, the random direction had the worst search times as indicated by longest search durations. Our results are supported by findings by Wolfe et al., [3], were it was demonstrated that the search task was fastest when the targets were oriented in a single direction rather than orientations in multiple direction.

We also found the presence of audio distractors affected the visual search time adversely. Background noise has been known to affect cognitive performances, especially in a younger age group [20]. Attention plays a tremendous role in processing of cognitive information required for proper development and functioning of regular scholastic progress. Quantitative relationship between attention, reading speed and academic performance has been shown by few studies [21]. The search of a word is a demanding cognitive task that requires attention. It is probable the increase in visual search time is as a result of disruption to this attention [22].

Many subject related factors can also affect visual search such as binocularity, the accommodative and vergence parameters. In our study, the subjects were selected after a preliminary ophthalmic evaluation that assessed the above parameters and the subjects were normal. It is unlikely that the intersubject difference in visual seach and the visual search task itself could have been influenced by these aspects. Saccadic eye movements are also shown to have an influence visual search especially for non-homogenous targets [23]. Randomization of the conditions and homogeneity of the targets have likely addressed the issue of the visual search affected by fixational eye movements, effect of learning and fatigue as indicated by the lack of correlation

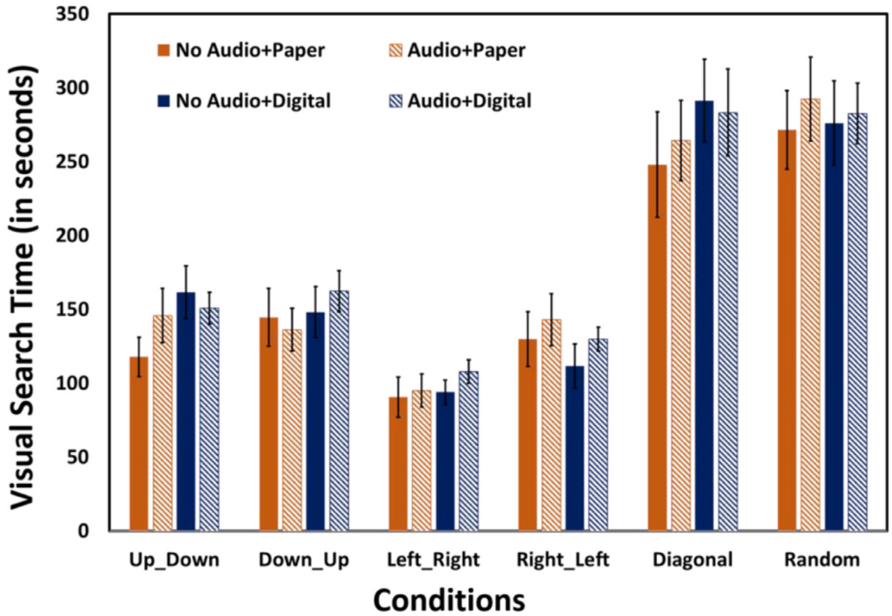

Fig. 5 VST for different search directions (bars) for paper medium (brown bard) and digital medium (blue bars). Conditions without audio distractors are represented with filled bars and with audio distractors are represented as striped bars. Values are averaged across subjects.

between order of testing and visual search times. However, it will be interesting to study the differences in visual search in presence of heterogenous targets in a group of individuals with and without orthoptic ocular status.

Even though no correlation was found between age and the visual search time, a slight tendency for the younger age group to perform better was observed with digital medium and in presence of audio distractors. It is likely that these observations reflect the current changing trends towards wider use of digital medium and alternative educational methods. This will be an interesting aspect worth exploring further.

Our results imply that visual search measured using a word search task is affected by the familiarity in the direction of search and familiarity in the medium. They further emphasize that the attention is degraded by the audiovisual interaction of distractors resulting in worsening of visual search performance influenced by poorer attention span. These findings have more implications on reading performance and general searching behavior of normal subjects, especially when switching from conventional paper medium to widespread digital media.

Conclusion

Visual search was the highest for left to right reading direction on a paper medium without any audio distractors. The visual search time was significantly delayed when the search direction was other than the conventional left-right direction and it was the most for random search direction. For the word search task, the presence of an audio distractor significantly increased the visual search time. Performing the task on a paper medium took lesser time than on a digital medium. The condition of random search direction on a digital medium of testing further delayed the visual search time. These factors could play a significant role in visual orientation and specific tasks such as reading. There was no particular association between age and visual search time and accuracy of visual search was not assessed. It will be interesting to assess visual search under these conditions.

Authors' contributions

AR conceptualized and designed the study, analysed the data and was a major contributor in writing the manuscript. MB was involved in data collection and data analysis. SB was involved in data collection and manuscript writing. RR was involved in data collection, data analysis and manuscript writing. All authors read and approved the final manuscript.

Funding

Funding information is not applicable /No funding was received.

Availability of data and materials

Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

Conflicts of interest

The authors declare that they have no competing interests

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