The Effect of Strabismus Surgery on the Dynamic Balance in Children With Strabismus

Serpil Hülya Çapar
serpilhulyaahmet@gmail.com

Istanbul University-Cerrahpaşa, Institute of Graduate Studies, Department of Audiology, Istanbul
Emin Karaman
Istanbul University-Cerrahpaşa, Cerrahpaşa Medical Faculty Department of Otorhinolaryngology, Istanbul
Eyyup Kara
Istanbul University-Cerrahpaşa, Faculty of Health Sciences, Department of Audiology, Istanbul
Olgu Çapar
University of Health Sciences, Prof. Dr. Cemil Taşçıoğlu City Hospital
Sibel Ahmet
University of Health Sciences, Beyoglu Eye Training and Research Hospital
Halide Çetin Kara
Istanbul University-Cerrahpaşa, Cerrahpaşa Medical Faculty, Department of Audiology, Istanbul
Akın Çakır
University of Health Sciences, Prof. Dr. Cemil Taşçıoğlu City Hospital
Birsen Gökyiğit
Yeni Yüzyıl University Medical Faculty, Department of Ophthalmology, Istanbul
Ahmet Ataş
Koç University Medical Faculty, Department of Otorhinolaryngology, Istanbul

Research Article

Keywords: Strabismus, strabismus surgery, computerized dynamic posturography, dynamic balance, postural control

Posted Date: June 26th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-3094725/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at Strabismus on June 18th, 2024. See the published version at https://doi.org/10.1080/09273972.2024.2367070.

Abstract

Purpose

To evaluate the effect of strabismus surgery on the dynamic balance by using computerized dynamic posturography in children with strabismus.

Methods

This study was designed as a prospective observational study. Hearing test and complete ophthalmological examinations were performed for all subjects. Patients with moderate and severe amblyopia, hearing loss at any level and/or any suspicion of balance impairment were excluded from the study. Postural stability evaluation was performed by computerized dynamic posturography including sensory organization test, adaptation test and rhythmic weight shift test. All tests were applied preoperatively and in the postoperative 1st and 3rd months respectively.

Results

Fifteen female and 12 male pre-adolescents aged between 7–12 (9.67 ± 1.62 years) were included in the current study. In the sensory organization test, the preoperative visual ratio percentages (73.19 ± 14.95%) improved statistically significantly at the postoperative 1st and 3rd months (78.59 ± 16.21% and 81,44 ± 14,18; p = 0.026, p = 0.021, respectively). The preoperative toes up (110,66 ± 33,48) and toes down (81,46 ± 28,36) adaptation tests improved statistically significantly at the postoperative 3rd month (88,74 ± 20,94 and 63,36 ± 16,03; p < 0.001, p = 0.001, respectively). In Rhythmic Weight Shift test, the postoperative 3rd month directional control (forward-backward) value (74.25 ± 11.51%) was statistically significantly higher compared to the preoperative directional control (forward-backward) value (67.76 ± 11.38%) (p = 0.011). The postoperative 3rd month directional control (forward-backward) value (74.25 ± 11.51%) was statistically significantly higher compared to the postoperative 1st month directional control (forward-backward) value (68.43 ± 14.00%) (p = 0.028).

Conclusion

Surgical treatment resulted in an improvement in the maintenance of dynamic balance in children with strabismus.

INTRODUCTION

Balance is the ability to remain in an upright position on a narrow resting surface without falling [1]. Maintaining the balance is an integration of complex motor responses involving the perception of stimuli, planning and regulation of movements to maintain a normal posture [2]. Central integration and rapid processing of visual, vestibular and somatosensory inputs are required to ensure correct postural control. The weakening of one of the systems providing postural control is compensated by other systems [3, 4].

Computerized Dynamic Posturography (CDP) is an objective method used to identify and distinguish disorders that may cause imbalance. CDP evaluates individuals dynamic balance using various test positions mimicking the conditions that may be encountered in daily life. It basically assesses the individuals ability to process and coordinate inputs from somatosensory, vestibular and visual systems to establish postural control [5]. On the contrary to static posturography, which uses stationary platforms to evaluate balance, CDP is performed with moving platforms. Thus CDP is able to provide more detailed and sensitive information than static posturography [6, 7].

Strabismus may be defined as a manifest deviation in which the visual axes do not intersect at the point of fixation. It impairs binocularity, stereopsis and depth of perception [8]. Horizontal deviation of the eyes is the most common form of strabismus; which may be either esotropia (manifest convergent squint) or exotropia (manifest divergent squint). It is common in children with genetic syndromes, premature birth, history of systemic disease, family history of strabismus, cerebral palsy [9].

Postural control is a dynamic and complex process which establishes balance with the interaction between visual, vestibular and somatosensory systems. Reduced effect of any one of these systems leads to postural adaptation via a compensation with the other systems [10]. Patients with strabismus use dominantly somatosensory and vestibular systems to maintain postural control [11, 12]. Besides, children especially with strabismus have more difficulty than adults in maintaining postural control in the presence of misleading signals [11–14]. There are few studies that focused on the effect of strabismus and its surgical treatment on postural stability with conflicting results. Some report early deterioration while the others claim the opposite [15–17]. Moreover all of these studies used static balance tests to analyze postural stability. However static balance evaluations cannot simulate properly the difficult conditions encountered in daily life.

For this reason, in the current study we used dynamic balance evaluations to investigate the effect of surgical correction of strabismus in relatively longer follow up time.

METHODS

A total of 27 pre-adolescent children with the diagnosis of strabismus (15 females, 12 males), aged between 7–12 (9.67 ± 1.62 years) were enrolled in the study. All subjects underwent strabismus surgery by the same surgeon (BG). The demographic and clinical characteristics of the subjects were given in detail in Table 1. All subjects were on routine follow-up and have received prophylactic treatment since initial diagnosis against amblyopia. Best corrected visual

acuity was evaluated with Snellen chart and stereoacuity was measured with TNO test. Strabismus evaluations were performed with unilateral and alternating cover tests at far (6 m) and near (40 cm) fixation distances and the angle of the deviation was measured using alternating cover test and prism bar. We tested all children at least one month after surgery so that the strabismus angle was stable and all children had adjusted to the new ocular alignment. Patients with normal otological examinations and middle ear findings, acoustical reflex thresholds between 85-95dB / 500-4000Hz and hearing thresholds between 500-4000Hz / 15dBHL and better were included in the study.

Patients with a diagnosis of vestibular, neurological and psychiatric diseases, moderate and severe amblyopia, any disease that can cause imbalance syndrome or limitation of movement, a history of falling without a cause in the last 6 months and using drugs affecting the central nervous system were excluded from the study.

The evaluation of middle ear functions was performed using GSI Tympstar V.2 (Grason-stadler Inc. Tiger / USA) imitansmeter device. For imitansmetric measurements, the static compliance value between 0.3-1.3ml and the peak pressure value between − 100daPa and + 50 daPa was accepted as the normality limit. Ipsilateral and contralateral acoustical reflex measurements were performed in all subjects at 500-1000-2000 and 4000Hz.

GSI AudioStar Pro (Grason-Stadler Inc., Tiger / USA) device was used for pure tone audiometry measurements. Airway hearing thresholds were measured between 125-8,000Hz using Eartone Gold 3A (Etymotic Research, Inc. / USA) insert earphones. Bone conduction hearing thresholds were determined using Radioear B 71 (Audiometer Allé 1 5500 Middelfart Denmark) headphones between 500-4000Hz. Pure tone audiometry and speech audiometry measurements were performed in a quiet cabin in accordance with ANSI S3.1-1991 standards.

Table 1
Demographic and clinical information of patients. BCVA: Best Corrected Visual Acuity; RE:Right Eye; LE:Left Eye; OU:Both Eyes; ET:Esotropia; XT:Exotropia; IX Exotropia; MR:Medial Rectus; LR: Lateral Rectus

Subjects	Age (Years)	BCVA (RE)	BCVA (LE)	Dominant Eye	Cycloplegic Autorefraction (RE)	Cycloplegic Autorefraction (LE)	Angle of Strabismus (Preoperative) (Prism D.)	Angle Of Strabismus (Postoperative 1.Month)	Angle Of Strabismus (Postoperative 3.Month)	Stereoacuity
1	8	1.0	1.0	LE	1.75	1.50 (-0.50)	XT 25 FAR IXT 20 NEAR	0	0	40"
2	11	1.0	0.8	RE	0.75 (-0.25)	0.50 (-1.75)	ET 18 FAR ET 25 NEAR	0	0	
3	12	0.8	1.0	LE	1.25	1.25	ET 10 FAR ET 25 NEAR	0	ET 4 FAR ET 8 NEAR	200"
4	10	0.8	1.0	LE	1.5 (-0.75)	0.50	XT 30 FAR XT 12 NEAR	0	0	
5	7	0.9	0.8	RE	0.75 (-1.00)	1.00 (-1.5)	ET 30 FAR ET 40 NEAR	ET 6 FAR ET 8 NEAR	0	
6	9	0,9	1.0	LE	2.00 (-1.00)	1.5 (-0.50)	ET 18 FAR ET 20 NEAR	ET 10 FAR ET 10 NEAR	ET 4 FAR ET 10 NEAR	
7	9	1.0	1.0	RE	1.50	1.50	XT 25 FAR XT 14 NEAR	0	0	40"
8	10	0,8	1.0	LE	2.00	1.00	ET 40 FAR ET 40 NEAR	0	0	100"
9	8	0,8	0.9	LE	2.25 (-1.00)	1.75 (-0.75)	ET 20 FAR ET 30 NEAR	ET 0 FAR ET 4 NEAR	ET 0 FAR ET 4 NEAR	
10	10	1.0	1.0	RE	3.25 (-2.25)	3.00 (-2.00)	ET 20 FAR ET 20 NEAR	0	ET 6 FAR ET 8 NEAR	
11	12	1.0	1.0	LE	1.00	1.00	ET 25 FAR ET 25 NEAR	0	ET 0 FAR ET 8 NEAR	
12	8	0.9	0.9	RE	3.00	3.25	ET 20 FAR ET 25 NEAR	ET 8 FAR ET 10 NEAR	ET 8 FAR ET 10 NEAR	
13	9	0.9	1.0	LE	2.25	1.75	XT 20 FAR XT 20 NEAR	0	0	40"
14	10	1.0	0.8	RE	-0.25 (-0.50)	-0.75 (-1.75)	ET 35 FAR ET 35 NEAR	ET 8 FAR ET 10 NEAR	ET 8 FAR ET 10 NEAR	
15	8	1.0	0.8	RE	3.5 (-1.00)	3.5 (-2.00)	ET 20 FAR ET 20 NEAR	0	ET 0 FAR ET 8 NEAR	
16	10	0.8	1.0	LE	-1.50	-1.00	ET 40 FAR ET 45 NEAR	0	0	100"
17	10	1.0	1.0	RE	0.75	1.25	ET 25 FAR ET 30 NEAR	0	0	

Subjects	Age (Years)	BCVA (RE)	BCVA (LE)	Dominant Eye	Cycloplegic Autorefraction (RE)	Cycloplegic Autorefraction (LE)	Angle of Strabismus (Preoperative) (Prism D.)	Angle Of Strabismus (Postoperative 1.Month)	Angle Of Strabismus (Postoperative 3.Month)	Stereoacuity
18	8	1.0	1.0	RE	2.25	2.00 (-0.25)	XT 40 FAR XT 30 NEAR	XT 8 FAR XT 4 NEAR	XT 8 FAR XT 4 NEAR	100"
19	12	1.0	0.9	RE	2.00	2.50	ET 12 FAR ET 18 NEAR	0	0	200"
20	10	0.8	0.8	LE	5.00	4.50	ET 18 FAR ET 25 NEAR	ET 8 FAR ET 10 NEAR	ET 8 FAR ET 10 NEAR	
21	12	0.8	1.0	LE	-1.75 (-2.00)	-1.00 (-1.00)	XT 40 FAR XT 35 NEAR	XT 10 FAR XT 8 NEAR	XT 10 FAR XT 8 NEAR	400"
22	8	0.9	1.0	LE	1.00 (-2.50)	1.25 (-1.75)	XT 35 FAR XT 30 NEAR	XT 8 FAR XT 8 NEAR	XT 8 FAR XT 8 NEAR	
23	10	1.0	1.0	RE	3.00	3.25 (-0.75)	ET 45 FAR ET 45 NEAR	ET 2 FAR ET 10 NEAR	ET 6 FAR ET 10 NEAR	
24	12	1.0	1.0	LE	-2.00 (-1.50)	-2.25 (-2.00)	XT 25 FAR XT 20 NEAR	0	0	40"
25	7	1.0	1.0	RE	-0.50	-0.75	XT 35 FAR XT 15 NEAR	0	XT 8 FAR XT 2 NEAR	40"
26	9	0.9	0.9	RE	1.5 (-0.75)	2.00 (-0.25)	ET 35 FAR ET 45 NEAR	ET 4 FAR ET 6 NEAR	ET 0 FAR ET 6 NEAR	
27	12	0.9	1.0	LE	-3.00	-1.50	XT 40 FAR XT 30 NEAR	0	XT 6 FAR XT 2 NEAR	

Sensory Organization Test (SOT), Adaptation Test (ADT) and Rhythmic Weight Shift Test (RWST) were performed in the preoperative period and in the 1st and 3rd postoperative months using NeuroCom Smart Balance Master (Neurocom International Inc. / USA) posturography equipment. The steps and the instructions of the tests were explained to the subjects before each test. In order to eliminate the risk of falling, all subjects were secured by wearing a special vest which did not limit sway (Fig. 1). Tests were performed bare feet on a movable platform.

Sensory Organization Test (SOT)

Evaluates subjects ability to process visual, vestibular and somatosensory inputs and to suppress inappropriate sensory information to maintain balance. Subject stands on dual-force plates in a 3 sided surround. The anterior-posterior sway is recorded throughout the test. The test consists of 6 different conditions. The subject performs 3 repetitions for each condition and each trial lasts 20 seconds. The conditions of SOT are explained in Table 2.

Table 2
Conditions in Sensory Organisation Test (SOT)

Condition	Base Support	Vision	Visual Surround
1	Fixed	Eyes open	Stable
2	Fixed	Eyes closed	Stable
3	Fixed	Eyes open	Sway referenced
4	Sway referenced	Eyes open	Stable
5	Sway referenced	Eyes Closed	Stable
6	Sway referenced	Eyes Open	Sway referenced

The Equilibrium Score (ES) is calculated via the computer's software by comparing the subject's anterior-posterior sway during each trial to maximal theoretical sway limits of stability (8° forward, 4.5° backward). 3 trials are averaged for the calculation of ES for each condition. ES is a percentage and scores range from 0–100%, with 100% indicating perfect stability and 0% indicating a fall. Subject's ability to process and coordinate the cues to maintain balance is classified as somatosensory ratio, visual ratio and vestibular ratio. Composite score is a weighted average which provides an overall information about subjects performance in postural stability since it emphasizes complex balance conditions. Higher scores indicate better performances. Visual preference is the ratio of conditions with unreliable visual input (conditions 3 and 6) compared to those in which vision is absent (conditions 2 and 5). Reduced visual preference ratio implies that the subject relies on visual cues even when they are unreliable [18]

Adaptation Test (ADT)

Evaluates subjects ability to adapt motor reactions and minimize center of gravity (COG) swaying with the unpredicted platform rotations. The test consists of 2 conditions with 5 trials of each condition. The platform rotates over a 2–5 seconds time interval and induces toes-up and toes-down movements without the patient's knowledge of what exact time the perturbation takes place. For each trial, computer software quantifies a sway energy score (SES), which is the magnitude of the force required to overcome induced postural instability. The mean score for each condition is calculated from the test results. Lower scores reflect good performances [18].

Rhythmic Weight Shift Test (RWST): Assesses voluntary ability to move COG from an initial central position to right-left and forward-backward limits at 3 different velocities: slow, medium and fast (3sec., 2sec. and 1 sec. peak to peak, respectively). During each task, the subjects view a real time display of their COG position relative to a target moving at the desired velocity. The subjects have to follow the moving target by moving their COG right/XXXef tor forward/backward without moving their feet or other body parts and control the load transfer at the same velocity as the target. For each direction and velocity, the RWST measures on-axis velocity and directional control. On-axis velocity is the COG movement velocity along the specified direction (°/s). Directional control is the ratio of the amount of movement in the intended direction to the amount of deviation from the ideal movement trajectory (%). The velocity and percentage reflect the average score of 6 movement repetitions in one plan. Higher scores indicate better directional control [18].

According to the CDP results preoperative, postoperative 1st and 3rd month scores from SOT, ADT and RWST were compared. IBM SPSS Version 20 Windows program was used for statistical analysis of the results. Descriptive statistics are given as number and percentage for categorical variables, mean, standard deviation, median, minimum and maximum for numerical variables. Comparison of test scores between groups was performed with Paired Sample T and Wilcoxon Signed Ranks tests. Statistical significance level of alpha was accepted as $p < 0.05$.

RESULTS

Twenty seven pre-adolescents with the diagnosis of strabismus (15 females, 12 males), aged between 7–12 (9.67 ± 1.62 years) were included in the study. CDP scores in preoperative period, postoperative 1st and 3rd months were compared respectively. Demographic and clinical information of the subjects are shown in Table-1.

According to the SOT results, the visual ratio at the postoperative 1st and 3rd months (78.59 ± 16.21% and 81,44 ± 14,18; $p = 0.026$, $p = 0.021$, respectively) were statistically significantly higher than the preoperative visual ratio (73.19 ± 14.95%) ($p = 0.026$). There were no statistically significant differences in other test subtypes (Table 3) (Fig. 2).

Table 3

Results of SOT, ADT and RWST in Preoperative Period, Postoperative 1st and 3rd Months. [a] Paired Simple Test. [b] Wilcoxon Signed Ranks Test. (*) indicates statictical significance (p < 0.05)

		Preoperative	*Postoperative 1st month*	*Postoperative 3rd month*	*Preoperative-Postoperative 1st month P value*	*Postoperative 1st month-Postoperative 3rd month P value*	*Preoperative-Postoperative 3rd month P value*
Sensory Organization Test	**Somatosensory Ratio**	*97,33 ± 4,26*	*96,11 ± 8,03*	*101,37 ± 12,25*	*0,886[b]*	*0,161[b]*	*0,073[b]*
	Visual Ratio	*73,19 ± 14,95*	*78,59 ± 16,21*	*81,44 ± 14,18*	**0,026[b]***	*0,303[b]*	**0,021[b]***
	Vestibular Ratio	*61,63 ± 14,97*	*65,48 ± 13,47*	*69,00 ± 22,34*	*0,326[a]*	*0,629[b]*	*0,107[b]*
	Visual Preference	*99,44 ± 8,04*	*97,04 ± 10,04*	*95,15 ± 20,36*	*0,361[b]*	*0,713[b]*	*0,476[b]*
	Composite Score	*70,52 ± 8,97*	*71,37 ± 8,64*	*72,70 ± 6,53*	*0,746[b]*	*0,567[b]*	*0,256[a]*
Adaptation Test	**Toes Up**	*110,66 ± 33,48*	*102,15 ± 32,19*	*88,74 ± 20,94*	*0,058[b]*	**0,006[a]***	**< 0,001[b]***
	Toes Down	*81,46 ± 28,36*	*73,02 ± 24,53*	*63,36 ± 16,03*	*0,073[b]*	**0,012[a]***	**0,001[b]***
Rhythmic Weight Shift Test	**On-axis Velocity (Right – Left)**	*5,43 ± 1,60*	*5,31 ± 1,33*	*5,31 ± 1,19*	*0,934[a]*	*0,990[a]*	*0,890[a]*
	Directional Control (Right – Left)	*76,73 ± 13,50*	*78,99 ± 7,06*	*79,37 ± 7,15*	*0,986[b]*	*0,629[b]*	*0,380[b]*
	On-axis Velocity (Forward – Backward)	*3,46 ± 0,95*	*3,32 ± 0,88*	*3,64 ± 0,85*	*0,334[a]*	*0,103[a]*	*0,226[a]*
	Directional Control (Forward – Backward)	*67,76 ± 11,38*	*68,43 ± 14,00*	*74,25 ± 11,51*	*0,972[b]*	**0,028[b]***	**0,011[b]***

According to the ADT results, the postoperative 3rd month toes up SES (88.74 ± 20.94) was statistically significantly lower than the preoperative toes up SES (110.66 ± 33.48) (p < 0,001). The postoperative 3rd month toes up SES (88.74 ± 20.94) was statistically significantly lower than the toes up SES in the postoperative 1st month (102.15 ± 32.19) (p = 0.006). When the preoperative toes down SES (81.46 ± 28.36) and postoperative 3rd month toes down SES (63.36 ± 16.03) were compared, the preoperative toes up SES was statistically significantly higher (p = 0,01). The postoperative 3rd month toes down SES (63.36 ± 16.03) was statistically significantly lower than the postoperative 1st month toes down SES (73.02 ± 24.53) (p = 0,012). There was no statistically significant difference in other tests (Table 3) (Fig. 3).

According to the RWST results, the postoperative 3rd month directional control (forward – backward) (74.25 ± 11.51%) was statistically significantly higher compared to the preoperative directional control (forward – backward) (67.76 ± 11.38%) (p = 0.011). The postoperative 3rd month directional control (forward – backward) (74.25% ± 11.51) was statistically significantly higher compared to the postoperative 1st month directional control (forward – backward) (68.43 ± 14.00%) (p = 0.028). There was no statistically significant difference in other tests (Table 3) (Fig. 4).

DISCUSSION

In this pilot study, we evaluated the postural stability of pre-adolescent children with strabismus in preoperative period and postoperative 1st and 3rd months. All subjects were tested at least one month after surgery so that the strabismus angle was stable and all subjects had adjusted to new ocular alignment. This is the first study in which dynamic balance evaluations were performed to investigate the effect of surgical correction of strabismus in relatively longer follow up time.

The vestibular and somatosensory systems are particularly responsible for processing and integrating inputs deriving from the motions within the body [19, 20]. On the other hand, the visual system provides orientation and interaction with the surrounding environment to adapt to dynamic changes[21, 22]. Although postural control in children with strabismus has not been investigated in detail, several studies state that postural control is impaired in children with strabismus [23, 24]. Even fewer studies evaluated the effect of surgical correction of strabismus on balance and the results are conflicting [15–17]. All of these studies used static balance tests. However, environmental factors are variable in everyday life. In this study, we used CDP to evaluate the influence of visual, vestibular and somatosensory systems separately on postural control.

According to SOT results, visual ratio significantly improved in the postoperative period with the most prominent improvement seen in the first postoperative month. This finding is in contrast with the study of Matsuo et al. [17] which states that body sway increases considerably 3 days after surgery in children with strabismus. Legrand et al. [15] also observed poor postural control in the early postoperative period (2 weeks after surgery) but second postural evaluations performed in 8 weeks after surgery showed an improvement in postural control. These conflicting results suggest that visual input is not the only parameter affecting postural control. Studies show that extraocular muscles have proprioceptive receptors which provide information about the position of the eye in the orbit [25]. And it is well known that strabismus surgery alters the proprioceptive information of the operated eye and an average of 8 weeks is needed for tissue healing [11, 16, 26]. We suggest that completed tissue healing, adaptation to new ocular alignment hence more accurate ocular proprioceptive input and better visual perception due to restored binocularity provided the most prominent improvement in visual ratio in postoperative 1st month. As expected, visual preference scores tend to decline in the postoperative period but the results were not statistically significant. Composite score provides overall balance condition and the capability of coordinating visual, vestibular and somatosensory systems [27]. In this study composite scores showed a slight, statistically insignificant improvement in the postoperative period. We think that this is because children with strabismus use compensatory mechanisms for their impaired visual systems to provide a good postural control [10, 13, 28].

The current study confirms and expands the study by Bucci et al.[11] showing that children with strabismus use somatosensory inputs to compensate for the deficiency in their visual system to maintain postural stability. Data obtained from our study showed that in the preoperative period, the somatosensory ratio (97,33 ± 4,26%) was higher than the visual ratio (73,19 ± 14,95%). Additionally in the first postoperative month, in which the most prominent improvement in visual ratio was found, we observed that the vestibular ratio and composite score increased, whereas somatosensory ratio decreased slightly. According to this interesting finding, we make the hypothesis that the realignment of the visual axis facilitates visual perception leading to a better postural stability with lesser dependence on compensatory mechanisms [11, 15, 16]. In other words, children with strabismus use all three systems more uniformly to ensure good postural stability at least a few weeks after strabismus surgery.

A novel aspect of this study is that this is the first study to evaluate motor control skills in balance control after strabismus surgery with ADT and RWST. On ADT, we found that the SES decreased in both toes up and toes down tests in the postoperative period. Forward – backward directional control on RWST also improved in the postoperative period. The most significant improvement in both tests were seen in the postoperative 3rd month. In their study, Ezane et al. analyzed postural performances of strabismic children in spatial and temporal domains on a stable and unstable platform. They found that when plantar proprioceptive information is misleading, strabismic children are less stable than age-matched normal children and they need more energy to provide postural control [23]. Our results are in accordance with the aforementioned study and in addition we showed that lesser amount of SES are needed to control stability in the postoperative period when ocular alignment is provided. Matsuo et al.[17] showed that the center of pressure deviated along the Y axis in exotropia patients after strabismus surgery. They suggested that the surgery-induced changes in the extraocular muscle proprioception might change the center of pressure. Reduction in SES in our study may also be related with a shift in center of pressure towards heels. RWST results showed better forward–backward directional control. Other parameters were statistically insignificant. The fact that we have observed improvement in one direction only could be related to the fact that in such a direction, the visual functions (binocularity, stereopsis, depth of perception) are used more dominantly to obtain good balance control and strabismic children are lacking in such normal input.

Relatively small sample size and the short follow-up period are the main limitations of our study. We think that evaluating the 1st year follow-up results and increasing the number of patients in future studies will provide us with more extensive information. Another limitation of our study is that children with strabismus can develop a fast compensation mechanism to the new extraocular muscle positions. For this reason, we think that conducting a similar study in patients with sudden paralytic strabismus would eliminate the compensation mechanism in investigating the effect of the visual system on balance.

CONCLUSION

In conclusion, we demonstrated in this pilot study that re-alignment of the eyes with surgery significantly improves dynamic balance parameters in children with strabismus. Ability to process visual inputs improves significantly with the establishment of binocularity. This improvement is most prominent in the 1st month after surgery due to the healing and adaptation process to new ocular alignment. Postural control is provided with less energy consumption and more accurate directional control in unstable conditions. We conclude that children with strabismus use visual, vestibular and somatosensory systems more uniformly to ensure good postural stability after strabismus surgery.

Declarations

Funding: The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Competing Interests: The authors report there are no competing interests to declare.

Author Contributions: All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Serpil Hülya Çapar, Emin Karaman, Eyyup Kara, Olgu Çapar, Sibel Ahmet Halide Çetin Kara, Akın Çakır, Birsen Gökyiğit and Ahmet Ataş. The first draft of the manuscript was written by Serpil Hülya Çapar and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Ethics Approval: All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the Bioethics Committee of Istanbul University – Cerrahpaşa, Cerrahpaşa Medical Faculty (No. 83045809/604.01/02-313595).

Consent to Participate: Written informed consent to participate in the study was obtained from the patients' parents.

Consent to Publish: The authors affirm that informed consent for publication of the image in Figure 1 was provided from the patients' parent.

This manuscript has not been published elsewhere and it has not been submitted simultaneously for publication elsewhere.

References

1. Uchiyama M, Demura S. The role of eye movement in upright postural control. Sport Sci. Health. 2009;5:21–27. doi:10.1007/s11332-009-0072-z.
2. Mettler A, Chinn L, Saliba SA, McKeon PO, Hertel J. Balance training and center-of-pressure location in participants with chronic ankle instability. J. Athl. Train. 2015;50:343–49. doi: 10.4085/1062-6050-49.3.94.
3. Brandt T., Vertigo Its Multisensory Syndromes, 2nd ed. Springer, 2003.
4. VanSant AF. The International Classification of Functioning, Disability and Health. Pediatr Phys Ther. 2006;18(4):237. doi:10.1097/01.pep.0000245823.21888.71.
5. Nashner LM. Computerized dynamic posturography. Handb. Balanc. Funct. Test., pp. 208–307, 1993.
6. Myers BL. Computerized Dynamic Posturography. In: Vestibular Learning Manual, Plural Publishing, 2011, pp. 99–107.
7. Chen CL, Chen FF, Lin CH, Lou SZ, Chang HY, Yeung KT. Effect of Anterior Ankle-Foot Orthoses on Weight Shift in Persons with Stroke. Arch. Phys. Med. Rehabil. 2015 Oct;96(10):1795–801. doi:10.1016/j.apmr.2015.05.003.
8. Chen X, Fu Z, Yu J, Ding H, Bai J, Chen J, Gong Y, Zhu H, Yu R, Liu H. Prevalence of amblyopia and strabismus in Eastern China: results from screening of preschool children aged 36–72 months. Br. J. Ophthalmol. 2016 Apr;100(4):515–9. doi: 10.1136/bjophthalmol-2015-306999.
9. Gunton KB, Wasserman NB, DeBenedictis C. Strabismus. Prim. Care. 2015 Sep;42(3):393–407. Doi: 10.1016/j.pop.2015.05.006
10. Friedrich M, Grein HJ, Wicher C, Schuetze J, Mueller A, Lauenroth A, Hottenrott K, Schwesig R. Influence of pathologic and simulated visual dysfunctions on the postural system. Exp. Brain Res. 2008 Mar;186(2):305–14. doi: 10.1007/s00221-007-1233-4.
11. Bucci MP, Soufi H, Villeneuve P, Colleville L, Bui-Quoc E, Lions C. Importance of proprioceptive information for postural control in children with strabismus before and after strabismus surgery. Front. Syst. Neurosci. 2016 Sep 6;10:67. doi:10.3389/fnsys.2016.00067
12. Papalia GF, Mangano G, Diaz Balzani LA, Cupo G, Giurazza G, Di Zazzo A, Coassin M, Papalia R. Strabismus and postural control: a systematic review. Musculoskelet. Surg., pp. 1–12, 2022, doi: 10.1007/s12306-022-00737-y. Forthcoming
13. Sparto PJ, Redfern MS, Jasko JG, Casselbrant ML, Mandel EM, Furman JM. The influence of dynamic visual cues for postural control in children aged 7–12 years. Exp Brain Res. 2006 Jan;168(4):505–16. doi: 10.1007/s00221-005-0109-8.
14. Gaertner C, Creux C, Espinasse-Berrod MA, Orssaud C, Dufier JL, Kapoula Z. Postural control in nonamblyopic children with early-onset strabismus. Invest. Ophthalmol. Vis. Sci. 2013 Jan 17;54(1):529–36. doi: 10.1167/iovs.12-10586
15. Legrand A, Bui-Quoc E, Vacher SW, Ribot J, Lebas N, Milleret C, Bucci MP. Postural control in children with strabismus: Effect of eye surgery. Neurosci. Lett. 2011 Aug 26;501(2):96–101. doi: 10.1016/j.neulet.2011.06.056.
16. Legrand A, Bui-Quoc E, Bucci MP. Re-alignment of the eyes, with prisms and with eye surgery, affects postural stability differently in children with strabismus. Graefe's Arch. Clin. Exp. Ophthalmol. 2012 Jun;250(6):849–55. doi: 10.1007/s00417-011-1845-z.
17. Matsuo T, Narita A, Senda M, Hasebe S, Ohtsuki H. Body sway increases immediately after strabismus surgery. Acta Med. Okayama. 2006 Feb;60(1):13–24. doi: 10.18926/AMO/30754.
18. NeuroCom International Inc. (2003). Instructions for Use: EQUITEST SYSTEM OPERATOR'S MANUAL. Version 8. Clackamas: NeuroCom International Inc.
19. Gaerlan MG, Alpert PT, Cross C, Louis M, Kowalski S. Postural balance in young adults: the role of visual, vestibular and somatosensory systems. J. Am. Acad. Nurse Pract. 2012 Jun;24(6):375–81. doi: 10.1111/j.1745-7599.2012.00699.x.
20. Simoneau GG, Ulbrecht JS, Derr JA, Cavanagh PR. Role of somatosensory input in the control of human posture. Gait Posture. 1995 Sep;3(3):115–22. doi: 10.1016/0966-6362(95)99061-O.
21. Wade MG, Jones G. The role of vision and spatial orientation in the maintenance of posture. Phys. Ther. 1997 Jun;77(6):619–28. doi: 10.1093/ptj/77.6.619.
22. Paulus W, Straube A, Brandt TH. Visual postural performance after loss of somatosensory and vestibular function. J. Neurol. Neurosurg. Psychiatry. 1987 Nov;50(11):1542–5. doi: 10.1136/jnnp.50.11.1542.
23. Ezane MD, Lions C, Bui Quoc E, Milleret C, Bucci MP. Spatial and temporal analyses of posture in strabismic children. Graefe's Arch. Clin. Exp. Ophthalmol. 2015 Oct;253(10):1629–39. doi: 10.1007/s00417-015-3134-8.
24. Lions C, Bui-Quoc E, Bucci MP. Postural control in strabismic children versus non strabismic age-matched children. Graefe's Arch. Clin. Exp. Ophthalmol. 2013 Sep;251(9):2219–25. doi: 10.1007/s00417-013-2372-x.
25. Buisseret P. Influence of extraocular muscle proprioception on vision. Physiol. Rev. 1195 Apr;75(2):323–38. doi: 10.1152/physrev.1995.75.2.323.
26. Steinbach MJ, Smith DR. Spatial localization after strabismus surgery: evidence for inflow. Science. 1981 Sep18;213(4514):1407–9. doi: 101126/science.7268444.
27. Cheng YY, Chen PY, Hsieh WL, Cheen JR, Kao CL. Correlation of the composite equilibrium score of computerized dynamic posturography and clinical balance tests. J. Clin. Gerontol. Geriatr. 2012 Jun;3(2):77–81. doi: 10.1016/j.jcgg.2012.04.004.
28. Ravaioli E, Oie KS, Kiemel T, Chiari L, Jeka JJ. Nonlinear postural control in response to visual translation. Exp. Brain Res. 2005 Jan;160(4):450–9 doi: 10.1007/s00221-004-2030-y.

Figures

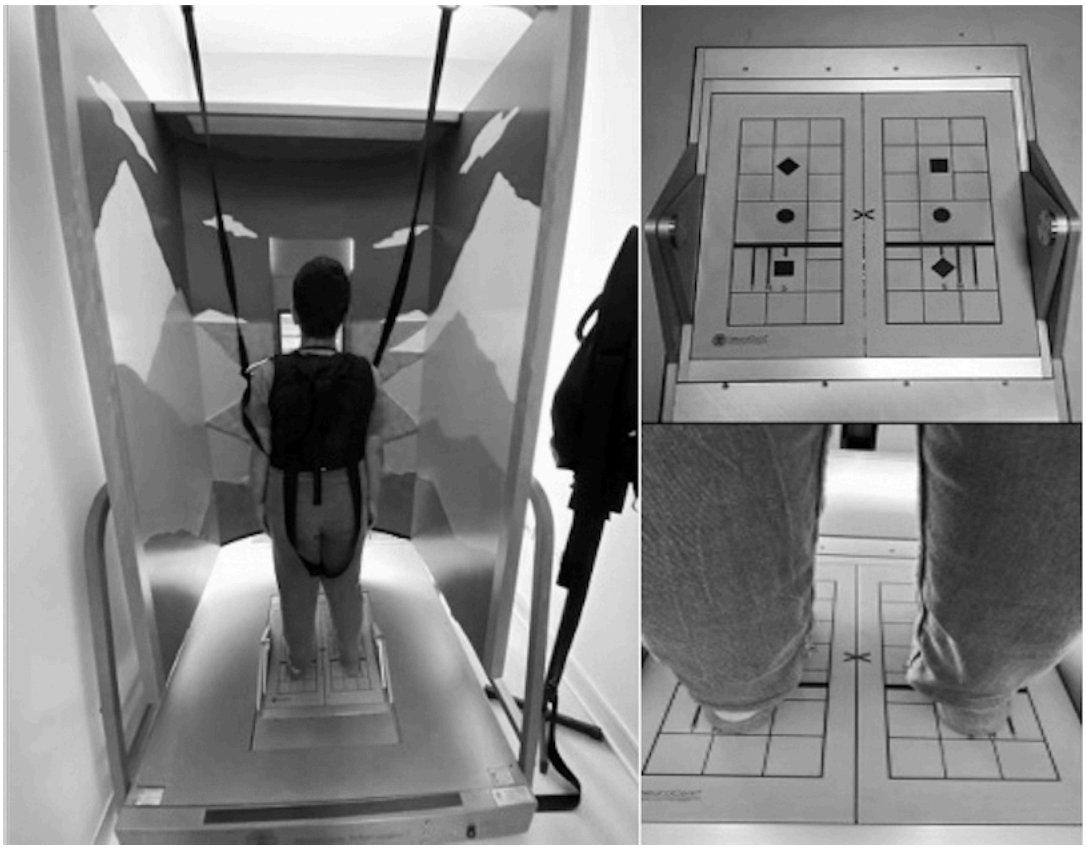


Figure 1

Simulation of patient positioning on movable test platform of computerized dynamic posturography device (Neurocom International Inc. / USA). Actual tests are performed barefoot

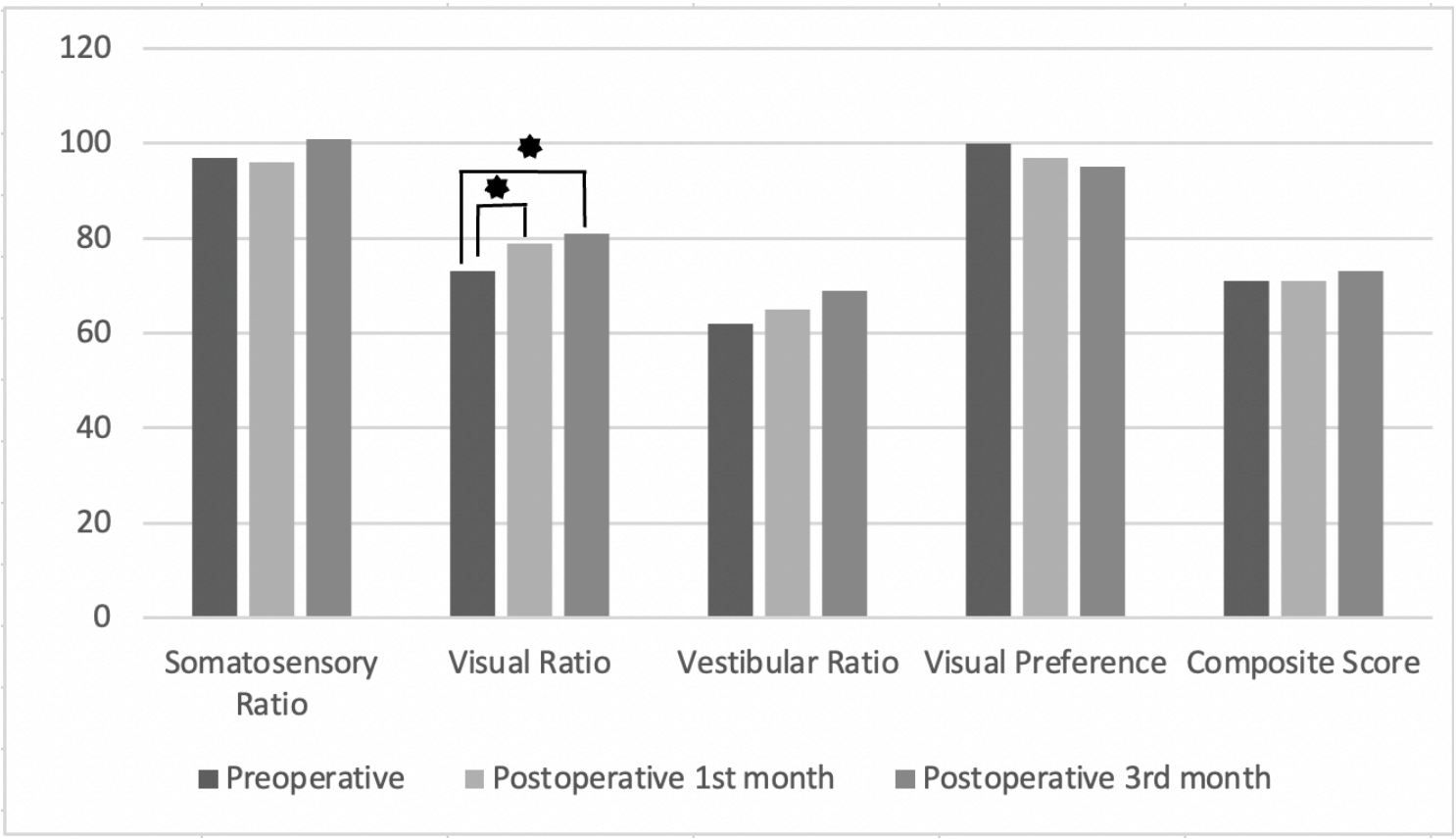


Figure 2

Results of SOT in Preoperative Period, Postoperative 1st and 3rd Months. (*) indicates statistical significance

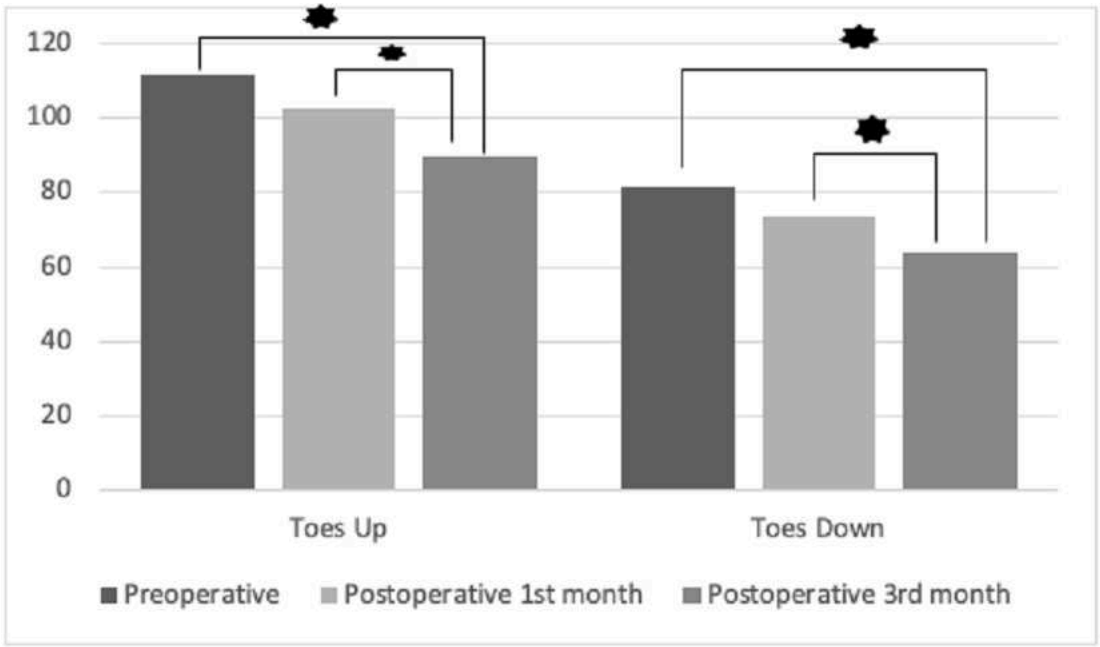


Figure 3

ADT test showssignificant reduction in Sway Energy Score throughout the study period. (*) indicates statistical significance

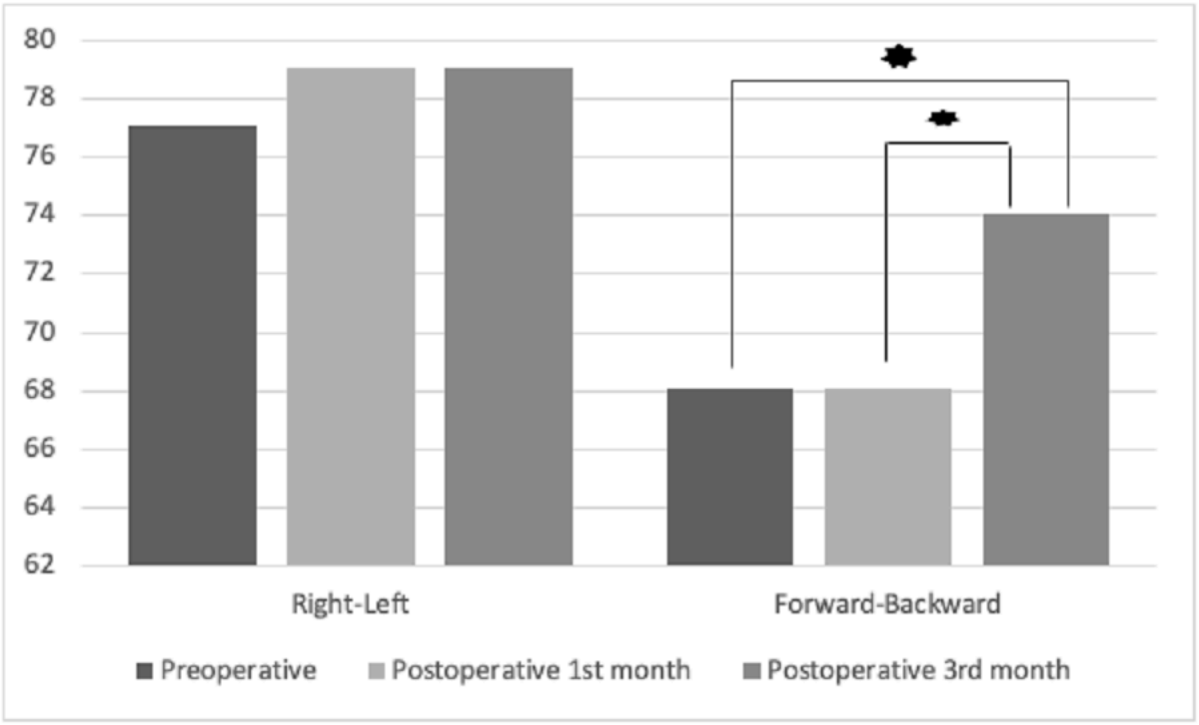


Figure 4

Results of RWST- Directional Control in Preoperative Period, Postoperative 1st and 3rd Months. (*) indicates statistical significance