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Crowded visual search in children with normal vision and children with visual impairment

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ABSTRACT

This study investigates the influence of oculomotor control, crowding, and attentional factors on visual search in children with normal vision ([NV], $n = 11$), children with visual impairment without nystagmus ([VI−nys], $n = 11$), and children with VI with accompanying nystagmus ([VI+nys], $n = 26$). Exclusion criteria for children with VI were: multiple impairments and visual acuity poorer than 20/400 or better than 20/50. Three search conditions were presented: a row with homogeneous distractors, a matrix with homogeneous distractors, and a matrix with heterogeneous distractors. Element spacing was manipulated in 5 steps from 2 to 32 minutes of arc. Symbols were sized 2 times the threshold acuity to guarantee visibility for the VI groups. During simple row and matrix search with homogeneous distractors children in the VI+nys group were less accurate than children with NV at smaller spacings. Group differences were even more pronounced during matrix search with heterogeneous distractors. Search times were longer in children with VI compared to children with NV. The more extended impairments during serial search reveal greater dependence on oculomotor control during serial compared to parallel search.

1. Introduction

Children with visual impairment (VI) show weaker visual search performance than children with normal vision (NV) (Tadin et al., 2012). Visual acuity is only moderately related to the degree of visual search performance in observers with VI, indicating that other factors also play a role (MacKeben & Fletcher, 2011; Tadin et al., 2012). In the present study, a visual impairment was defined as having visual acuity equal to or better than 20/400 and equal to or poorer than 20/50. There are at least three factors that can influence visual search performance of children with VI: (i) oculomotor control (MacKeben & Fletcher, 2011), (ii) crowding (the inability to identify target objects when they are surrounded by visual clutter: Whitney & Levi, 2011), and (iii) attention, i.e. the mechanism enabling us to select relevant information out of irrelevant noise (Carrasco, 2011; Carrasco, Ling, & Read, 2004). It should be kept in mind that these three factors are interdependent. For example, brain areas involved in visuo-motor modules are also involved in spatial attention networks (Braddick & Atkinson, 2011), and visual search task characteristics (e.g., element spacing) influence oculomotor behaviour (van Zoest, Donk, & Theeuwes, 2004; Vlaskamp, Over, & Hooge, 2005). Therefore, the aim of this study is not to disentangle the contributions of these factors, but to investigate under which circumstances visual search impairment is greatest in children with VI. The motivation for the present study is to expand our understanding of the (combined) contribution of these factors to impaired visual search performance in children with VI. Besides scientific reasons, this is important in order to develop effective rehabilitation programs for these children.

Poor oculomotor control can set a limitation on visual search performance (Liu, Kuyk, & Fuhr, 2007; MacKeben & Fletcher, 2011). The decision of where and when to move the eyes is strongly influenced by the characteristics of the specific search task and the density of the visual array, as well as the viewer strategies (van Zoest & Donk, 2004; van Zoest, Donk, & Theeuwes, 2004). The presence of involuntary ocular oscillations (i.e., nystagmus) during visual search might degrade performance, because of the need for refixations after an involuntary eye movement. A large part of the population of children with VI experiences nystagmus due to the presence of an ocular disorder, while there are also children with VI due to 'idiopathic' or 'motor' nystagmus (Fu et al., 2011). The degree of fixational instability in nystagmus is correlated with the degradation of visual acuity (Simmers, Gray, & Winn, 1999). Up to now, there are no studies in children with VI that have analyzed

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oculomotor behaviour during visual search, but it is to be expected that search times are longer for children with VI with accompanying nystagmus (VI+nys) due to the need for refixations.

A second factor setting a limit on visual search performance is crowding. Crowding occurs when target perception is deteriorated by the presence of nearby contours or patterns and can be minimized when contours are placed at a distance beyond the threshold at which distractors interfere with target recognition ('critical distance') (see Levi, 2008, for a review). Visual information from the periphery is used to guide eye movements and a breakdown of this information by crowding can degrade saccadic search (de Vries et al., 2011; Vlaskamp & Hooge, 2006). During visual search in adults with NV, decreasing the element spacing to distances smaller than 1.5° causes longer search times, longer fixation durations, more fixations, and smaller saccades (Vlaskamp, Over, & Hooge, 2005). In addition to element spacing, stimulus configuration can also influence the strength of the phenomenon. In central vision, surrounding distractors placed above, below and on both lateral sides of the target are more potent elicitors of crowding than laterally placed distractors (Atkinson et al., 1985; Toet & Levi, 1992; Vlaskamp & Hooge, 2006). Increasing object density degrades visual search performance in adults with VI (Dougherty et al., 2009; Liu, Kuyk, & Fuhr, 2007). There is evidence that crowding effects are stronger in children with VI than in children with NV at 8° eccentricity (Tadin et al., 2012) and in central vision (Huurneman et al., 2012a). Furthermore, crowding effects in central vision are even stronger for children with VI+nys than children with VI−nys (Huurneman et al., 2012a). These findings are in line with studies reporting stronger lateral interactions in adults with nystagmus (Chung & Bedell, 1995; Huurneman et al., 2012b; Pascal & Abadi, 1995). Thus, it might be expected that children with VI, especially children with VI+nys, experience small spacing as a bottleneck during search performance.

Spatial attention is the third limiting factor in visual search tasks (Carrasco, 2011). Search tasks with homogeneous distractors (i.e. parallel search) are considered preattentive, and tasks with heterogeneous distractors (i.e. serial search) require focal attention (Casco, Gidiuli, & Grieco, 2000; Treisman & Gelade, 1980). Children from the age of 6 years onwards show improved performance on serial search tasks (Ruskin & Kaye, 1990), which could be related to improvements in attentional top-down control (Hommel, Li, & Li, 2004). There is evidence that children with ophthalmic disorder, i.e. children with corrected-to-normal visual acuity, but a history of strabismus, nystagmus or cataract, have attentional impairments as demonstrated by omissions during cancellation tasks and slower execution times than children with NV (Cavezian et al., 2013). As reported above, children with VI show impaired visual search performance (serial search in a wide-field naturalistic display) and stronger peripheral crowding effects, which might both be caused by limited attentional resolution (Carrasco, 2011; Tadin et al., 2012). Because of the reported attentional impairments of children with VI, these children might show disproportionately poor performances on serial tasks compared to children with NV.

The contribution of the above mentioned factors on visual search performance will be investigated in three visual search tasks. The role of oculomotor control is investigated by comparing performance of children with VI+nys with children with VI−nys or NV. The role of crowding is investigated by manipulating element spacing and stimulus configuration (row versus matrix search). Finally, homogeneous and heterogeneous distractors were used so as to manipulate attentional load during task performance. Three hypotheses were evaluated: (i) children with VI+nys show poorer performance than children with NV on visual search tasks with small element spacing, (ii) there are no group differences in the row configuration, but children with VI are expected to show weaker performance than children with NV in the matrix configuration with homogeneous distractors, and (iii) children with VI show a disproportionately poor search performance on serial tasks compared to children with NV.

2. Method

2.1. Participants

Eleven children with NV, 11 children with VI without nystagmus (VI−nys), and 26 children with VI with accompanying nystagmus (VI+nys) participated. Inclusion criteria for all groups were: (a) age between 6 and 8 years, (b) normal developmental level, (c) birth at term ($\geqslant$36 weeks of gestation), and (d) birth weight $\geqslant$3000 g. Inclusion criteria for the children with VI was visual acuity between 20/400 and 20/50. Exclusion criteria were the presence of multiple impairments and/or central scotomas. Table 1 presents the characteristics of the children (age, distance visual acuity, and near visual acuity). Clinical characteristics of patients can be found in Table 2. Children with NV were included from regular primary schools in the Netherlands. Children with VI were included from client databases of all Dutch vision rehabilitation centres.

Written consent was obtained from the parents of the participants. A local ethics committee approved the study before the assessments were conducted (CMO Arnhem Nijmegen). The study was conducted in accordance with the Declaration of Helsinki.

2.2. Ophthalmological examination

All children were examined ophthalmologically before the experiment started. Visual acuity was measured binocularly at 6 m with the tumbling E-chart at 6 m (Taylor, 1978) under controlled lighting conditions. Near visual acuity was determined with the LH-version of the *C*-test at 40 cm, which contains a crowded version with interoptotype spacing of 2.6′ (′ refers to minutes of arc) and an uncrowded version with interoptotype spacing of at least 30′ (Haase & Hohmann, 1982; Huurneman et al., 2012a; Hyvarinen, Nasanen, & Laurinen, 1980).

A gross estimation of the visual field was obtained by confrontational techniques. Testing central visual fields was not yet possible in these young children. However in near vision tasks there were no signs of central scotomas. Objective refraction was obtained after cycloplegia and if necessary the spectacle correction was prescribed or changed before the experiment started. Children with glasses had to wear them during the entire study.

2.3. Procedure

Children sat at a distance of 60 cm from the monitor wearing their best available optical correction. Viewing was binocular.

Table 1
Characteristics of children with normal vision (NV), children with visual impairment without nystagmus (VI−nys), and children with VI with accompanying nystagmus (VI+nys). Mean age, distance and near visual acuity (decimal notation), and near visual acuity as determined with the staircase method are given. Numbers in parentheses are standard deviations.

	NV	VI−nys	VI+nys
Age in months	92 (12)	90 (11)	90 (10)
N	11	11	26
DVA[a]	1.17 (0.08)	0.28 (0.12)	0.25 (0.10)
NVA[b]	1.70 (0.38)	0.41 (0.14)	0.35 (0.16)
NVA staircase	n.a.	0.42 (0.14)	0.35 (0.14)

[a] Distance visual acuity (DVA) measured with E-gratings at 6 m.
[b] Near visual acuity (NVA) measured with LH-single symbols at 40 cm.