How do flanking objects affect reaching and grasping behaviour in participants with macular disorders?

Shahina Pardhan (1)*, Carmen Gonzalez-Alvarez (1), Ahalya Subramanian (1,2). Susana TL Chung (1, 3)

1. Vision and Eye Research Unit (VERU), Postgraduate Medical Institute, Eastings 204a, Anglia Ruskin University, Cambridge, UK
2. Department of Optometry and Visual Science, City University London, London, UK
3. School of Optometry, University of California, Berkeley, USA

*corresponding author

Shahina Pardhan,

Vision and Eye Research Unit (VERU)

Post Graduate Medical Institute

Anglia Ruskin University,

Cambridge CB1 1PT

Abstract

Purpose: To investigate how objects (flankers) placed on either side of a target affect reaching and grasping behaviour in visually impaired (VI) subjects due to macular disorders compared to 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 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 further away (medium level crowding). Compared to 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 behaviour is compromised in subjects with VI due to macular disorders compared to normals. 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.

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 behaviour in subjects diagnosed with macular disorders who are likely to suffer from central visual impairment.

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 & Mishkin (1) 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 visuo-motor transformations for the guiding action and is not used for the spatial localisation 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 pre-shape 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 co-ordinated 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 (on-line 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 organisation 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 which 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 that the strategy is not for obstacle avoidance alone. A recent paper by Chapman and Goodale (13) shows differences in patterns of behaviour when a target becomes an obstacle compared to 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 el (14) claims that the density of clutter is important for visual perception and limits the discrimination performance whilst it is relatively uninformative for grasping behaviour. 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 to those who did not. In addition, differences in instructions may also play a part: some studies (18) 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 to 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 Castiello(15) and Bonfiglioli and Castiello (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 colour, have a selective influence on the kinematic parameters of the grasp whilst the transport component remains unaffected. Studies by Chapman and Goodale (20) have demonstrated how the position, size, depth and height of the nearby objects interact to affect reaching and grasping behaviour.

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 reading (29-31) in subjects with normal vision, amblyopia (32-35) and visual impairment (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, colour, contrast polarity, spatial frequency etc (36, 38-40). It has also been shown that both the magnitude and extent of crowding are greater in peripheral vision when compared to the fovea.

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 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 visual impairment caused by macular disorders do not suffer from more crowding than normal subjects . For instance, reading speed for subjects with central visual impairment 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 visual impairment do not require larger object separation to recognise common objects (such as a water bottle, a truck or a lamp), when compared to 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 (56). We interpret these findings as an adaptation or learning effect, since crowding can be reduced through perceptual learning (57).

To date, previous studies have demonstrated how reaching and grasping behaviour is affected by flankers around a target in normal vision subjects. In addition, there are studies that have investigated how visual impairment affects reaching and grasping of a single target (58-61). Despite the evidence that subjects with central visual impairment 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 behaviour is compared to age matched normal subjects.

Methods

Subjects

Eleven subjects macular disorders who were attending the University's low vision clinic took part. The demographics of all subjects are given in Table 1.

Table 1: Demographic data for subjects with normal vision (N) and visually impaired (VI) subjects with macular disorders who participated in the study. 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.

	Type	Condition	Age	Duration of Condition (years)	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	0.45	1.20
3	VI	Juvenile macular dystrophy	54	30	1.25	1.18
4	VI	Dry AMD	82	3	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	CVI	Dry AMD	74	3	0.75	1.20
9	CV1	Early onset macular dystrophy	76	33	0.75	0.78
10	CVI	Dry AMD	77	3	1.05	1.25
11	CVI	Stargardt	51	36	1.05	1.04

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 etc. Age matched older subjects (51 to 82 years) with normal vision (visual acuity of 0.00 LogMAR in each eye and 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 visual impairment 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 Declarations of Helsinki were observed.

In the first set of analysis, the effect of crowding was ascertained in all subjects with visual impairment. 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. The Vicon 460 consists of a data station which is linked to 6 high-resolution cameras (Mcam2) located at different positions in the laboratory. More details, including a figure of the set-up, are given in Pardhan et al (60-61). The Mcam2 has a 1280 X 1024 pixel resolution (pixel size of 12 micron square) and the data were collected at 50 frames per second. The mean spatial resolution for the 6 cameras was 0.5 mm with a standard deviation 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) 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 (9.5mm) were attached, with small pieces of non-allergic adhesive tape, to the dominant hand of the participant. The markers were placed at six anatomic positions and were at least 1cm 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 centre of the cylinder, which acted as the target. The target and non target objects were identical white cylinders (4cm 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 X 108cm) 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 infra-red marker:

1. target in isolation (no crowding)
2. two flankers placed one target diameter away (medium level crowding)
3. two flankers placed half a target diameter away (high level crowding)

Subjects were instructed to reach and grasp the target presented at the centre 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 (62). 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 pre-viewing the target size and location. Subjects completed each size-distance combination 3 times, randomly ordered.

Training was given to all subjects prior to data collection to familiarise them with the markers on their hand and the experimental procedure. In order to decrease inter-subject 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 inter-subject 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 3D co-ordinates of the markers for each trial included:

General kinematic parameters:

- Onset Time (sec): 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.
- Movement Duration (sec): 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 (sec): the time taken to decelerate. This indicates the execution or on-line 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 (sec): the time taken from the time at maximum grip aperture to the time at the termination of the movement. This parameter explores the on-line 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 Analysis of Variance (ANOVA) for subjects with VI for the three levels of crowding (no crowding (1), medium crowding (2), and high crowding (3)). Post Hoc Tukey's Test was conducted, when the crowding condition was significant.

Table 2: Repeated Measures Analysis of Variance (ANOVA) for subjects with VI for the three levels of crowding (no crowding (n), medium crowding (m), and high crowding (h)).

Kinematic	No crowding (n)	Medium crowding (m)	High crowding (h)	ANOVA
Onset Time (sec)	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 (sec)	**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/sec)	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 (sec)	**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 (sec)	0.30 (SE 0.02)	0.33 (SE 0.03)	0.33 (SE 0.04)	$F_{2, 42}$= 0.485 p=0.62

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. Post Hoc Tukey's 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. Post Hoc Tukey's test shows significant differences between no crowding and high crowding (p=0.016), and between medium crowding 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). Post Hoc Tukey's 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 to when the target was presented with nearby objects. Post Hoc Tukey's test shows significant differences between all levels of crowding: no crowding and high crowding (p=0.04), medium crowding 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).

Subjects with VI vs. age matched subjects with normal vision.

The effect of the presence and absence of VI, size and distance of the target was analysed. Table 3 shows results from a Repeated Measures Analysis of Variance (ANOVA) combining visual group (2) (VI and normal) x crowding condition (3) (no crowding (n), medium crowding (m) and high crowding (h) .

Table 3: Repeated Measures Analysis of Variance (ANOVA) to examine any differences between the two visual groups (2).

Kinematic Parameters	Visually Impaired	Normal	ANOVA Visual Group
Onset Time (sec)	**0.74 (SE 0.07)**	**0.35 (SE 0.08)**	**$F_{1, 38}$ =13.622 p=0.0006**
Movement Duration (sec)	**1.32 (SE 0.07)**	**1.06 (SE 0.07)**	**$F_{1,38}$ =5.77 p=0.02**
Maximum Velocity (m/sec)	0.89 (SE 0.04)	0.90 (SE 0.05)	$F_{1,40}$ =0.01 p=0.91
Time After Maximum Velocity (sec)	**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 (sec)	**0.32 (SE 0.02)**	**0.22 (SE 0.026)**	**$F_{1,36}$ =6.90 p=0.01**

General parameters

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

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.

Fig 1 here

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 confidence intervals.

Figure 2 here

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 (Figure 3) between the two visual groups (p=0.04) although there were no significant interaction effects.

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 confidence intervals.

Figure 3 here

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 visual impairment (p=0.01) although there were no significant interaction effects (Figure 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.

Figure 4: Time After Maximum Grip Aperture: Subjects with VI took longer time after maximum grip aperture was obtained compared to normal subjects (p=0.01). There were no significant interaction effects (p>0.05). Vertical bars denote 0.95 confidence intervals.

Figure 4 here

Discussion

The study demonstrates that subjects with visual impairment 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 visual impairment. Maximum velocity decreased whilst the time after maximum velocity increased with increased crowding in subjects with visual impairment. 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 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 further 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 to those who have just been diagnosed. This has been explored in one of our previous studies (60). In this study, although subjects with visual impairment were not as efficient and take 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 visual impairment 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 visual impairment compare to 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 visual impairment. No interaction effects were shown. This demonstrates that subjects with VI required more time to recognise 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 to normal subjects, thereby indicating the need for more time for 'on-line' 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 reading (52) and object recognition (55) 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 visual impairment, it is important to note that not all indices are significantly worse when compared to 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 behaviour 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 visual impairment has yet to be ascertained.

References:

1. Ungerleider M. Two cortical visual systems, Eds Ingle DJ, Goodale MA and Mansfield RJW. *Analysis of Visual Behavior.* Boston: MIT Press 1982:549-86.

2. Goodale MA, Milner AD. Separate visual pathways for perception and action. *Trends Neurosci*. 1992; 15:20-5.

3. Goodale MA. Visual pathways supporting perception and action in the primate cerebral cortex. *Curr Opin Neurobiol*. 1993; 3:578-85.

4. Goodale MA, Meenan JP, Bulthoff HH, Nicolle DA, Murphy KJ, Racicot CI. Separate neural pathways for the visual analysis of object shape in perception and prehension. *Curr Biol*. 1994; 4:604-10.

5. Goodale MA, Westwood DA, Milner AD. Two distinct modes of control for object-directed action. *Prog Brain Res.* 2004; 144:131–144

6. Chieffi S, Gentilucci M. Coordination between the Transport and the Grasp Components During Prehension Movements. Exp Brain Res. 1993; 94:471-7.

7. Jakobson LS, Goodale MA. Factors affecting higher-order movement planning: a kinematic analysis of human prehension. *Exp Brain Res.* 1991; 86:199-208.

8. Tresilian JR. Selective attention in reaching: when is an object not a distractor? *Trends Cogn Sci*. 1999; 3:407-8.

9. Gangitano M, Daprati E, Gentilucci M. Visual distractors differentially interfere with the reaching and grasping components of prehension movements. *Exp Brain Res*. 1998; 122:441-52.

10. Jackson SR, Jackson GM, Rosicky J. Are non-relevant objects represented in working memory? The effect of non-target objects on reach and grasp kinematics. *Exp Brain Res.* 1995; 102:519-30.

11. Mon-Williams M, Tresilian JR, Coppard VL, Carson RG. The effect of obstacle position on reach-to-grasp movements. *Exp Brain Res.* 2001; 137:497-501.

12. Tipper SP, Lortie C, Baylis GC. Selective reaching: evidence for action-centered attention. *J Exp Psychol Hum Percept Perform.* 1992; 18:891-905.

13. Chapman CS, Goodale MA. Obstacle avoidance during online corrections. *J Vis*. 2010; 10:17.

14. Bulakowski PF, Post RB, Whitney D. Visuomotor crowding: the resolution of grasping in cluttered scenes. *Front Behav Neurosci.* 2009; 3:49.

15. Castiello U. Grasping a fruit: selection for action. *J Exp Psychol Hum Percept Perform*. 1996; 22: 582-603.

16. Castiello U. Mechanisms of selection for the control of hand action. *Trends Cogn Sci.* 1999; 3:264-71.

17. Castiello U. Reply to Tresilian. *Trends Cogn Sci.* 1999; 3:408.

18. Howard LA, Tipper SP. Hand deviations away from visual cues: indirect evidence for inhibition. *Exp Brain Res.* 1997; 113: 144-52.

19. Bonfiglioli C, Castiello U. Dissociation of covert and overt spatial attention during prehension movements: selective interference effects. *Percept Psychophys.* 1998; 60: 1426-40.

20. Chapman CS, Goodale MA. Missing in action: the effect of obstacle position and size on avoidance while reaching. *Exp Brain Res.* 2008; 191: 83-97.

21. Stuart JA, Burian HM. A study of separation difficulty. Its relationship to visual acuity in normal and amblyopic eyes. *Am J Ophthalmol.* 1962; 53: 471-7.

22. Flom MC, Weymouth FW, Kahneman D. Visual Resolution and Contour Interaction. *J Opt Soc Am.* 1963; 53: 1026-32.

23. Bouma H. Interaction effects in parafoveal letter recognition. *Nature.* 1970: 11;226:177-8.

24. Toet A, Levi DM. The two-dimensional shape of spatial interaction zones in the parafovea. *Vis Res.* 1992; 32:1349-57.

25. Levi DM, Klein SA, Aitsebaomo AP. Vernier acuity, crowding and cortical magnification. *Vis Res.* 1985; 25:963-77.

26. Louie EG, Bressler DW, Whitney D. Holistic crowding: selective interference between configural representations of faces in crowded scenes. *J Vis.* 2007; 7:24 1-11.

27. Fosse P, Valberg A, Arnljot HM. Retinal illuminance and the dissociation of letter and grating acuity in age-related macular degeneration. *Optom Vis Sci.* 2001 78: 162-8.

28. Wallace JM, Tjan BS. Object crowding. *J Vis*.2011; 11: 19, 1-17

29. Chung ST. Reading speed benefits from increased vertical word spacing in normal peripheral vision. *Optom Vis Sci.* 2004; 81: 525-35.

30. Pelli DG, Tillman KA, Freeman J, Su M, Berger TD, Majaj NJ. Crowding and eccentricity determine reading rate. *J Vis.* 2007; 7: 20 1-36.

31. Levi DM, Song S, Pelli DG. Amblyopic reading is crowded. *J Vis*. 2007; 7: 1-17.

32. Levi DM, Klein SA. Vernier acuity, crowding and amblyopia. *Vis Res.* 1985; 25: 979-91.

33. Levi DM, Hariharan S, Klein SA. Suppressive and facilitatory spatial interactions in amblyopic vision. *Vis Res*. 2002; 42: 1379-94.

34. Hariharan S, Levi DM, Klein SA. "Crowding" in normal and amblyopic vision assessed with Gaussian and Gabor C's. *Vis Res*. 2005; 45: 617-33.

35. Regan D, Giaschi DE, Kraft SP, Kothe AC. Method for identifying amblyopes whose reduced line acuity is caused by defective selection and/or control of gaze. *Ophthalmic Physiol Opt*. 1992; 12: 425-32.

36. Chung ST, Levi DM, Legge GE. Spatial-frequency and contrast properties of crowding. *Vis Res.* 2001; 41: 1833-50.

37. Latham K, Whitaker D. Relative roles of resolution and spatial interference in foveal and peripheral vision. *Ophthalmic Physiol Opt.* 1996; 16: 49-57.

38. Kooi FL, Toet A, Tripathy SP, Levi DM. The effect of similarity and duration on spatial interaction in peripheral vision. *Spat Vis:* 1994; 2: 255-79.

39. Poder E. Effect of colour pop-out on the recognition of letters in crowding conditions. *Psychol Res*. 2007; 71: 641-5.

40. Chung ST, Mansfield JS. Contrast polarity differences reduce crowding but do not benefit reading performance in peripheral vision. *Vis Res.* 2009; 49: 2782-9.

41. Jacobs RJ. Visual resolution and contour interaction in the fovea and periphery. Vis Res. 1979; 19: 1187-95.

42. Timberlake, GT, Mainster MA, Peli E, Augliere RA, Essock EA, Arend LE. Reading with a macular scotoma. Retinal location of scotoma and fixation area. Invest Ophthalmol Vis Sci. 1986; 27: 1137–1147.

43. Fletcher DC, Schuchard RA. Preferred retinal loci relationship to macular scotomas in a low-vision population. Ophthalmology. 1997; 104: 632–638.

44. Schuchard RA, Naseer S, de Castro K. Characteristics of AMD patients with low vision receiving visual rehabilitation. J Rehab Res Develop. 1999; 36: 294–302.

45. Crossland MD, Rubin GS. The use of an infrared eyetracker to measure fixation stability. Optom Vis Sci. 2002; 79: 735–739.

46. Legge, GE, Rubin GS, Pelli DG, Schleske MM. Psychophysics of reading. II. Low vision. Vis Res. 1985; 25: 253–265.

47. Fine EM, Peli E. Scrolled and rapid serial visual presentation texts are read at similar rates by the visually impaired. J Opt Soc Am A: Opt, Image Sci Vis. 1995; 12: 2286–2292.

48. Fletcher, DC, Schuchard RA, Watson G. Relative locations of macular scotomas near the PRL: Effect on low vision reading. J Rehab Res Develop. 1999; 36: 356–364.

49. Toet A, Levi DM. The two-dimensional shape of spatial interaction zones in the parafovea. Vision Res 1992; 32:1349-1357.

50. Pelli DG, Palomares M, Majaj NJ. Crowding is unlike ordinary masking: distinguishing feature integration from detection. J Vis. 2004;4:1136-1169.

51. Chung STL, Levi DM, Legge GE. Spatial-frequency and contrast properties of crowding. Vis Res. 2001;41:1933-1850.

52. Chung STL. Dependence of reading speed on letter spacing in central vision loss. Optom Vis Sci. 2012; in press.

53. Chung STL, Jarvis SH, Woo SY, Hanson K, Jose RT. Reading speed does not benefit from increased line spacing in AMD patients. Optom Vis Sci. 2008; 85:827-833.

54. Calabrese A, Bernard J-B, Hoffart L, Faure G, Barouch F, Conrath J, Castet E. Small effect of interline spacing on maximal reading speed in low-vision patients with central vision loss irrespective of scotoma size. Invest Ophthalmol Vis Sci. 2010;51:1247-1254.

55. Wallace JM, Chung STL, Tjan BS. Crowding in individuals with age-related macular degeneration. Abstract for Vision Sciences Society Meeting 2012.

56. Chung STL, Lin Y. The two-dimensional shape of spatial interaction zones at the PRLs of observers with central vision loss. Invest Ophthalmol Vis Sci. 2008; 49: E-abstract 1509.

57. Chung STL. Learning to identify crowded letters: does it improve reading speed? Vis Res 2007; 47: 3150-3159.

58. Timberlake GT, Omoscharka E, Quaney BM, Grose SA, Maino JH. The Effect of Bilateral Macular Scotomas from Age-related Macular Degeneration on Reach-to-grasp Hand Movement. *Invest Ophthalmol Vis Sci.* 2011; 52: 2540-50

59. Timberlake GT, Grose SA, Quaney BM, Maino JH. Retinal image location of hand, fingers, and objects during manual tasks. *Optom Vis Sci.* 2008; 85: 270-8.

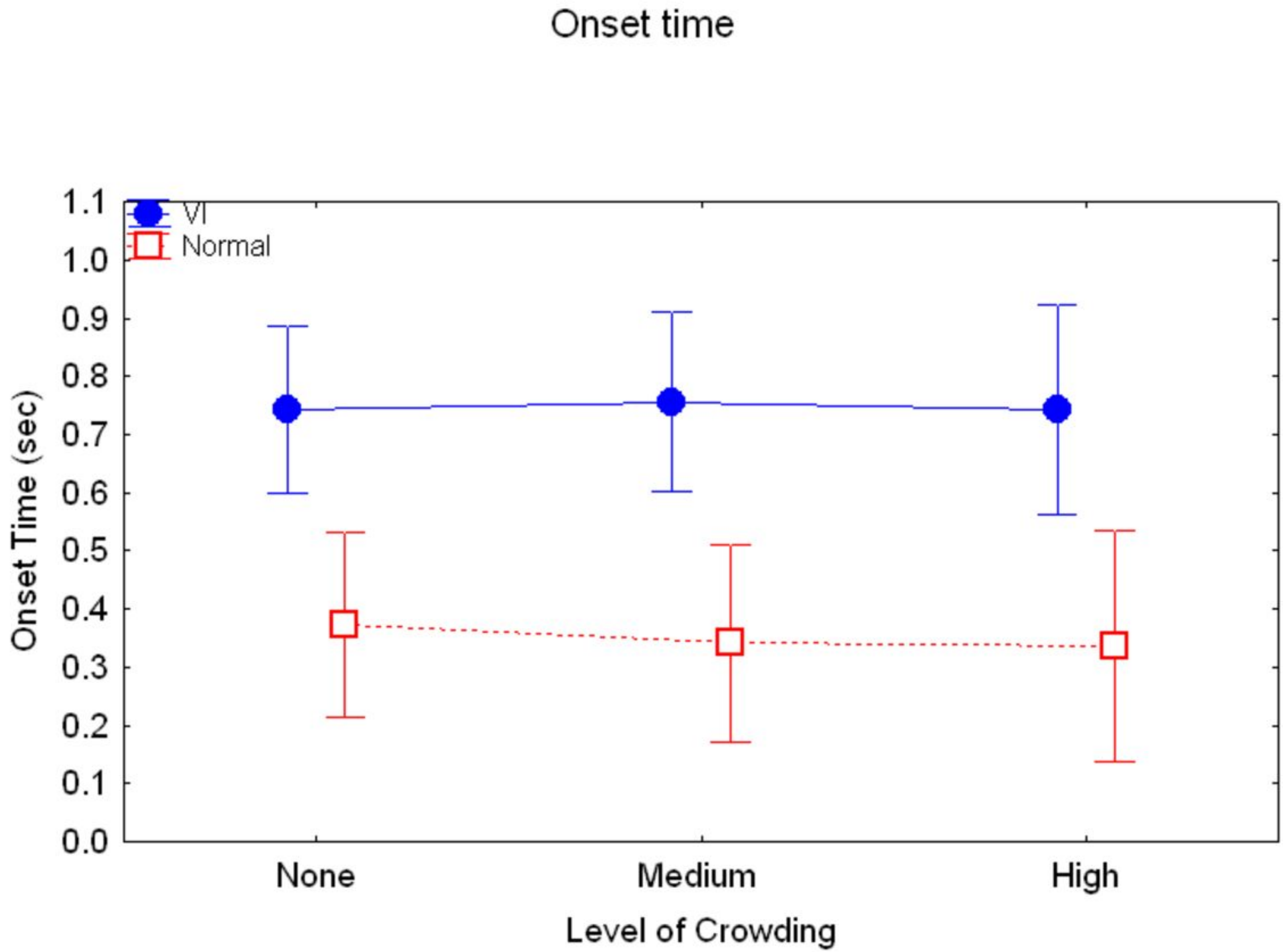
60. Pardhan S, Gonzalez-Alvarez C, Subramanian A. How does the presence and duration of central visual impairment affect reaching and grasping movements? *Ophthalmic Physiol Opt*. 2011; 31: 233-9.

61. Pardhan S, Gonzalez-Alvarez C, Subramanian A. The effect of target contrast on prehension in patients with central visual loss. *Optom Vis Sci.* 2012; *in press*

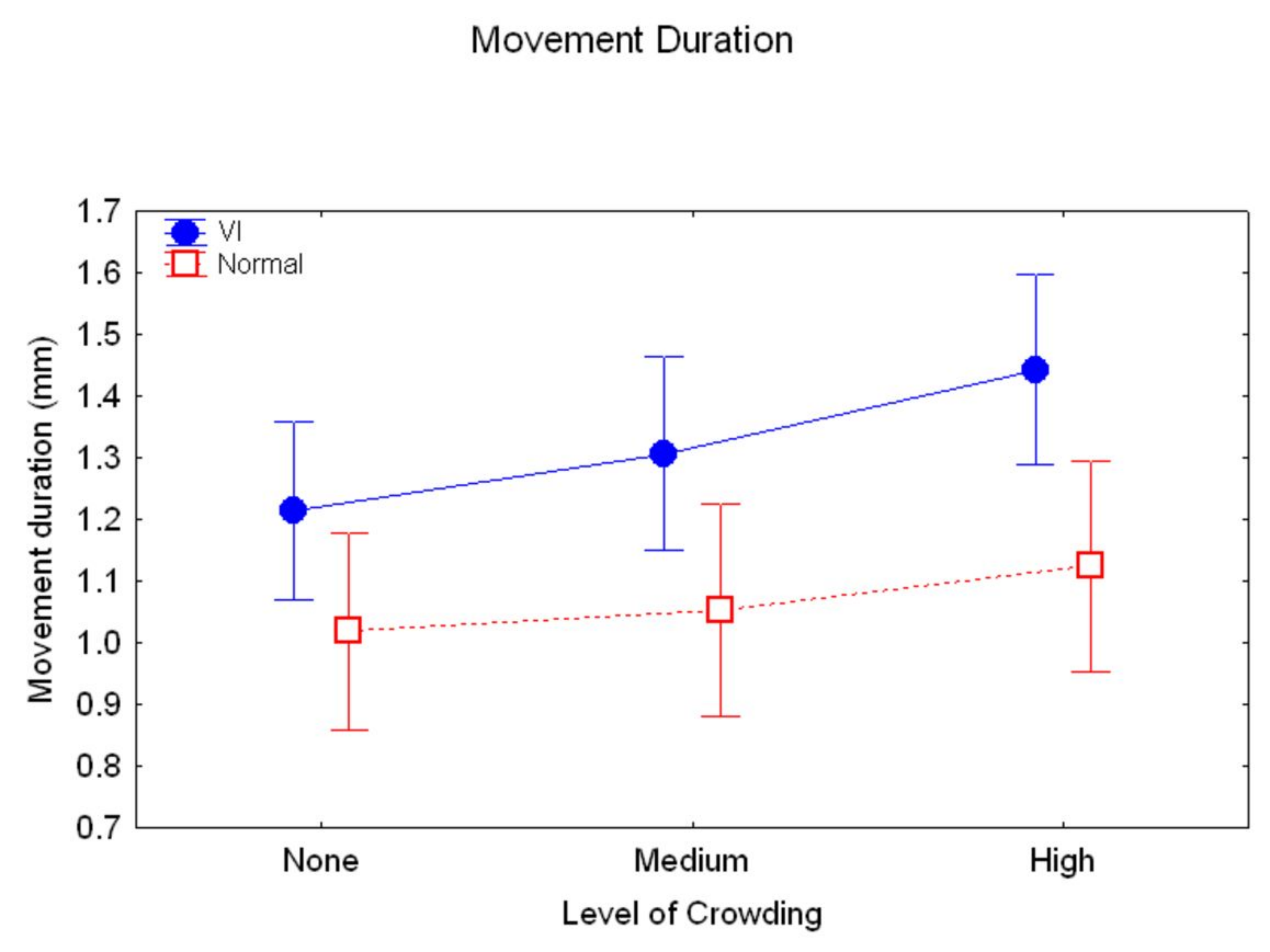
62. Oldfield RC. (1971). The assessment and analysis of handedness: The Edinburgh inventory. Neuropsychologia. 1971; 9: 97-113

Precis summary

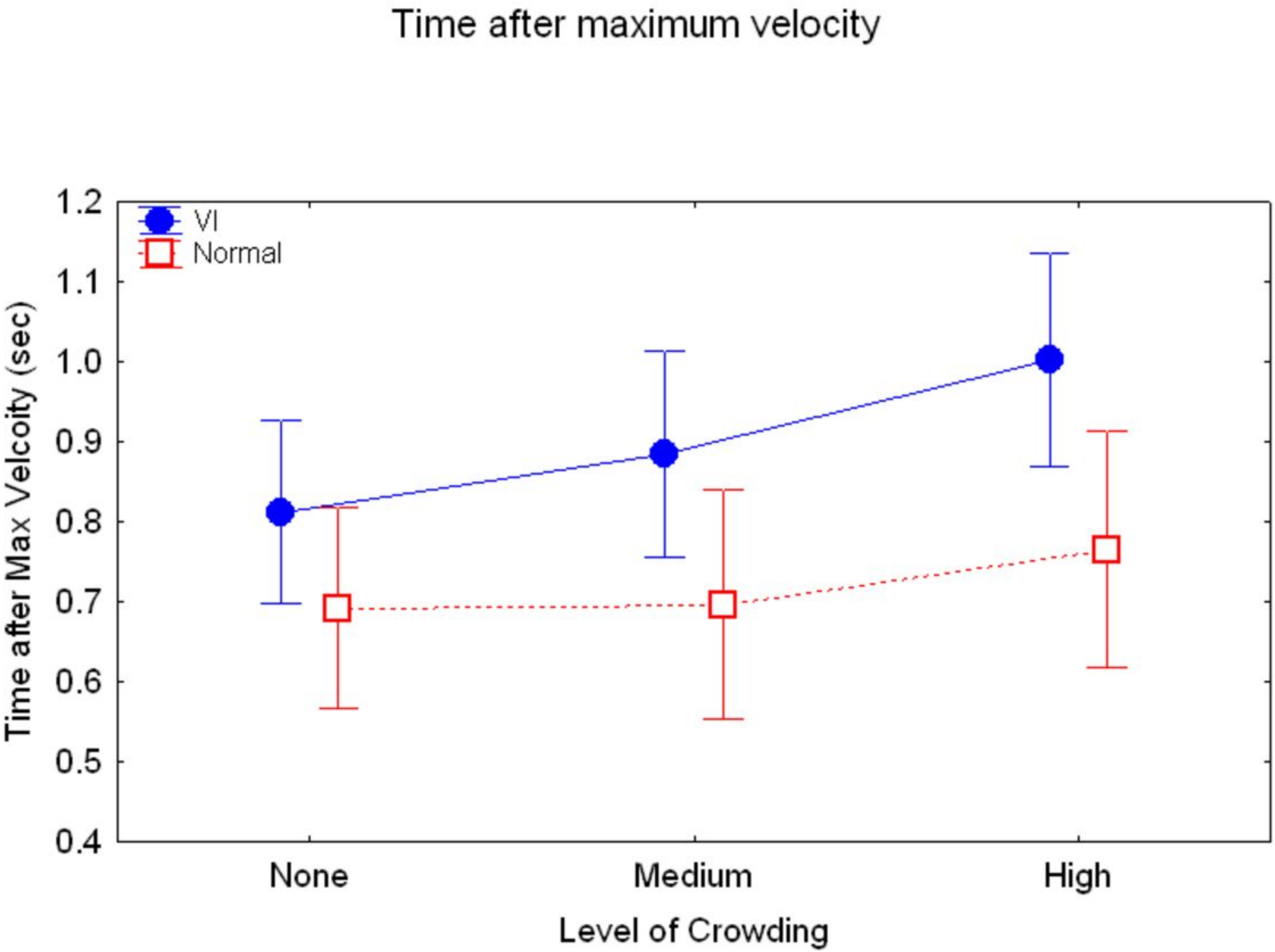
Reaching and grasping behaviour is compromised in crowding conditions for subjects suffering from macular disorders. Flankers placed half an object diameter away resulted in greater deterioration in performance than those placed further away.

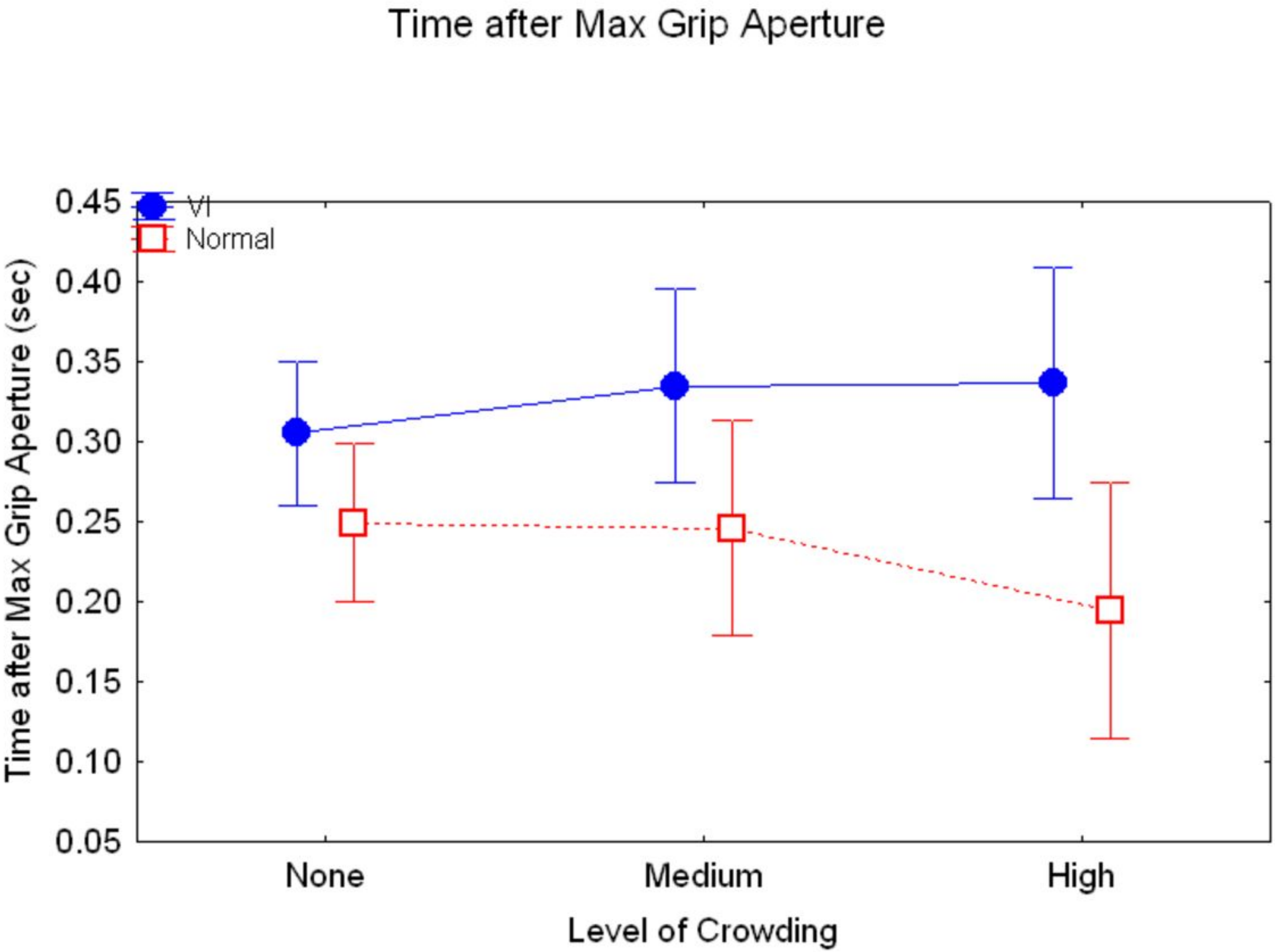


Onset time
VI
Normal
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Onset Time (sec)
None
Medium
High
Level of Crowding



Movement Duration
VI
Normal
Movement duration (mm)
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
None
Medium
High
Level of Crowding


Time after maximum velocity
VI
Normal
Time after Max Velcoity (sec)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
None
Medium
High
Level of Crowding


Time after Max Grip Aperture
VI
Normal
Time after Max Grip Aperture (sec)
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
None
Medium
High
Level of Crowding