

How Do Flanking Objects Affect Reaching and Grasping Behavior in Participants with Macular Disorders?

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PURPOSE. To investigate how objects (flankers) placed on either side of a target affect reaching and grasping behavior in visually impaired (VI) subjects due to macular disorders compared with age-matched normals.

METHODS. Subjects reached out to grasp a cylindrical target placed on its own and when it had two identical objects (flankers) placed either half or one target diameter away on each side of the target. A motion analysis system (Vicon 460) recorded and reconstructed the 3-dimensional (3D) hand and finger movements. Kinematic data for transport and grasping mechanisms were measured.

RESULTS. In subjects with VI, crowding effected the overall movement duration, time after maximum velocity, and maximum grip aperture. Maximum effect was shown when the flankers were placed close to the target (high-level crowding) with a decreased effect shown for flankers placed farther away (medium-level crowding). Compared with normals, subjects with VI generally took longer to initiate the hand movement and to complete the movement. Time after maximum velocity and time after maximum grip aperture were also longer in subjects with VI. No interaction effects were found for any of the indices for the different levels of crowding in the two visual groups.

CONCLUSIONS. Reaching and grasping behavior is compromised in subjects with VI due to macular disorders compared with normals, and crowding affected performance for both normal subjects and those with VI. Flankers placed half an object diameter away showed greater deterioration than those placed further away. (*Invest Ophthalmol Vis Sci.* 2012;53:6687-6694) DOI:10.1167/iovs.12-9821

In everyday life, reaching and grasping movements are not carried out in isolation, but are almost always performed in the presence of other objects. Obviously, vision plays a big role in this and, to date, very little data exist on how objects nearby affect reaching and grasping behavior in subjects diagnosed

with macular disorders who are likely to suffer from central visual impairment (VI).

Reaching and grasping movements can be measured using two main components: transport and grasping. The two main streams implicated in this are ventral and dorsal. Ungerleider and Mishkin¹ postulated that the dorsal stream established the spatial location of the target, while the ventral stream identified the target. Later research suggests that the dorsal stream is mainly used for computing the visuomotor transformations for the guiding action and is not used for the spatial localization of targets.²⁻⁵ Prior to starting a reaching and grasping movement, information about the location of the target and its properties would be used to plan the movement and to preshape the grip. The transport component is normally measured using indices including the peak velocity, time taken to peak velocity, and deceleration times. The grasping component gives an account of the posture of the fingers when they are picking up the target, and is typically measured using the grip aperture, time to, and time after the grip. Although independent, both the grasping and transport components have been shown to be closely coordinated during the execution of the movement.^{6,7} General parameters, such as the time to movement onset and the overall movement duration, provide information about the overall planning and online control of prehension. Movement planning is examined using parameters such as the time taken to maximum velocity. Once the movement has commenced, corrections to the movement trajectory (online control) can be made to compensate for any errors in the initial planning and to add dynamic visual and haptic feedback about the positions of the moving hand and target. This can be examined using time after maximum grip aperture. The need to avoid obstacles or non-targets/distracters/flankers, as they are sometimes referred to in the literature, is likely to lead to changes in the organization and control of the transport component, the grasping component or both.

Various studies have examined prehensile movements in the presence of nearby objects in subjects with normal vision.⁸⁻¹² Grip apertures become smaller and movement times longer if objects are placed close to the target. The speed of the movement depends on the distance between obstacles, with movements becoming faster when the distance between the target and obstacles is increased. Slowing down the movements when the obstacles are close to the target allows a more effective use of visual feedback to enable subjects to alter their speed and/or direction of movement in order to avoid possible collision. In addition, a smaller maximum grip aperture avoids collisions between the fingers and the obstacles close by. It has been shown that location of the obstacle influences the maximum grip aperture with smaller effects for obstacles placed behind the target rather than on either side.⁹ Interestingly, objects that are not in the direct path of the target have also been seen to influence reaching and grasping performance. Objects placed on the contralateral side have been shown to divert the ipsilateral hand away, suggesting

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that the strategy is not for obstacle avoidance alone. A recent paper by Chapman and Goodale¹³ shows differences in patterns of behavior when a target becomes an obstacle compared with when it does not. They suggest that the entire workplace is encoded and that all objects are represented for an informed decision by the online correcting system. On the other hand, recent work by Bulakowski et al.¹⁴ claims that the density of clutter is important for visual perception and limits the discrimination performance, whilst it is relatively uninformative for grasping behavior. However, not all studies report a disruption to the reaching and grasping kinematics in the presence of obstacles.^{10,15-17} Various differences in targets and methodology may explain these differences. For example, subjects having prior knowledge of the target location might demonstrate better performance compared with those who did not. In addition, differences in instructions may also play a part: some studies¹⁸ required subjects to perform fast and accurate reaches rather than natural movements that would have led to shorter overall movement times. Jackson et al.¹⁰ studied the effects of nearby objects on what they called 'memory representation' condition. Subjects carried out normal reaching and grasping movements with their eyes open and compared them with when the eyes were closed. Although they reported no significant differences in either the transport and grasping components with and without nearby objects when the eyes were open, under 'memory representation' conditions, both reaching and grasping performance were reduced in the presence of the these objects.

Studies by both Castiello¹⁵ and Bonfiglioli et al.,¹⁹ using different fruits of varying sizes as targets and nearby objects, showed how non-targets influenced grip aperture: smaller grip apertures occurred when the obstacle (such as a cherry or mandarin) was smaller than the target (apple). As no effect was found for the transport mechanism, they suggested that the intrinsic properties of the obstacle, such as size and color, have a selective influence on the kinematic parameters of the grasp, whilst the transport component remains unaffected. Studies by Chapman and Goodale²⁰ have demonstrated how the position, size, depth, and height of the nearby objects interact to affect reaching and grasping behavior.

In visual perception the effect of non-target objects on the perception of targets has been researched extensively. Crowding occurs when visual performance with respect to isolated targets decreases in the presence of 'non-targets.' Crowding affects letter resolution and identification,²¹⁻²⁴ vernier acuity,²⁵ face identification,^{26,27} object recognition,²⁸ and reading²⁹⁻³¹ in subjects with normal vision, amblyopia,³²⁻³⁵ and VI (see below). It has been postulated that the effects of crowding are maximal when the flankers are spatially closest to the target,^{22-25,36,37} or when the target and the flankers are most similar in terms of shape, color, contrast polarity, spatial frequency, and so on.^{36,38-40} It has also been shown that both the magnitude and extent of crowding are greater in peripheral vision when compared with the fovea.⁴¹

In patients with macular disorders, many clinical visual functions are compromised including visual acuity, contrast sensitivity, fixation stability,⁴²⁻⁴⁵ and reading.⁴⁶⁻⁴⁸ In the presence of macular disorders, patients are likely to rely on their peripheral or parafoveal retina for functional vision. As crowding has been shown to be more substantial in the normal parafovea and periphery than in the fovea,⁴⁹⁻⁵¹ it has been suggested that people with macular disorders would suffer from more crowding than people with normal vision who use their fovea. However, to our knowledge, there is no published evidence demonstrating increased crowding in people who suffer from macular disorders. On the contrary, there is evidence that people with central VI caused by macular disorders do not suffer from more crowding than normal

subjects. For instance, reading speed for subjects with central VI does not improve with increased letter or line separation beyond the standard spacing, which presumably reduces crowding among letters or lines of text.⁵²⁻⁵⁴ Similarly, subjects with central VI do not require larger object separation to recognize common objects (such as a water bottle, a truck, or a lamp), when compared with their normally sighted counterparts.⁵⁵ There is also evidence showing the crowding zones (spatial regions over which crowding occurs) measured at the preferred retinal locus of subjects with central vision loss are reduced in size in subjects with central loss when compared with the normal periphery (Chung STL, et al. *IOVS*.2008;49: E-abstract 1509). We interpret these findings as an adaptation or learning effect, since crowding can be reduced through perceptual learning.⁵⁶

To date, previous studies have demonstrated how reaching and grasping behavior is affected by flankers around a target in normal vision subjects. In addition, there are studies that have investigated how VI affects reaching and grasping of a single target.⁵⁷⁻⁶⁰ Despite the evidence that subjects with central VI caused by macular disorders do not suffer as much from crowding as in the normal periphery, for tasks such as reading, letter, and object recognition, very little is known about how nearby objects (crowding) affects reaching and grasping in these subjects. The present study examines how subjects with macular disorders carry out visually guided reaching and grasping movements for a target that is flanked by other objects. A combined effect of reduced central visual acuity and crowding of targets on reaching and grasping behavior is compared with age-matched normal subjects.

METHODS

Subjects

Eleven subjects from Anglia Ruskin University (Cambridge, UK) with macular disorders who were attending the University's low vision clinic took part. The demographics of all subjects are given in Table 1.

All visually impaired subjects had been diagnosed with bilateral macular problems by an ophthalmologist. Ophthalmoscopy revealed macular changes, which were also evidenced by central scotoma on the Amsler charts in all subjects. No subjects had any other ocular problems such as corneal opacities, and so on. Age-matched older subjects (51-82 years) with normal vision (visual acuity of 0.00 LogMAR in each eye and contrast sensitivity (CS) score greater than 1.65 log units, without any history of amblyopia or any diagnosed ocular pathology) were also recruited. The mean age of the normal subjects was 67 (SD = 10.87) years and for those with VI it was 71 years (SD = 11.48). A *t*-test showed no significant differences in age between the normal group and the visually impaired group ($P = 0.45$). Informed consent was obtained from subjects after the explanation of the nature and possible consequences of the study. Ethical clearance was obtained from the University's ethical committee and the Declaration of Helsinki was observed.

In the first set of analysis, the effect of crowding was ascertained in all subjects with VI. In the second analysis, data were compared against age-matched normal subjects.

Apparatus and Stimuli

Data collection and analysis were performed using the purpose built Vicon 460-6 cameras system (Vicon, Oxford, UK). The Vicon 460 consists of a data station which is linked to six high-resolution cameras (Mcam2; Vicon) located at different positions in the laboratory. More details, including a figure of the setup, are given in Pardhan et al.^{59,60} The Mcam2 has a 1280 × 1024 pixel resolution (pixel size of 12 micron square) and the data were collected at 50 frames per second. The mean

TABLE 1. Demographic Data for Subjects with Normal Vision (N) and VI Subjects with Macular Disorders Who Participated in the Study

	Type	Condition	Age	Duration of Condition (y)	Binocular CS (Log)	Binocular VA (logMAR)
1	N	n/a	71	n/a	1.65	-0.02
2	N	n/a	79	n/a	1.65	0.00
3	N	n/a	70	n/a	1.65	0.00
4	N	n/a	53	n/a	1.80	-0.07
5	N	n/a	73	n/a	1.65	-0.08
6	N	n/a	82	n/a	1.65	-0.04
7	N	n/a	59	n/a	1.85	-0.10
8	N	n/a	51	n/a	1.80	-0.10
9	N	n/a	68	n/a	1.85	0.00
1	VI	Neovascular AMD	80	1.5	1.05	1.15
2	VI	Neovascular AMD	70	3.0	0.45	1.20
3	VI	Juvenile macular dystrophy	54	30	1.25	1.18
4	VI	Dry AMD	82	3.0	1.20	1.02
5	VI	Dry AMD	83	1.5	0.90	1.30
6	VI	Juvenile macular dystrophy	60	30	1.30	1.20
7	VI	Stargardt	75	30	0.60	1.38
8	VI	Dry AMD	74	3.0	0.75	1.20
9	VI	Early onset macular dystrophy	76	33	0.75	0.78
10	VI	Dry AMD	77	3.0	1.05	1.25
11	VI	Stargardt	51	36	1.05	1.04

Binocular CS: Binocular contrast sensitivity; Binocular VA: Binocular visual acuity.

The median contrast sensitivity scores for the VI and the normal subjects were 1.05 Log and 1.65 Log units, respectively.

The median LogMAR acuities for the VI and the normal subjects were 1.20 LogMAR and -0.04 LogMAR, respectively.

spatial resolution for the six cameras was 0.5 mm with a SD of 0.1 mm. As the subject's hand moves through the capture area, the light from the marker is reflected back into the camera lens and stimulates a light sensitive plate creating a video signal. The Vicon Workstation controls the cameras and strobes and also collects the signals. The signals are then transferred to a computer on which the Vicon software (Polygon; Vicon) was installed. Polygon collated and processed the data from all six cameras by combining the original calibration data to reconstruct the digital motion in three dimensions (kinematic data). In addition, two video cameras videotaped the sessions. In this way, the participant's hand movements were completely recorded.

Six circular fluorescent and reflective markers (9.5 mm) were attached, with small pieces of nonallergic adhesive tape, to the dominant hand of the participant. The markers were placed at six anatomic positions and were at least 1 cm apart: nail of the index finger, middle of the index finger, base of the index finger, head of the radius at the wrist, nail of the thumb, and base of the thumb. One marker was placed at the center of the cylinder, which acted as the target. The target and non-target objects were identical white cylinders (4-cm high and 4 cm in diameter) presented against a black background. The central target cylinder was always placed straight ahead on the midline of the seated participant. The table height was constant in all the trials.

Subjects sat comfortably in front of a table (83 × 108 cm), which was covered with a black cloth and on which the targets were placed.

Two object distances (360 and 560 mm) and three crowding conditions (including no crowding) were used. The distance was calculated as the depth of the central target measured on the midline of the seated participant. The target object was always placed in the middle of the three objects and was identified by an infrared marker: (1) target in isolation (no crowding), (2) two flankers placed one target diameter away (medium-level crowding), and (3) two flankers placed half a target diameter away (high-level crowding).

Subjects were instructed to reach and grasp the target presented at the center of the three objects, or the single object if it was presented alone. All trials were randomized. Three trials per distance and crowding combination were recorded, and an average was taken for each condition.

Procedure

Subjects were instructed to make accurate and natural reaches with their dominant hand and pick up the object with their thumb and index finger only. Reaches were made under binocular viewing conditions with normal room illumination and all subjects were corrected optimally, as determined by a subjective refraction, for a working distance of 40 cm. Hand dominance was determined prior to starting the experiment with the Edinburgh Handedness Questionnaire.⁶¹ Subjects were instructed to keep their eyes closed between trials and only to open them when they heard the word 'start' to commence a new trial. This prevented subjects from previewing the target size and location. Subjects completed each size-distance combination three times, randomly ordered.

Training was given to all subjects prior to data collection to familiarize them with the markers on their hand and the experimental procedure. In order to decrease intersubject variability, due to different subject latencies at the beginning of the trial, and in order to obtain accurate measurements for the total time taken for the reaching and grasping movements, measurement and analysis commenced when the marker on the fingertip moved on the computer screen. The trial ended as soon as the cylinder was picked up, to avoid any intersubject differences in the latency between the cylinder being picked up and the vertical movement of the hand stopping.

RESULTS

There were no trials with any errors. All subjects completed all the trials without knocking the cylinders over and were able to pick up the target cylinder. The kinematic measures derived from the 3 dimensional coordinates of the markers for each trial included:

General Kinematic Parameters.

- Onset time (seconds): the time between the audible signal and the participant moving their hand from the starting position. The marker on the index finger enabled detection of movement onset.

TABLE 2. Repeated Measures ANOVA for Subjects with VI for the Three Levels of Crowding

Kinematic	No Crowding (n)	Medium Crowding (m)	High Crowding (h)	ANOVA
Onset time (s)	0.74 (SE 0.08)	0.75 (SE 0.08)	0.74 (SE 0.11)	$F_{2,42} = 0.02$ $P = 0.97$
Movement duration (s)	1.21 (SE 0.08)	1.30 (SE 0.09)	1.40 (SE 0.097)	$F_{2,42} = 12.25$ $P = 0.001$
Maximum velocity (m/s)	0.94 (SE 0.05)	0.91 (SE 0.06)	0.83 (SE 0.05)	$F_{2,42} = 2.488$ $P = 0.05$
Time after maximum velocity (s)	0.81 (SE 0.06)	0.88 (SE 0.07)	1.00 (SE 0.08)	$F_{2,42} = 0.679$ $P = 0.002$
Maximum grip aperture (mm)	133 (SE 2.43)	130 (SE 2.04)	120 (SE 1.10)	$F_{2,42} = 38.64$ $P = 0.0001$
Time after maximum grip aperture (s)	0.30 (SE 0.02)	0.33 (SE 0.03)	0.33 (SE 0.04)	$F_{2,42} = 0.485$ $P = 0.62$

- Movement duration (seconds): the time taken from when the movement commenced to when the target was grasped. It did not include the onset time. The marker on the target enabled detection when the target had been grasped.

Kinematic Parameters Relating to the Transport Component.

- Maximum velocity (mm/sec): maximum speed of the movement.
- Time after maximum velocity (seconds): the time taken to decelerate. This indicates the execution or online control of the transport component

Kinematic Parameters Relating to the Grasping Component.

- Maximum grip aperture (mm): calculated as the maximum distance between the thumb tip and index nail markers.
- Time after maximum grip aperture (seconds): the time taken from the time at maximum grip aperture to the time at the termination of the movement. This parameter explores the online control of the grasping component.

Maximum grip aperture and time to maximum grip aperture represent the planning of the grasping component.

Effect of Crowding of Subjects with VI. As the main aim of the study was to explore the effect of crowding in the two visual groups, data across the two different distances have been collapsed. Table 2 shows the results from a two-way repeated measures ANOVA for subjects with VI for the three levels of crowding (no crowding [1], medium crowding [2],

and high crowding [3]). Tukey's post hoc test was conducted, when the crowding condition was significant.

General Parameters. The presence of nearby objects did not affect the onset time of the movement. Movement duration was significantly longer in the presence of the flankers. Tukey's post hoc test shows significant differences between no crowding and high crowding ($P = 0.001$) as well as for high-crowding and medium-crowding conditions ($P = 0.002$). Medium crowding was not significantly different to no-crowding conditions ($P = 0.07$).

The Transport Component. Maximum velocity was significantly lower in the presence of nearby objects. Tukey's post hoc test shows significant differences between no crowding and high-crowding ($P = 0.016$), and between medium- and high-crowding conditions ($P = 0.01$). No significant difference existed between no- and medium-crowding conditions ($P = 0.9$).

Time after maximum velocity was significantly longer with crowding conditions ($P = 0.002$). Tukey's post hoc test shows a significant difference between no crowding and high crowding ($P = 0.001$), and also between medium-crowding and high-crowding ($P = 0.002$) conditions.

The Grasping Component. As expected, subjects opened their hand wider when the target was presented in isolation ($P = 0.0001$) compared with when the target was presented with nearby objects. Tukey's post hoc test shows significant differences between all levels of crowding: no crowding and high crowding ($P = 0.04$), medium- and high-crowding conditions ($P = 0.001$), and no- and medium-crowding conditions ($P = 0.001$).

Time spent after maximum grip aperture was not affected by the presence of nearby objects ($P = 0.62$).

TABLE 3. Repeated Measures ANOVA to Examine Any Differences between the Two Visual Groups (2)

Kinematic Parameters	Visually Impaired	Normal	ANOVA Visual Group
Onset time (s)	0.74 (SE 0.07)	0.35 (SE 0.08)	$F_{1,38} = 13.622$ $P = 0.0006$
Movement duration (s)	1.32 (SE 0.07)	1.06 (SE 0.07)	$F_{1,38} = 5.77$ $P = 0.02$
Maximum velocity (m/s)	0.89 (SE 0.04)	0.90 (SE 0.05)	$F_{1,40} = 0.01$ $P = 0.91$
Time after maximum velocity (s)	0.89 (SE 0.05)	0.71 (SE 0.06)	$F_{1,36} = 4.51$ $P = 0.04$
Maximum grip aperture (mm)	127.9 (SE 1.85)	128.5 (SE 2.02)	$F_{1,36} = 0.048$ $P = 0.82$
Time after maximum grip aperture (s)	0.32 (SE 0.02)	0.22 (SE 0.026)	$F_{1,36} = 6.90$ $P = 0.01$

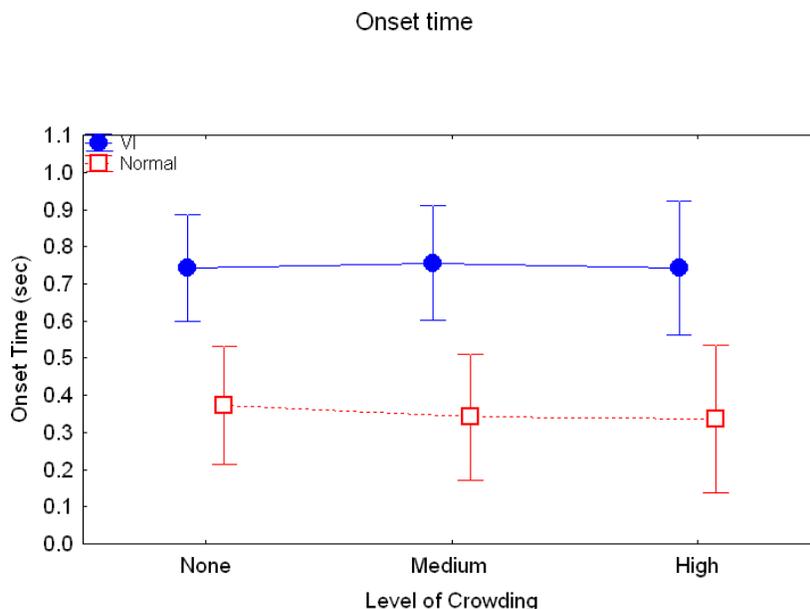


FIGURE 1. Onset time: subjects with VI took longer to start the movement than subjects with normal vision for all levels of crowding ($P = 0.001$). There were no significant interaction effects ($P > 0.05$). Vertical bars denote 0.95 confidence intervals (CIs).

Subjects with VI versus Age-Matched Subjects with Normal Vision. The effect of the presence and absence of VI, size, and distance of the target was analyzed. Table 3 shows results from a repeated measures ANOVA combining visual group (2) (VI and normal) \times crowding condition (3) (no crowding [n], medium crowding [m] and high crowding [h]).

General Parameters. Significant differences were found for the onset time (Fig. 1) and total movement duration (Fig. 2). Subjects with VI took longer to start the movement and execute the movement than subjects with normal vision. There were no significant interaction effects.

The Transport Component. The main parameter of the transport component, maximum velocity, was not significantly different between the visual groups ($P = 0.91$) indicating that the transport component was planned in a similar way for both groups of subjects for all three crowding conditions.

Times after maximum velocity (deceleration) were significantly different (Fig. 3) between the two visual groups ($P = 0.04$), although there were no significant interaction effects.

The Grasping Component. There was no significant difference in maximum grip aperture of the hand for the two visual groups with crowding ($P = 0.82$).

Time after maximum grip aperture increased in subjects with VI ($P = 0.01$), although there were no significant

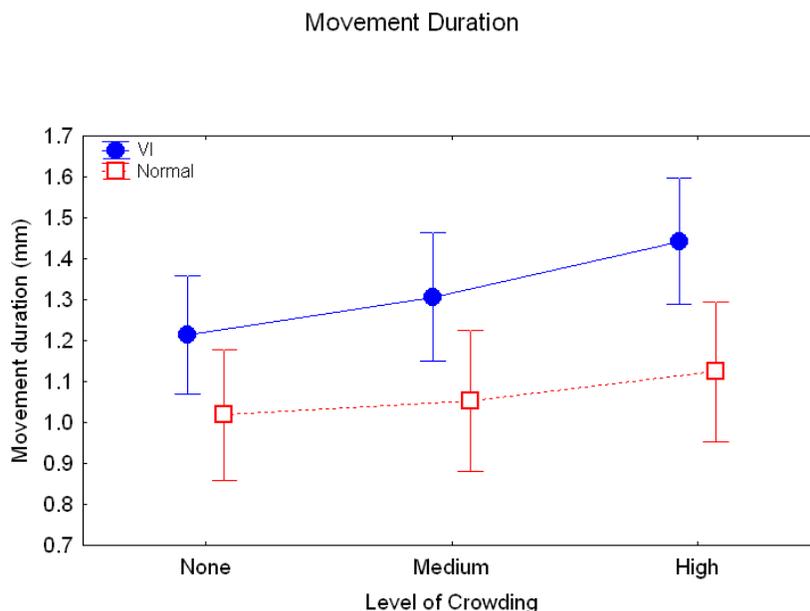


FIGURE 2. Movement duration: subjects with VI took longer to complete the movement than subjects with normal vision for all levels of crowding ($P = 0.020$). There were no significant interaction effects ($P > 0.05$). Vertical bars denote 0.95 CIs.

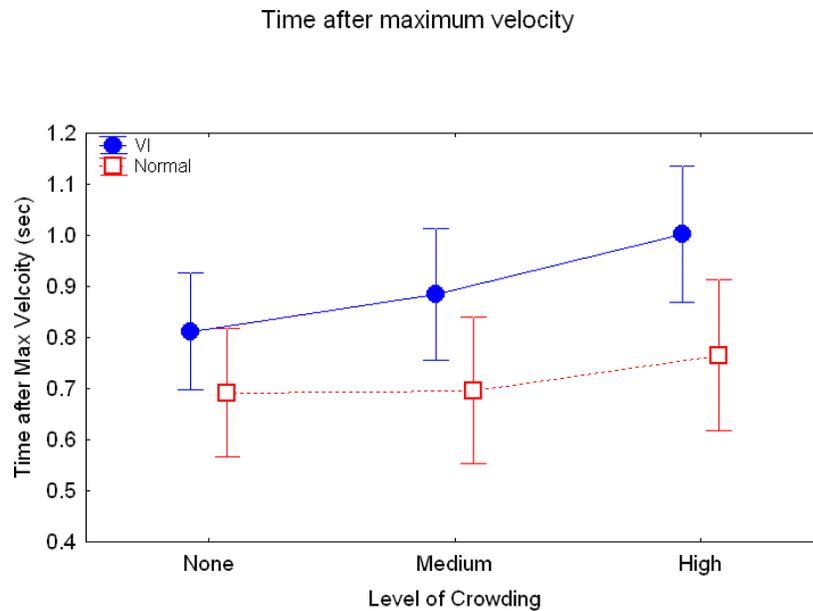


FIGURE 3. Time after maximum velocity: subjects with VI took longer time after maximum velocity was attained compared to normal subjects for all levels of crowding ($P = 0.048$). There were no significant interaction effects ($P > 0.05$). Vertical bars denote 0.95 CIs.

interaction effects (Fig. 4). The extra time required for the deceleration and time after maximum grip aperture indicates the need for extra effort required by the visually impaired for ‘online adjustments’ once the movements had started.

DISCUSSION

The study demonstrates that subjects with VI were not affected by crowding for some kinematic indices such as onset time and time after maximum grip aperture. Crowding did, however, affect total movement duration, maximum velocity, time after maximum velocity, and maximum grip aperture in subjects

with VI. Maximum velocity decreased, whilst the time after maximum velocity increased with increased crowding in subjects with VI. Movement duration increased as the distance between the nearby objects and the target decreased, agreeing with previous studies.¹¹ The increase in movement duration was due to an increase in the time after maximum velocity, which allowed subjects to use more visual feedback to modify the trajectory of the hand without touching the additional objects. As expected, introducing nearby objects on either side of the target led to a change in the kinematics of the grasping component: maximum grip aperture was smaller when the targets were flanked by nearby objects with a decreased grip

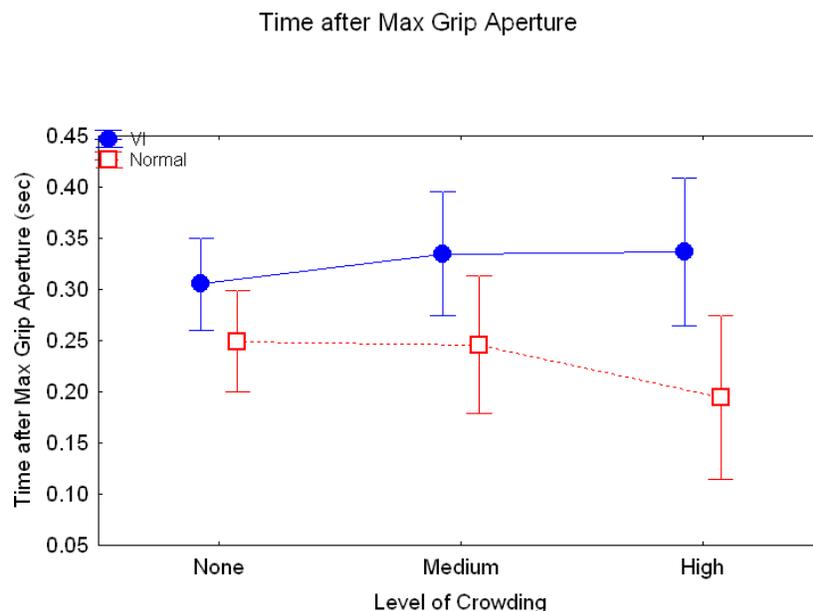


FIGURE 4. Time after maximum grip aperture: subjects with VI took longer time after maximum grip aperture was obtained compared with normal subjects ($P = 0.01$). There were no significant interaction effects ($P > 0.05$). Vertical bars denote 0.95 CIs.

size as the distance between the targets and nearby objects was reduced. The mechanism to avoid collision with additional objects has been reported in subjects with normal vision.¹¹

For indices that showed significant effects of crowding, post hoc analysis generally showed significant differences between no crowding and high crowding, and between medium crowding and high crowding. Only maximum grip aperture showed a significant difference between no crowding and medium crowding. This indicates that, generally, medium crowding, when nearby objects are placed one target diameter away, demonstrates a minimal influence on the majority of kinematic indices. Reaching and grasping performance will, therefore, not be significantly affected if the flanker is placed farther than one target diameter away from the target and that more peripherally placed objects (i.e., beyond one target diameter, will, therefore, have minimal capacity to interfere).

It would be interesting to explore whether subjects with longer duration of the disease would perform differently compared with those who have just been diagnosed. This has been explored in one of our previous studies.⁵⁹ In this study, although subjects with VI were not as efficient and took longer than normal subjects to carry out the task generally, no interaction effects for the different crowding levels were obtained between the two groups. This suggests that the duration of the VI may not make a big difference. In addition, it is not possible to examine this effect with the number of subjects we have in this study. A large scale study could possibly investigate this in the future.

How did the subjects with VI compare with those with normal vision? A significant difference between the two groups of subjects was found in the time needed to initiate the movement as shown by an increased onset time in subjects with VI. No interaction effects were shown. This demonstrates that subjects with VI required more time to recognize and localize the target and start the movement. After that, no differences as a result of crowding were shown. In addition, although subjects with VI also showed poorer performance in the latter part of the movement noted by an increased time spent after maximum velocity time, and time after maximum grip aperture compared with normal subjects, thereby indicating the need for more time for 'online' adjustments, no effect of crowding was shown with these indices either.

In patients with macular disorders, it is quite likely that these patients use their peripheral vision and adopt a peripheral retinal locus (PRL). Considering that crowding is more substantial in the normal parafovea and periphery than in the fovea, it would not be unreasonable to expect that these patients would suffer from more crowding than normal subjects who use their fovea. Interestingly, our data showed very little difference on the effect of crowding on the reaching and grasping behavior between the VI and the normal subjects. This result is consistent with recent reports on perception in that crowding is not more detrimental to reading⁵² and object recognition⁵⁵ for people with central visual loss than for normal subjects.

In everyday life, reaching and grasping movements are not carried out in isolation, but are usually performed in the presence of other objects. From a practical point of view, the data of this study suggest that minimal interference would be obtained if the objects were separated, at least by one target diameter. Although some reaching and grasping performance is slower in patients with VI, it is important to note that not all indices are significantly worse when compared with normal subjects. Maximum velocity and maximum grip aperture are similar. The lack of any interaction effects between the different levels of crowding with the two visual groups suggest that crowding does not adversely influence the behavior in subjects with VI any more than it does in normal subjects. How

these effects are influenced by visual acuity, object contrast, depth of field, and magnitude of visual field loss in subjects with VI has yet to be ascertained.

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