Four paradigms to study visual–spatial attention of myopic subjects

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Abstract

We describe four protocols for evaluating the attentional skills of myopic and control subjects in target stimulus detection tasks; simple reaction times (RT) are recorded. Two protocols are designed to study both automatic and voluntary orienting of attention. Modified implicit orienting paradigms [Q. J. Exp. Psychol. 32A (1980) 2; J. Exp. Psychol. Gen. 109 (1980) 160] are used in which cues elicit a shift of attention but gaze is maintained on a central fixation point. A third paradigm is designed to study the time-course of focusing; two circles (focusing cues) of different diameters are randomly presented on a point of the visual space where attention has been previously shifted. Seven SOAs (stimulus onset asynchrony) are used. The fourth paradigm was designed to evaluate visual search; three circular arrays of four, eight and twelve stimuli are randomly presented around a fixation point and subjects have to detect the target stimulus inside one of the circles (the other circles are distracters). Since some attentional deficits are associated with myopia [Invest. Ophthalmol. Vis. Sci. 38 (1997) 1725; Cogn. Brain Res. 8 (1999) 369], these protocols could be useful both in the detection of deficits in subjects on the verge of becoming myopics and in the development of cognitive training programs to reduce attentional deficits. © 2001 Elsevier Science B.V. All rights reserved.

1. Type of research

These protocols are simple procedures to evaluate the visual–spatial attention capacities of subjects having eye refractive defects such as myopics [21]. However, these protocols have been also successfully used in normal subjects [4] and in children with developmental cognitive deficits such as dyslexia [9].

Myopia is a refractive error of the eye which has been classically attributed to a defect of the genetic control of eye bulb growth [27]. However, myopia may also develop from an anomalous adaptation of the visual system to some environmental conditions such as: a protracted near-vision [24], visual deprivation [22] and restricted living spaces and low ambient lighting [27]. Forrest indicated that myopics undergo a narrowing of the perceptual–attentional field so that they would show a bias for a central processing approach concomitant with inattention for the information arising from the periphery of the visual field [10]. Therefore, myopia seems to be a complex pathology in which there are both structural and cognitive changes. Some attentional deficits appear to be associated with refractive changes of the eyes [2,21], and possibly they can be detected with the experimental procedures described below.

2. Time required

(a) Ophthalmological examination of subjects: 30 min each subject.

(b) Preparation of the computer programs for stimuli presentation, storage and analysis of data, and recording of ocular movements: approx. 2 h.
(e) Implicit orienting testing: 40 min for each subject (two sessions of 20 min).
(d) Focusing testing: 40 min for each subject (two sessions of 20 min).
(e) Visual search testing: 40 min for each subject (two sessions of 20 min).

3. Materials

(a) Autorefractometer to measure the refractive capacity of the eyes under total cycloplegia.
(b) Echobiometer to measure the length of the eye and the anterior–posterior chamber.
(c) A Pentium II personal computer and a 19-inch video monitor.
(d) A head–chin rest to maintain a fixed distance between eyes and screen throughout the testing session.
(e) Infrared spectacles connected to an amplifier, an analogue–digital converter, a computer and a video monitor to monitor eye movements.
(f) Set of lenses or contact lenses to correct refractive errors of myopic subjects.
(g) MEL software [19].
(h) Language reference guide [18].
(i) System to control the room lighting.

4. Detailed procedure

The refractive capacity of the subject’s eyes (myopics and emmetropics) was measured by autorefractometry (Autorefractometer Canon) under total cycloplegia. The myopics’ refractive error ranged between \(-0.50\) D and \(-5.0\) D, whereas the refractive capacity of controls ranged between \(+0.25\) D and \(+1.0\) D. Myopics and control subjects with a refractive error above \(-5\) D and \(+1\) D were excluded. Length of the eye and depth of the anterior–posterior chamber were measured by an Echobiometer (Tomey Automatic A-Scan). Mean depth of the anterior chamber of myopics was around 4.0 mm, whereas that of controls was around 3.6 mm. The anterior–posterior axial length of the eye in myopics was around 24.5 and 25 mm, whereas that of controls was around 23 mm.

All tests were performed in a dimly-lit room in mesopic conditions. Subjects sat in front of a video screen with a background brightness of 0.5 cd/m². They were positioned in an adjustable head-and-chin rest so that the distance between eyes and screen was kept at 40 cm. Eye movements were monitored by means of infrared spectacles capable of detecting an eye displacement of 1°. The spectacles were connected to an amplifier and an analogue–digital converter, whose output signals were further analysed by a computer. The spectacles were fitted with suitable correcting lenses, or myopics wore their own contact lenses. Therefore, myopics performed the tasks with a corrected refractive capacity and optimal visual acuity.

Stimuli, event times, control of eye movements, recording of RTs and statistical analysis of data were programmed and performed by MEL software [18,19].

4.1. Voluntary orienting

An experimental paradigm was designed to test the performance of myopics in voluntary or endogenous orienting of attention (Fig. 1). Voluntary implicit orienting was elicited by presenting the orienting cue on the central part of the visual field and using a long SOA (stimulus onset asynchrony) between cue and target. Central cognitive cues elicit a shift of attention by an act of will [11,16]. In addition, voluntary orienting seems to reach its maximal efficiency after about 500 ms from cue presentation [13,23].

The beginning of each trial was marked by a 1000 Hz tone and the appearance of the fixation point at the centre of the screen, consisting of a white cross (1.4° of visual angle, 24 cd/m² brightness); the fixation point remained on the screen throughout the duration of the trial. Subjects were instructed to fixate the point and not to shift their gaze. After an interval of 500 ms, two circles (3° of visual angle and 24 cd/m² brightness), appeared at 16° to the right and to the left of the fixation point. Then, after further 500 ms, the cue, consisting in an horizontal arrow (3° and 14 cd/m² brightness), appeared above the fixation point for 100 ms, pointing either to the right or to the left visual field (in valid and invalid trials) or to both sides (in neutral trials). The sequence of presentation of the arrows was randomised. The subjects were instructed to shift their attention to the circle indicated by the unidirectional arrow or to both circles if the arrow was bidirectional. The target
stimulus, a white spot (0.5° and 24 cd/m² brightness), appeared at the centre of one of the two circles for 200 ms (Fig. 1). On valid trials, the target appeared into the circle indicated by the cue; on invalid trials, the target appeared into the circle opposite to that indicated by the cue; on neutral trials, the target appeared randomly into one of the two circles. SOAs were 150 and 500 ms. When the subjects detected the target they had to press the spacebar on the keyboard as quickly as possible and their RT was recorded by the computer. The maximum time allowed to respond was 1 s; after this time, an error was computed and the trial was discarded. Some randomly-occurring trials, called catch-trials, were presented, in which the stimulus did not appear and the subjects did not have to respond. The few trials in which eye movements were recorded were automatically rejected by the computer and were not replaced.

Each experimental session consisted of 248 trials divided into two blocks of 124 trials. Each block consisted of 64 valid trials (32 for each SOA), 32 neutral trials (16 for each SOA), 16 invalid trials (eight for each SOA) and 12 catch-trials. Between the two blocks of trials the subjects were allowed a 30 min break. Mean RT analysis was done using a three-way repeated measures ANOVA, with one between-subject factor: group (myopics vs. controls); and two within-subject factors: type of trial or condition (valid, invalid and neutral) and SOA (150 and 500 ms).

4.2. Automatic orienting

In the second experiment the performance of myopics and controls was studied in a paradigm in which implicit attention was automatically or exogenously oriented (Fig. 2). The orienting cue consisted in an abrupt onset on the periphery of the visual field followed by the target [26]. These experimental conditions are thought to elicit a purely automatic shift of attention [8].

The onset of each trial was marked by a 1000 Hz tone and projection of the fixation point at the centre of the screen. Fixation consisted of a white cross (1.4° of visual angle, 24 cd/m² brightness) which remained on the screen throughout the trial. The subjects were instructed to fixate the cross and not to move the eyes. After a delay of 500 ms, four identical boxes (squares of 3° of visual angle; 24 cd/m² brightness) were presented, two aligned on the right and two on the left of the fixation point. The two inner boxes were at 8° whereas the two outer boxes were at 16° of visual angle. After an interval of 500 ms, the cue consisted of a vertical arrow (3° of visual angle) which was presented for 100 ms under one of the boxes (in valid and invalid trials) or under each box (in neutral trials). The sequence of the cued box and whether only one box was cued or all of them, was randomised. The subjects were instructed to shift their attention to the cued box (valid and invalid trials) or to distribute their attention to all boxes (neutral trials). After a 500 ms time-interval, the target stimulus (a white spot of 0.5° and 24 cd/m² brightness) was shown for 200 ms at the centre of one box. In valid trials the target stimulus appeared inside the cued box; in invalid trials the target was randomly shown inside one of the uncued boxes, whereas in neutral trials the target appeared randomly inside one of the cued boxes. As soon as the stimulus was shown, the subjects had to press the spacebar and simple RT was recorded. The maximum time allowed to respond was 1 s: a response beyond this time was considered an error and the trial was discarded but not replaced.

Each subject completed 198 trials divided into three blocks of 66 trials each. Overall, 42% of the trials were valid, 18% were invalid, 30% were neutral and 10% were catch-trials. In few trials eye movements were recorded but they were automatically rejected by the computer and were not replaced. Analysis of variance (ANOVA) for mean RTs had one between-subject factor: group (myopics vs. controls) and two within-subject factors: type of trial (valid, invalid and neutral) and position (inner vs. outer boxes).

4.3. Attentional focusing

The third experimental paradigm was designed to study the time-course of attentional focusing in both groups of subjects (Fig. 3). Focusing is supposed to be sequential and independent of orienting [4,5]. Focusing is activated after attention is oriented towards an object in the visual field and basically consists in adapting the spatial width of attentional resources to the size of the observed object [7].

The beginning of each trial was indicated by a 2 kHz warning tone. Then, the computer presented a pre-cue (a green spot of 0.5°, 14 cd/m² brightness) on a point of the screen for 250 ms. Subjects had to shift to, and keep their gaze on, that point. The spatial position of the pre-cue...
changed from one trial to the next. Subsequently, the pre-cue disappeared and after an interval of 150 ms, the focusing cue was presented on the pre-cued location. The cues were two circles of either 2.5° or 7.5° (24 cd/m² bright). After a variable SOA, a target stimulus (a white spot of 0.5° and 24 cd/m² brightness) was flashed on the centre of the cue for 200 ms. SOAs were 33, 66, 130, 240, 400, 500 and 800 ms. The type of cue and SOA varied randomly from trial to trial. Subjects had to press the spacebar as soon as the target stimulus was shown; simple RTs were recorded. Maximum time allowed to respond was 1 s.

The experimental session consisted of 378 trials divided into three blocks of 126 trials. Each block comprised 56 trials with the smaller cue (2.5°) and 56 with the larger cue (7.5°). In each block, there were 16 trials for each SOA. In each block, there were also 14 catch trials (the cue but not the target stimulus) presented randomly among the trials. Mean RTs were analysed by a two-way repeated measures ANOVA with one between-subject factor (myopics and controls) and two within-subject factors: cue-size and SOA.

4.4. Visual search

The fourth experimental paradigm was designed to study the strategies adopted by myopics and controls in a visual search task (Fig. 4). The task consisted in the identification of a salient target among a certain number of distracters. The target was defined by a feature which distracters lacked. Two strategies were used to perform the task: (1) a serial search item by item or by groups of items in a focused modality [20]; and (2) a distributed attention and parallel processing modality (pop-out) [6,12,17].

Apparatus and brightness were the same as in previous experiments. Each trial started with the presentation of a fixation point (a cross of 1.4°) accompanied by a 1 kHz tone. The cross remained on the centre of the screen throughout the trial. After a delay of 500 ms, the stimuli (circles of 2.5°) appeared for 200 ms at a distance of 15° from the fixation point and were arranged in a circular manner. Three displays were used: four, eight and 12 circles. In 50% of the trials, the display showed the target stimulus (white spot 0.5°, 24 cd/m² bright) at the centre of one of the circles. In the remaining trials the display was composed entirely of distracters. The position of the target in the display and the type of the three display sizes varied randomly from trial to trial. When a display with the target appeared, the subject had to press the spacebar as quickly as possible; simple RTs were recorded. The maximum time allowed for response was 1 s. When the display contained no target, the subject had to refrain from responding. Eye movements were monitored as in previous experiments.

The experimental session consisted of 144 trials divided into two blocks of 72 trials, each of which included 36 trials with and 36 without the target. In each subset of 36 trials, 12 presented a display of four circles, 12 of eight circles and 12 of 12 circles. Data were analysed by a two-way ANOVA for RTs, with display-size (four, eight and 12 circles) as within-subject factor and group (myopics and controls) as between-subject factor.

5. Results

We applied these protocols to a total of 96 right-handed subjects aged between 18 and 22 years, half myopics and half control emmetropics. The number of subjects was 32, 20, 24 and 20 in Experiments 4.1 to 4.4, respectively.

Before beginning the experimental procedure, the subjects made a certain number of trials (practice trials) until
they were completely confident with the procedure. The errors consisted mainly of responses given to catch-trials and few anticipatory responses (responses given before or concurrently to the stimulus presentation). Error trials were not replaced. Errors were usually less than 2% and they were not analysed. Accuracy was not a dependent variable.

In voluntary or endogenous orienting of attention myopics and controls performed similarly [21]. Overall mean RTs were: myopics, 340 ms and controls, 361 ms; myopics were slightly faster than controls but this difference was not statistically significant. The SOA factor was also insignificant. The type of trial factor (valid, neutral and invalid) was significant (P<0.0001) but the interactions group×type of trial and group×SOA were not (P = 0.83 and P = 0.32, respectively) [21]. Briefly, these results indicate that myopics showed a voluntary orienting similar to that of controls. In fact, in both groups RTs were faster on valid trials compared with neutral trials (benefits; [14,15]) and they were slower on invalid trials than on neutral trials (costs; [14,15]).

In contrast, myopics showed a deficit in automatic orienting of attention [21]. The myopics’ overall RTs were slower but not statistically different from those of controls (348 ms and 329 ms; P = 0.46). However, the deficit was present only when the myopics had to shift attention to 16° in the periphery of the visual field (outer boxes) but not at 8° (inner boxes). The group×box position interaction was significant (P < 0.019); RTs for the inner boxes were similar in the two groups (336 ms for myopics and 324 ms for controls). However, in outer boxes the RTs of myopics were significantly slower than those of controls (361 vs. 335 ms, respectively). The group×type of trial interaction was not significant (P > 0.8).

Overall, the focusing capacity and the time-course of control of focusing in myopics and controls were not statistically different [21]. Myopics tended to be slower than controls (333 ms vs. 318 ms, respectively). The group×type of cue and group×SOA interactions were not significant: P = 0.66 and P = 0.45, respectively.

Myopics performed differently than controls in the visual search task [21]. Group factor was significant (P < 0.02); myopics were slower than controls (471 ms vs. 437 ms, respectively). The group×display-size interaction was significant (P < 0.02), thus indicating that size of the display affected the performance of myopics but not that of controls. In other terms, controls showed similar RTs for the three display sizes (437, 432, 440 ms), whereas RTs of myopics increased from four to eight and from eight to 12 stimuli (463, 469, 481 ms).

6. Discussion

The validity of the protocols relies on some technical aspects which allowed to easily implement them: (1) experimental paradigms can be easily built and modified with MEL software program [18,19]; stimuli and event times can be programmed; (2) MEL allows RTs to be recorded trial after trial and to be statistically analysed; (3) ocular movements during trials can be controlled and eventually discarded.

The experimental procedures can easily be applied to both adult subjects and children ([9]. They are completely safe, painless and tolerated. Subjects performed the simple detection tasks with no signs of discomfort, fatigue and drop of motivation. Duration of the performance in each set of trials and in each paradigm was about 20 min. Before the beginning of the experimental session, subjects were fully instructed about the aims of the experiment and procedures. A certain number of practice trials were allowed to make sure that subjects completely mastered the procedure. Trials are divided into equal blocks, and a 30-min interval between them is allowed. No discomfort or fear was detected when subject wore the infrared spectacles for recording eye movements during trials.

An interesting hypothesis is that the attentional deficits of myopics could be present before, or concurrent with, the onset of the eye structural changes. An early detection of these deficits could be considered as an index indicating either the onset of refractive changes or a high probability that they will develop soon afterwards. Furthermore, subjects on the verge of becoming myopics could receive specific training procedures aimed at expanding the distribution of attentional resources. Training would make them more efficient in detection of peripheral cues and may favour the use of parallel-efficient processing to resolve visual search tasks [25]. In other terms, training would expand the myopics’ perceptual-attentional field and may attenuate their tendency to a central processing bias.

It is unlikely that the elimination or attenuation of attentional deficits can slow down the development of myopic processes, although Forrest [10] claimed that important elements for the onset of myopia lie in the psychological approach of subjects when confronted with a visual task, their attitude and motivation. On the other hand, however, improved attentional control of visual behaviour may attenuate some of the typical attitudes which accompany the refractive defect (‘myopic behaviour’): reluctance in relation to motor activities, a higher level of introversion, reduced self-confidence and reflectiveness than non-myopics [3]. Angi et al. [1] found that myopics show a significantly higher level of anxiety than normal subjects and a tendency to a higher degree of somatisation and inadequacy (memory problems, poor concentration).

6.1. Alternative protocols

Currently, the myopic process starts during development and therefore the attentive skills should be tested and corrected in children. The question is: can children receive...
cognitive tests like those described here for adults? The answer is positive, provided some changes are introduced in the experimental procedure: i.e. a lower number of trials. In a study on spatial attention in dyslexic children, Facoetti et al. [9] showed that they can be administered tests in which they must keep their gaze on the fixation point, shift and focus their attention according to instructions. In addition, children also had to make a quick motor response when the target was shown on the screen.

7. Quick procedure

(i) Refractive indexes and eye measurements (eye length and depth of anterior–posterior chamber) of myopic and emmetropic subjects are evaluated through an ophthalmologic examination of the eyes.

(ii) Subjects sit in front of a video screen and a head–chin rest provides a fixed distance of 40 cm between the eyes and the screen. They wear infrared spectacles connected with a recording system which controls ocular movements. Myopics perform the four attentive tasks with corrected refraction and optimal visual acuity.

(iii) Overall, trials start with the presentation of the fixation point (1.4° white cross shown on the centre of the screen). After a time interval, boxes (squares or circles) appear laterally and after another time interval the cue is shown and indicates to which box or boxes attention must be oriented. Then, after a time interval, the target stimuli are flashed into the cued or uncued box. Subjects have to press the keyboard spacebar as quickly as possible. Simple RTs are recorded.

(iv) Voluntary orienting of attention is measured by presenting two circles, one on each visual field. The orienting cue is a horizontal arrow shown centrally above the fixation point and points to one of the circles (uni-directional arrow in valid and invalid trials) or both circles (bidirectional arrow in neutral trials). Afterwards, the target stimulus is shown inside one of the circles.

(v) Automatic orienting of attention is measured by presenting four boxes, two on the left and two on the right of the fixation point. Subsequently, a vertical arrow which is the orienting cue, is shown under one box (in valid or invalid trials) or under each box (in neutral trials). The target stimulus is subsequently presented inside one of the boxes.

(vi) Control and time-course of attentional focusing are studied by presenting a circle of 2.5° or of 7.5° centrally, and after different time intervals or SOAs, the target stimulus is shown inside the circle. Subjects respond by pressing the spacebar.

(vii) Visual search performance is measured using arrays of four, eight or 12 circles arranged circularly around the fixation point. In 50% of the trials, subjects have to localize the circle with the target and to press the spacebar. In the remaining 50% of the trials the target does not appear and subjects have to refrain from responding.

(viii) Mean RTs are statistically analysed by an ANOVA using both within- and between-subject factors. Trials in which eye movements are recorded are discarded and not replaced.

References