European Journal of Ophthalmology / Vol. 14 no. 3, 2004 / pp. 200-205

# Visual recognition time in strabismus: small-angle versus large-angle deviation

C. SCHIAVI[1], R. BOLZANI[2], M.G. BENASSI[2], C. BELLUSCI[1], E.C. CAMPOS[1]

[1]Ophthalmology Unit
[2]Department of Psychology, University of Bologna, Bologna - Italy

PURPOSE. *To measure the possible differences in monocular detection time of a threshold visual acuity stimulus (recognition time [RT]) between patients with small-angle and large-angle strabismus.*
METHODS. *Ten patients with free alternating esotropia were tested (10 to 18 years old): five with small-angle esotropia (≤7°), five with large-angle esotropia (15° to 20°). Six age-matched normal subjects served as controls. The RT of the threshold stimulus was measured in both eyes sequentially for stimuli presented in the center of a computer monitor (RT 1). Moreover, we measured the time necessary for identifying the same threshold visual acuity stimulus generated on the computer screen in the moment in which fixation is taken up by one eye after occlusion of the second eye (RT 2). Using the same setting, RT was also measured monocularly in all strabismic and normal subjects who were originally looking at a luminous fixation point positioned horizontally at 6.5 and 15 degrees from the center of the monitor (RT 3).*
RESULTS. *The multivariate analysis of variance for repeated measures indicated that there was no statistical difference in RT 1 between groups. The mean RT 2 was significantly longer (p<0.001) in large-angle strabismic eyes when compared with that of normal control eyes. The mean RT 2 in small-angle strabismic eyes did not differ significantly from that of normal eyes. Finally, RT 3 (both at 6.5° and 15° of eccentricity) did not show any significant difference in the three different study groups.*
CONCLUSIONS. *The authors hypothesized that alternating strabismus patients may have a significant advantage in maintaining a small-angle deviation, as a large-angle deviation would require longer RT in the moment the deviated eye takes up fixation. It can be speculated that the extension of re-fixation movement, obviously shorter in small-angle strabismus patients, is the main factor responsible for longer RT occurring in large-angle strabismus patients. (Eur J Ophthalmol 2004; 14: 200-5)*

KEY WORDS. *Extraocular muscle surgery, Proprioception, Saccade, Strabismus, Visual discrimination*

*Accepted: February 29, 2004*

## INTRODUCTION

Strabismus eye surgery for comitant strabismus without normal binocular vision acts on normally innervated muscles and attempts a correction of a centrally based error control. A surgically induced change in the mechanics of the eye muscles is usually quite stable, even if under- and overcorrections occur. The stability of surgical results, in the range from orthotropia to small-angle strabismus, is attrib-

1120-6721/200-06$15.00/0

utable to several mechanisms. Among them are strabismus surgery per se and anomalous binocular vision supported by anomalous retinal correspondence, typical of microstrabismus (1). Isoacuity as well as free alternation of fixation are also relevant (2). The weight of proprioception from the extraocular muscles, which has been demonstrated to exist, remains to be established (3).

Insufficient data are available on further elements involved in supporting the stability of the angle of deviation after strabismus surgery. We hypothesized the presence of an advantage of small-angle versus large-angle strabismus, because in the first instance alternation of fixation is obtained more rapidly.

In strabismus patients, the presence of free random alternation in fixation is a sign of the absence of amblyopia and improves the acquisition of visual information (4). The purpose of the present investigation was to evaluate possible differences in rapidity of detection of a threshold visual acuity stimulus ((recognition time (RT)) between patients with small-angle and large-angle free alternating strabismus. There is, to our knowledge, no evidence in the literature on RT measurements in strabismus patients.

We hypothesized that the alternating strabismus patients may have a significant advantage in maintaining a small-angle deviation, as a large-angle deviation would require longer recognition time in the moment the deviated eye takes up fixation.

## MATERIALS AND METHODS

### *Subjects with strabismus*

Ten patients with comitant convergent strabismus (esotropia) participated in these experiments (age range 10 to 18 years, mean 14.6, SD 2.2). Patients were recruited at the Ophthalmology Service of the University of Bologna and were divided into two groups: patients with small-angle esotropia with free alternation (deviation: 4 to 7 degrees, n=5) and patients with large-angle esotropia with free alternation (deviation: 15 to 20 degrees, n=5). These subjects underwent complete eye examination and the angle of deviation was measured with the prism cover test. Only patients with early-onset comitant strabismus (earlier than 4 years of age) with free alternation were included in the study. No patient had ever undergone extraocular muscles surgery. All patients had visual acuity in both eyes (corrected or uncorrected) of 6/6 without amblyopia with refractive errors ranging from –1 to +1.5 sphere diopters. Myopic refractive errors were properly corrected. Binocular vision was evaluated with Bagolini striated glasses and the Irvine four-prism diopter test. In all patients no positive response was obtained at the TNO stereo-test. Clinical characteristics of each subject are shown in Table I. No subjects showed neurologic or psychiatric disorders.

### *Control subjects*

Six healthy volunteers served as controls (age range 12 to 17 years, mean 14.5, SD 2.1). Visual acuity in these subjects was at least 6/6 with correction of the refractive errors. Stereoacuity values at the TNO test were 60 sec of arc or better. None of these subjects had a history of oculomotor disease.

The investigation adhered to the tenets of the Declaration of Helsinki and was approved by the Ethical-Scientific Committee of the University of Bologna. Informed consent was obtained from all subjects or children's parents.

### *Experimental procedures*

In a dark room, subjects were seated 3 meters in front of a computer monitor used to generate visual stimuli. The background luminance was 3.1 cd/m$^2$ while the symbol luminance was 0.2 cd/m$^2$. For all subjects, corrected visual acuity of each eye was first measured with Snellen Es (linear scale) generated on the screen. Subjects had to recognize at least 4 out of 5 central Es to define visual acuity threshold (method of ascending limits). Subjects were positioned at a chinrest and fixated a central small spot of white light generated on the computer screen. All subjects were instructed to press on an infrared mouse when the E orientation was discriminated. Recognition time of the threshold stimulus (RT 1) was measured in both eyes sequentially and the order of the eyes was randomized. After a variable interval (5 to 10 sec), an assistant pressed the spacing bar of the computer keyboard; the light spot disappeared, and an E stimulus appeared in the center of the monitor. The target for RT 1 was a single E of the threshold visual acuity size,

**TABLE I -** CLINICAL CHARACTERISTICS OF SUBJECTS

| Subject | Age yr | BCVA (RE, LE) | Angle of strabismus degrees | Binocular vision | Stereoacuity TNO test |
|---|---|---|---|---|---|
| | | | Small-angle strabismus | | |
| 1 | 10 | 6/6, 6/6 | 4° ET | ARC | Absent |
| 2 | 18 | 6/6, 6/6 | 5° ET | ARC | Absent |
| 3 | 14 | 6/6, 6/6 | 7° ET | Suppression | Absent |
| 4 | 14 | 6/6, 6/6 | 5° ET | ARC | Absent |
| 5 | 16 | 6/6, 6/6 | 7° ET | Suppression | Absent |
| | | | Large-angle strabismus | | |
| 6 | 16 | 6/6, 6/6 | 17° ET | Suppression | Absent |
| 7 | 12 | 6/6, 6/6 | 15° ET | Suppression | Absent |
| 8 | 15 | 6/6, 6/6 | 20° ET | Suppression | Absent |
| 9 | 16 | 6/6, 6/6 | 20° ET | Suppression | Absent |
| 10 | 15 | 6/6, 6/6 | 15° ET | Suppression | Absent |

BCVA = Best-corrected visual acuity; RE = Right eye; LE = Left eye; ET = Esotropia; ARC = Anomalous retinal correspondence

obtained during the first part of the experiment. The infrared mouse was again used for signaling E orientation. The E disappeared and the program automatically measured the time from the appearance of the E stimulus to the pressure on the mouse button. Ten practice trials were given before the measurements were begun. Young, naïve subjects may have different amounts of practice/testing before criterion level is attained. We found that 10 trials were adequate to obtain valid measurements. Experiments were repeated four times and measurements were taken only when the stimulus was identified correctly in all four experiments. In the presence of an erroneous answer, the four trials were repeated until the correct choice for all E orientations was obtained. In this way we were confident of the accuracy of the detection of the E orientation. According to this criterion, about 5% of the trials were rejected in the three different study groups. Data from the two eyes were combined.

Using the same setting, a measure of recognition time (RT 2) was taken after a fixation switch. The time for recognizing the threshold visual acuity stimulus was measured from the moment in which a cover was moved from the eye to be examined to the fellow eye. The cover movement was mechanical and was driven by the computer. Subjects fixated the central luminous spot: after an interval of occlusion of the examined eye varied randomly (5 to 10 sec), the cover was moved to the fellow eye. Simultaneously, an E stimulus appeared on the computer screen. Subjects pressed the mouse button when the stimulus was recognized and the program automatically measured the time from the appearance of the E stimulus until the pressure on the mouse button. Ten trials were performed before obtaining four valid measurements that were taken only when the stimulus was identified correctly in all four experiments. About 7% of the trials were rejected in the large-angle strabismus group, whereas 5% of the trials were rejected in the small-angle strabismus group and controls.

The mean RT 1 and RT 2 with standard errors (± SE) was calculated in both small-angle and large-angle strabismus groups and in controls. Moreover, the absolute difference (ΔRT) between the mean value of RT 1 and RT 2 was calculated for both eyes in all subjects. Recognition time 1 is the interval between the appearance of the E stimulus on the monitor and the observer's finger pressing the mouse; recognition time 2 is the interval between the appearance of the E stimulus, the fixation switch saccade to foveate the target, and hitting the mouse. Therefore, we obtained a value (ΔRT) related to the rapidity and accuracy of the fixation switch saccade of the eye redressing from the position of deviation. The mean ΔRT with standard deviation (± SD) was calculated for the three different study groups.

Recognition time (RT 3) was also measured monocularly in all strabismic and normal subjects who were originally looking at a luminous fixation point positioned horizontally at 6.5 and 15 degrees from the center of the monitor. The fixation points were positioned in order to induce re-fixation movements through abduction, considering that patients were esotropic. Therefore the fixation points were put right to the monitor for the left eyes and left to the monitor for the right eyes. In this way the subjects were compelled to execute a re-fixation movement necessary to bring the stimulus on the fovea and thus recognize it. We used the fixation point positioned with 6.5° of eccentricity to simulate the re-fixation movement occurring in small-angle deviation, and 15° of eccentricity to reproduce a large-angle deviation. RT 3 was measured in order to establish whether differences in recognition times found in large-angle deviation could be explainable with the eccentricity per se. RT 3 was measured with the same procedure as RT 1. All strabismic and normal subjects were instructed to fixate monocularly a luminous spot positioned first at 6.5 and then 15 degrees from the center of the monitor. After 5 to 10 sec of interval, the eccentric fixation point disappeared and an E stimulus of the threshold visual acuity size appeared in the center of the monitor. Subjects pressed on an infrared mouse when the E orientation was discriminated. About 5% of the trials were rejected in the three study groups.

### Data analysis

The data were analyzed by the SPSS package version 10. The general linear model was applied for a multivariate analysis of variance to analyze the difference both in RTs (RT 1, RT 2, and RT 3) and in ΔRT between strabismus groups and normal control group. The dependent measure was the length of the response.

## RESULTS

The multivariate analysis of variance for repeated measures indicated that there was a statistically significant difference in RT 2 between the groups ($F_{2, 12}$ = 29.9; p<0.001). Significant interactions were found between groups and ΔRT ($F_{2, 12}$ = 40.2; p<0.001). No differences were found in RT 1 or in RT 3 among the three different study groups.

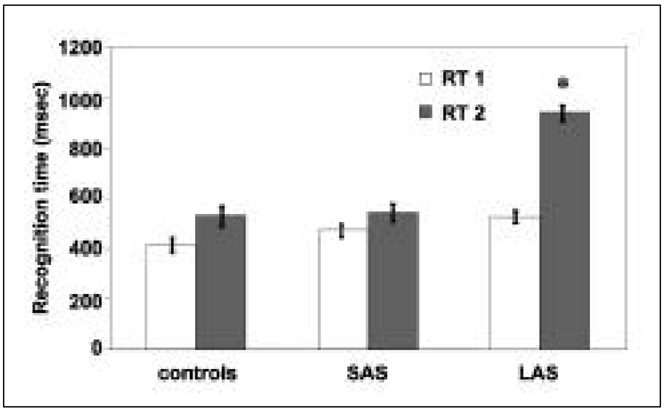


**Fig. 1** - *Means of recognition time 1 (RT 1, empty bars) and recognition time 2 (RT 2, gray bars). Vertical lines indicate the SE. *Significant difference (p<0.001) with respect to controls. SAS = small-angle strabismus group; LAS = large-angle strabismus group.*

Figure 1 shows the mean (± SE) RT 1 and RT 2 both in small- and large-angle strabismus groups and in controls. The mean RT 1 was 470.6 (± 27.0) msec in small-angle strabismus group and 524.2 (± 24.2) msec in large-angle strabismus group; neither of these means was significantly different from that of the normal control group (mean 412.1 ± 22.0 msec). The mean RT 2 in the large-angle strabismus group was 938.2 (± 34.7) msec, significantly larger than that of normal subjects (mean 529.7 ± 31.7 msec; p<0.001). On the contrary, in the small-angle strabismus group the mean RT 2 was 541.5 (± 38.8) msec with no statistically significant difference with respect to the normal control group.

The mean RT 3 (± SE) measured with the fixation point positioned with 6.5° of eccentricity was 633 (± 29.8) msec in the small-angle strabismus group and 641 (± 35.4) msec in the large-angle strabismus group (Tab. II); neither of these means was significantly different from that of the normal control group (mean 597 ± 26 msec). Similarly, the mean RT 3 measured with the fixation point located with 20° of eccentricity was 861 (± 39.6) msec in small-angle strabismus patients and 875 (± 43) msec in large-angle strabismus patients. Neither of these values was significantly different from that found in normal subjects (mean 767 ± 33.3 msec).

**TABLE II -** MEAN RT 3 (± SE) MEASURED WITH THE FIXATION POINT ORIGINALLY POSITIONED WITH 6.5° AND 20° OF HORIZONTAL ECCENTRICITY

| Groups | RT 3 6.5° msec | RT 3 20° msec |
|---|---|---|
| Small-angle group | 633 (± 29.8) | 861 (± 39.6) |
| Large-angle group | 641 (± 35.4) | 875 (± 43.0) |
| Control group | 597 (± 26.0) | 767 (± 33.3) |

RT = Recognition time

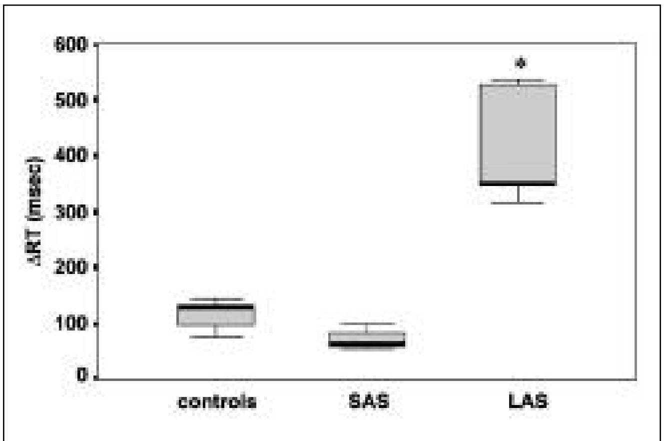


**Fig. 2 -** *Means with standard deviation (box plot) of ΔRT. Vertical lines indicate the extreme values and horizontal bold lines indicate the median values. *Significant difference (p<0.001) with respect to controls. SAS = small-angle strabismus group; LAS = large-angle strabismus group.*

Figure 2 summarizes the ΔRT in the three different study groups. The mean ΔRT was 414.0 (± 47.8) msec in the large-angle strabismus group, significantly longer than in the normal control group (mean 117.6 ± 10.3 msec; $p<0.001$). No significant differences in ΔRT between small-angle strabismus patients and controls were found.

## DISCUSSION

The basic result of this study is that RT 2 in large-angle strabismus patients was significantly longer in comparison to that observed in normal subjects. In contrast, RT 2 was not significantly increased in small-angle free alternating patients as compared to normal controls. This could be simply explained with the amplitude of fixation switch saccades, obviously shorter in small-angle than in large-angle deviations. Indeed, it is self-explanatory that RT 2 will be longer in large-angle strabismus because of the additional distance the eye must travel to make the fixation switch.

Strabismus patients usually changed fixation from one eye to the other by a conjugate saccade, whose duration is about 80 msec (5). In our experiments we found that ΔRT (RT 2-RT 1) values were reasonably close to this duration (100 msec) in the small-angle strabismus group as well in normal subjects.

It is interesting in our results that the difference in ΔRT between small-angle and large-angle strabismus groups is very large (about 300 msec). This difference cannot be explained by the typical duration of the saccades. Probably, there are some other variables that prolong RT 2 in large-angle strabismus patients. We hypothesized that RT 2 was longer in the large-angle strabismus group probably because of multiple re-fixation saccades involved when an eye of a patient with large-angle strabismus takes up fixation (6-8). It may be plausible that patients with small-angle strabismus do not need to make many re-fixation saccades. The target will be falling on a closer retinal proximity to the previous fixation. The retinal architecture is such that an object falling closer to the fovea is likely to be located with more accuracy (1).

Moreover, we also measured monocular recognition time (RT 3) of the eyes originally looking at an eccentric fixation point, in order to exclude other factors than amount of the angle of deviation for longer RT 2 occurring in large-angle strabismus patients. Specifically, we wanted to exclude that the binocular suppression or anomalous retinal correspondence (ARC) could have some bearing on RT 2; i.e., prolonged RT 2 could be due not just to prolonged excursion of the eye but to the necessity of releasing binocular sensory adaptations.

Occlusion of one eye during our experimental procedures obviously eliminated a possible role of suppression and/or ARC as the subjects were never in a binocular condition (i.e., with both eyes open). Mean RT 3 found in all study groups was longer than RT 2; this suggests that RT 2 measurements were not influenced by suppression phenomena. We simulated the re-fixation movement occurring in patients with convergent alternating strabismus and did not find any difference in RT 3 (both at 6.5° and 20° of eccentricity) between strabismus patients and normal subjects. This implies that the amount of re-fixation eye movement could be sufficient to explain the difference in RT 2 between large-angle and small-angle strabismus patients. It can be speculated that the extension of re-fixation movement, obviously shorter in small-angle strabismus patients, is the main factor responsible for longer RT 2 occurring in large-angle strabismus patients, even if we cannot exclude that blinks during the target search are implied.

Moreover, we did not find any significant difference in RT 2 between small-angle strabismus patients and normal subjects. It can be speculated that the large reduction in RT 2 of small-angle as compared to large-angle strabismus could be the result of an adaptive mechanism occurring in small-angle strabismus patients but not in large-angle deviations.

Our data could confirm the hypothesis that a small-angle deviation offers besides an anomalous binocular vision also an improvement of monocular visual performance. The improvement could be the result of central adaptation, e.g., more efficient tuning of motor commands when the two eyes are better aligned (9-12). There is, in fact, a close relationship between level of binocular function and eye-muscle proprioception, and the interaction between them is altered by the presence of strabismus (3). As a consequence, it could be speculated that signals related to the eye-muscle proprioception originated from the two eyes are relatively more integrated in presence of small-angle strabismus rather than in large-angle deviation.

In conclusion, besides known factors such as anomalous binocular vision and isoacuity, the presence of a small-angle strabismus is a favoring mechanism for maintaining stable the angle of deviation. Free alternation, which is advantageous per se, is more readily possible if the fixation switch takes place in short periods of time.

## ACKNOWLEDGEMENTS

*Supported by Fondazione Cassa di Risparmio in Bologna, MURSTex60% Università di Bologna, Italy (To E.C.C.).*

Reprint requests to:
Prof. Emilio C. Campos
Clinica Oculistica dell'Università
via Massarenti, 9
40138 Bologna, Italy
campos@alma.unibo.it

## REFERENCES

1. von Noorden GK, Campos EC. Binocular Vision and Ocular Motility. Theory and Management of Strabismus. 6th ed. St Louis, MO: Mosby; 2002: 222-39.
2. Campos EC. Amblyopia. Surv Ophthalmol 1995; 40: 23-39.
3. Lennerstrand G, Tian S, Han Y. Effects of eye muscle proprioceptive activation on eye position in normal and exotropic subjects. Graefes Arch Clin Exp Ophthalmol 1997; 235: 63-9.
4. van Leeuwen AF, Collewijn H, de Faber J-TNH, van der Steen J. Saccadic binocular coordination in alternating exotropia. Vision Res 2001; 41: 3425-35.
5. Steinbach MJ. Alternating exotropia: temporal course of the switch in suppression. Invest Ophthalmol Vis Sci 1981; 20: 129-33.
6. Ciuffreda KJ, Kenyon RV, Stark L. Increased saccadic latencies in amblyopic eyes. Invest Ophthalmol Vis Sci 1978; 17: 697-702.
7. Ciuffreda KJ, Kenyon RV, Stark L Abnormal saccadic substitution during small-amplitude pursuit tracking in amblyopic eyes. Invest Ophthalmol Vis Sci 1979; 18: 506-16.
8. Kapoula Z, Bucci MP, Eggert T, Garraud L. Impairment of the binocular coordination of saccades in strabismus. Vision Res 1997; 37: 2757-66.
9. Bagolini B. Part I. Sensorial anomalies in strabismus: suppression, anomalous correspondence, amblyopia. Doc Ophthalmol 1976; 41: 1-22.
10. Bagolini B. Part II. Sensorio-motorial anomalies in strabismus: anomalous movements. Doc Ophthalmol 1976; 41: 23-41.
11. Bucci MP, Kapoula Z, Yang Q, Roussat B, Bremond-Gignac D. Binocular coordination of saccades in children with strabismus before and after surgery. Invest Ophthalmol Vis Sci 2002; 43: 1040-7.
12. Campos EC, Zanasi MR. Die anomalen Fusionsbewegungen: der senso-motorische Aspekt des anomalen Binokularsehens. Albrecht Von Graefes Arch Clin Exp Ophthalmol 1978; 205: 101-11.