

ORIGINAL ARTICLE

Open Access



# Degraded oculomotor function and its implications on balance in pediatric strabismus

Fatma Telci<sup>1,2\*</sup>, Figen Karabekiroğlu<sup>3</sup>, Leyla Niyaz<sup>4</sup> and Talha Cogen<sup>5</sup>

## Abstract

**Background** Children with visual impairment often exhibit poor postural control. However, the effects of strabismus on oculomotor system components and its impact on balance in children are not yet fully understood. This study aims to determine the potential effects of oculomotor functions on balance skills in children with strabismus.

**Methods** A total of 30 children aged between 6 and 10 years participated in this study. Fifteen children diagnosed with strabismus were included in the strabismus group ( $8.07 \pm 1.33$  years), and 15 healthy children without any vision problems were included in the control group ( $8.03 \pm 1.49$  years). All children underwent a comprehensive hearing evaluation, bedside neurological and balance examinations, the Pediatric Balance Scale (PBS) assessment to assess balance function, and Videonystagmography (VNG) tests to measure oculomotor function.

**Results** In the saccade test, no significant differences were found between the groups in terms of latency, accuracy, and speed ( $p > 0.05$ ). The strabismus group showed significantly lower pursuit test gains (except the left eye at 0.4 Hz) ( $p < 0.05$ ) and significantly higher asymmetries (except the right eye at 0.4 Hz) ( $p < 0.05$ ). No significant difference was observed between the groups in optokinetic test gains ( $p > 0.05$ ). The strabismus group had significantly lower scores on the 360-degree rotation task (10th item) ( $p = 0.027$ ) and total PBS scores ( $p = 0.029$ ). Correlation analysis revealed statistically significant negative correlations between strabismus angle and optokinetic test gains, pursuit test gains, and PBS total scores, with varying correlation strengths ( $p < 0.05$  and  $-0.639 < r < -0.338$ ).

**Conclusions** Strabismus adversely affects the optokinetic and pursuit systems, as well as balance in children. Furthermore, an increase in the strabismus angle is associated with greater adverse effects on these functions. The lower scores obtained in the PBS scores of the strabismus group indicate that strabismus may negatively affect balance skills in activities of daily living. Early intervention and targeted therapies should be considered to mitigate these effects and support the development of balance skills in children with strabismus.

**Keywords** Oculomotor Function, Pediatric balance scale, Strabismus, Videonystagmography

## Background

Balance is the adaptation of body position to changing situations and ensuring postural stability. Three systems, namely the visual system, proprioceptive system, and vestibular system, are involved in maintaining balance [1]. A disorder in any of these systems can affect the other two systems and negatively impact balance [2, 3]. Abnormal balance affects the harmony in gross and fine motor movements in children and leads to poor academic performance, delayed social development, and impaired general health [4].

\*Correspondence:

Fatma Telci  
ftmtelci@gmail.com

<sup>1</sup> Department of Audiology, Institute of Graduate Studies, İstanbul University-Cerrahpaşa, İstanbul, Türkiye

<sup>2</sup> Department of Audiometry, Health Services Vocational School, Harran University, Şanlıurfa, Türkiye

<sup>3</sup> Department of Otorhinolaryngology, Faculty of Medicine, Tokat Gaziosmanpaşa University, Tokat, Türkiye

<sup>4</sup> Department of Ophthalmology, Faculty of Medicine, Ondokuz Mayıs University, Samsun, Türkiye

<sup>5</sup> Department of Audiology, Faculty of Health Sciences, İstanbul University-Cerrahpaşa, İstanbul, Türkiye

Visual impairments affect balance skills and cause sensory reweighting of the balance inputs in the acute period [5]. The importance of visual information for balance control is evident in two phenomena: postural stability decreases significantly when the eyes are closed, and postural sway increases when a large portion of the visual environment moves [6–8].

Strabismus is a common visual disorder in infancy and is observed in approximately 2.5% of children under the age of 7 [9]. Strabismus is defined as the misalignment of the visual axes of the eyes, where both eyes are unable to simultaneously direct their fovea at the same object [10]. The etiology of childhood strabismus is not fully known, but both genetic and environmental factors are thought to contribute [11].

Children with strabismus are reported to have lower postural control compared to their peers without strabismus [12]. Studies focusing on postural control after oculomotor surgical realignment of the eyes have reported improvements in postural stability after surgery in children with strabismus [13–16]. Although surgical approaches to the oculomotor system have shown improvements in postural stability, the effects of strabismus on the components of the oculomotor system and its contribution to balance skills are not yet fully understood.

Videonystagmography (VNG) is currently the most widely used method for recording eye movements and allows the evaluation of oculomotor functions with oculomotor tests (including saccade, pursuit, optokinetic, gaze, spontaneous nystagmus tests) [17]. VNG can also be used as an auxiliary tool in the clinical examination of children with strabismus [18].

We hypothesize that changes in visual system inputs resulting from strabismus may affect oculomotor function. Knowledge of these effects may improve the rehabilitative approach to patients with balance impairment and additional visual impairment. Accordingly, our study aims to evaluate oculomotor functions in children with strabismus and to determine the possible consequences of strabismus on balance skills.

## Methods

### Participants

The sample size for the study was determined using a pre-hoc power analysis conducted with GPower 3.1.9.7 software. The analysis was based on the average effect size values recommended by Cohen [19]. It was determined that a total of 30 participants, comprising 15 children in the normal group and 15 children in the strabismus group, would be required to perform the statistical analyses with a 95% confidence interval and a power of 0.8.

A total of 30 children aged between 6 and 10 years were included in the study. The children were divided into two groups, the strabismus group and the control group. Fifteen children (8 females, 7 males) diagnosed with strabismus constituted the study group ( $8.07 \pm 1.33$  years) and 15 healthy children (8 females, 7 males) without vision problems constituted the control group ( $8.03 \pm 1.49$  years).

Children in the study group were included based on the following criteria: no vestibular disorders, normal hearing findings, and visual acuity sufficient to see the visual target used in the VNG test for both eyes. Children were excluded from the study group if they had any ophthalmologic disease other than strabismus, history of surgery, or neurological, psychiatric, systemic, and/or orthopedic disorders. All children in the study group had esotropia. The control group consisted of typically developing children without any vision problems.

### Hearing evaluation

Hearing evaluations of all participants were performed in a soundproof test chamber using a GSI AudioStar Pro™ (Grason Stadler Inc., Eden Prairie, MN, USA) clinical audiometer. TDH 39 over-the-ear headphones were used for air-conduction stimulation, and the Radioear B-71 bone vibrator was used for bone conduction stimulation. Pure tone audiometry and speech audiometry were administered to all participants. The pure tone average was calculated as the arithmetic mean of the hearing thresholds obtained at 500, 1000, 2000, and 4000 Hz in both ears. Children with air-conduction hearing thresholds within normal limits and an air–bone gap of no more than 10 dB were included in the study.

GSI TymStar Pro™ (Grason Stadler Inc., Eden Prairie, MN, USA) was used to evaluate middle ear function and acoustic reflex. In the evaluation, tympanograms obtained by using 85 dB SPL (Sound Pressure Level) stimulus at 226 Hz in the pressure range of +200 to –400 daPa. Tympanograms were evaluated using the classification of Jerger [20]. Children with type A tympanogram were included in the study. 95 dB HL (Hearing Level) and above stimuli were used to examine the presence of ipsilateral and contralateral acoustic reflexes at 500, 1000, 2000, and 4000 Hz. Children with bilateral ipsilateral and contralateral acoustic reflex responses were included in the study.

### Bedside examination methods

In order to exclude participants with peripheral and central vestibular pathology from the study, Fukuda Stepping Test [21, 22], Tandem Gait Test [23], Dysdiadokinesia Test [24], Finger-Nose Test [25] and Past-Pointing Test [22] were applied to all children. The results of these tests were normal for all participants in the study.

### Videonystagmography (VNG)

Micromedical Technologies INC. VisualEyes™ 4-channel VNG (Chatham, US) and Spectrum 9 software were used to record a separate VNG recording for each child. The following tests of the VNG instrument were administered to all children.

#### Saccade test

The participants were asked to look simultaneously at a visual stimulus illuminated consecutively at different locations on the horizontal axis on a light board without moving their heads. Stimuli were presented randomly in varying directions, time, and distance. The test was terminated after a total of 30 jumps were presented. Speed, accuracy, and latency were evaluated for both eyes.

#### Pursuit test

The participants were instructed to simultaneously follow a visual stimulus of different frequencies (0.1, 0.2, and 0.4 Hz) moving left and right on a light board with their eyes without moving their heads. The visual stimulus was presented for 40 s at 0.1 Hz, 20 s at 0.2 Hz, and 15 s at 0.4 Hz. Gain and asymmetry values were assessed separately for both eyes at all frequencies.

#### Optokinetic test

Visual stimuli flowing from right to left and left to right were presented to each participant. Each direction was recorded for 15 s with a visual stimuli speed of 30°/s. Gain values were evaluated separately for both eyes.

#### Gaze test

The patient was instructed to look at a target 20° to the right and left, 15° above and below the midline without moving their head. Each direction was recorded for 20 s and the presence of nystagmus was examined. None of the participants had gaze-evoked nystagmus.

#### Spontaneous nystagmus test

A 30-s recording was taken for both fixation and non-fixation conditions separately and the presence of spontaneous nystagmus was examined. Children without spontaneous nystagmus were included in the study.

Dix-Hallpike and Roll Tests: Participants were examined for the presence of vestibular pathology by applying positional tests. Children whose eye movements were recorded and who were free of dizziness, nausea, and nystagmus were included in the study.

#### Pediatric balance scale (PBS)

The PBS assesses children's functional balance in activities of daily living. The scale consists of 14 items and each item is scored between 0–4. A higher total score indicates

a better balance function [26]. In order to compare the balance skills between the strabismus and control groups, the PBS was applied to all children in the study, each item was scored between 0 and 4, and the total score obtained by the children was calculated.

#### Ethical considerations

This study was approved by a local ethics committee (number: B.30.2.ODM.0.20.08/1774–1790). The study was conducted in accordance with the ethical principles stated in the Declaration of Helsinki. Voluntary consent forms were obtained from all participants and their caregivers.

#### Data analysis

The statistical analysis of the data set was performed using IBM SPSS Statistics version 29 (IBM, NY, USA). The Shapiro–Wilk test was employed to assess the normality of the data. The internal consistency of the PBS items was evaluated through Cronbach's alpha. Descriptive statistics, including mean, standard deviation, and percentages, were utilized to visually inspect the data. Pearson correlation analysis was applied to parametric data, while Spearman correlation analysis was used for nonparametric data to identify potential correlations. For comparing the means of independent samples, the Independent Samples *t*-test was used for parametric data, and the Mann–Whitney *U* test was applied for nonparametric data. Results with a *p*-value of less than 0.05 were considered statistically significant.

#### Results

This study included a total of 30 children aged 6 to 10, divided into two groups: a study group (strabismus group) of 15 children (8 females, 7 males) diagnosed with strabismus ( $8.07 \pm 1.33$  years), and a control group of 15 healthy children (8 females, 7 males) without any vision problems ( $8.03 \pm 1.49$  years). Demographic findings of both groups are listed in Table 1.

#### Videonystagmography test

##### Saccade test

The average latencies of saccadic eye movements for the left eye leftward, left eye rightward, right eye leftward, and right eye rightward saccadic movement in both the study and control groups are shown in Table 2. No statistically significant differences were found in the latencies of saccadic eye movements between the study and control groups ( $p > 0.05$ ). However, the study group exhibited higher average latencies for saccadic eye movements compared to the control group.

The mean accuracy (%) of saccadic eye movements of all children in the study and control groups was within

**Table 1** Demographics of the sample

	Strabismus (M±SD)	Control (M±SD)	<i>p</i>
Sample size	15	15	–
Age (years)	8.07 ± 1.33	8.03 ± 1.49	0.853
Age at strabismus diagnosis (years)	3.45 ± 2.16	–	–
VA with right eyeglass	0.93 ± 0.11	–	–
VA with left eyeglass	0.87 ± 0.18	–	–
VA without the right eyeglasses	0.79 ± 0.22	–	–
VA without left eyeglass	0.80 ± 0.24	–	–
SA with glasses(ΔD)	17.40 ± 12.93	–	–
SA without glasses (ΔD)	40.43 ± 17.02	–	–

*M* mean, *SD* standard deviation, *VA* visual acuity, *SA* strabismus angle, *ΔD* prism diopter

**Table 2** Descriptive data for saccadic eye movements of each group

Saccade test			
Latency (ms)	Group	Mean±SD	<i>p</i>
Left eye leftward saccade	Strabismus group	247.60 ± 39.22	<i>p</i> > 0.05
	Control group	229.00 ± 31.77	
Left eye rightward saccade	Strabismus group	246.53 ± 38.42	
	Control group	230.20 ± 28.55	
Right eye leftward saccade	Strabismus group	243.40 ± 38.48	
	Control group	228.87 ± 31.80	
Right eye rightward saccade	Strabismus group	251.13 ± 40.36	
	Control group	228.13 ± 28.92	

**Table 3** Frequency of hypometric saccades in saccadic eye movements and their statistical comparisons for both groups

Hypometric saccade	Groups	<i>n</i> %	<i>p</i>
Left eye leftward saccade	Strabismus group	6–40%	<i>p</i> > 0.05
	Control group	5–33%	
Left eye rightward saccade	Strabismus group	8–53%	
	Control group	5–33%	
Right eye leftward saccade	Strabismus group	6–40%	
	Control group	6–40%	
Right eye rightward saccade	Strabismus group	8–53%	
	Control group	6–40%	

normal limits. Hypermetric saccades were not observed in saccadic eye movements in all children in the study and control groups. Hypometric saccades were observed in saccadic eye movements in some children in both groups. The frequency of hypometric saccades in saccadic eye movements in the strabismus and control groups is shown in Table 3. There was no statistically significant difference between the study and control groups

**Table 4** The right and left eye pursuit gain values at each frequency for both groups

Pursuit test				
Gain	Groups	Mean ± SD	<i>p</i>	
0.1 Hz	Left eye	Strabismus group Control group	0.81 ± 0.15 0.91 ± 0.11	<i>p</i> = 0.036*
	Right eye	Strabismus group Control group	0.68 ± 0.22 0.90 ± 0.10	
0.2 Hz	Left eye	Strabismus group Control group	0.85 ± 0.13 0.98 ± 0.07	<i>p</i> = 0.002*
	Right eye	Strabismus group Control group	0.77 ± 0.23 0.96 ± 0.07	
0.4 Hz	Left eye	Strabismus Group Control group	0.88 ± 0.15 0.94 ± 0.06	<i>p</i> > 0.05
	Right eye	Strabismus group Control group	0.76 ± 0.19 0.93 ± 0.06	

\* : statistically significant (*p* < 0.05)

in terms of the frequency of hypometric saccades in saccadic eye movements (*p* > 0.05).

In all children in the strabismus and control groups, the speed and accuracy of saccadic eye movements were within normal limits. There was no significant difference between the groups regarding the speed and accuracy of saccadic eye movements (*p* > 0.05).

**Pursuit test**

The mean gain values for the right and left eyes of the strabismus and control groups in the pursuit test at frequencies of 0.1, 0.2, and 0.4 Hz are shown in Table 4. A statistically significant difference in pursuit gain was found between the study and control groups at all frequencies (*p* < 0.05) except for the left eye at 0.4 Hz (*p* > 0.05), with the study group showing lower gain averages for both eyes at 0.1, 0.2, and 0.4 Hz.

The mean right and left eye asymmetry (%) in the pursuit test at frequencies of 0.1, 0.2, and 0.4 Hz for the strabismus and control groups are shown in Table 5. A statistically significant difference in asymmetry was found between the strabismus and control groups at all frequencies except for the right eye at 0.4 Hz. The strabismus group exhibited higher mean asymmetry for both eyes in the pursuit test at 0.1, 0.2, and 0.4 Hz compared to the control group.

**Optokinetic test**

The mean right and left eye gains of the strabismus and control groups in response to leftward and rightward flowing stimuli at a speed of 30°/s in the optokinetic test are shown in Table 6. There was no statistically significant

**Table 5** Mean right and left eye asymmetry by frequency in the pursuit test for both groups

Pursuit test			
Asymmetry (%)	Groups	Mean ± SD	<i>p</i>
<b>0.1 Hz</b>	Left eye	Strabismus group 12.80 ± 12.89 Control group 5.20 ± 5.45	<b><i>p</i> = 0.032*</b>
	Right eye	Strabismus group 12.07 ± 9.59 Control group 4.40 ± 4.70	<b><i>p</i> = 0.009*</b>
<b>0.2 Hz</b>	Left eye	Strabismus group 10.67 ± 9.25 Control group 3.13 ± 2.88	<b><i>p</i> = 0.008*</b>
	Right eye	Strabismus group 11.13 ± 13.55 Control group 3.47 ± 3.16	<b><i>p</i> = 0.027*</b>
<b>0.4 Hz</b>	Left eye	Strabismus group 8.67 ± 9.52 Control group 4.33 ± 4.81	<b><i>p</i> = 0.041*</b>
	Right eye	Strabismus group 10.93 ± 11.34 Control group 4.53 ± 4.88	<i>p</i> > 0.05

\* : statistically significant (*p* < 0.05)

**Table 6** Mean right and left eye gains by stimulus direction in the optokinetic test for both groups

Optokinetic test			
Gain	Groups	Mean ± SD	<i>p</i>
<b>Leftward flowing stimuli (L 30°/sn)</b>	Left eye	Strabismus group 0.73 ± 0.23 Control group 0.80 ± 0.11	<i>p</i> > 0.05
	Right eye	Strabismus Group 0.73 ± 0.23 Control group 0.79 ± 0.11	
<b>Rightward flowing stimuli (R 30°/sn)</b>	Left eye	Strabismus group 0.69 ± 0.23 Control group 0.72 ± 0.12	
	Right eye	Strabismus group 0.70 ± 0.25 Control group 0.73 ± 0.13	

difference in optokinetic test gains between the two groups (*p* > 0.05).

**Gaze test**

None of the children in the strabismus or control group showed nystagmus in the gaze test when looking to the right, left, up, and down.

**Pediatric balance scale (PBS)**

In the study and control groups, the scores of the PBS items and the PBS total score were evaluated. First, it was determined that the PBS had high internal consistency ( $\alpha = 0.851$ ). All children in both groups scored the same and achieved the highest score (4 points) on items 1, 2, 4, 5, 6, 7, 8, and 12 of the PBS. Consequently, these items were excluded from further statistical comparisons, and

**Table 7** Item scores (for items 3, 9, 10, 11, 13, and 14) and total score averages of the PBS for both groups

PBS	Strabismus Group Mean ± SD	Control Group Mean ± SD	<i>p</i>
3rd item	3.93 ± 0.26	4	<i>p</i> > 0.05
9th item	3.80 ± 0.41	3.93 ± 0.26	<i>p</i> > 0.05
10th item	3.33 ± 0.90	3.93 ± 0.26	<b><i>p</i> = 0.027*</b>
11th item	3.80 ± 0.41	4	<i>p</i> > 0.05
13th item	3.80 ± 0.41	4	<i>p</i> > 0.05
14th item	3.58 ± 0.54	3.69 ± 0.49	<i>p</i> > 0.05
<b>Total</b>	54.25 ± 1.74	55.56 ± 0.53	<b><i>p</i> = 0.029*</b>

\* : statistically significant (*p* < 0.05)

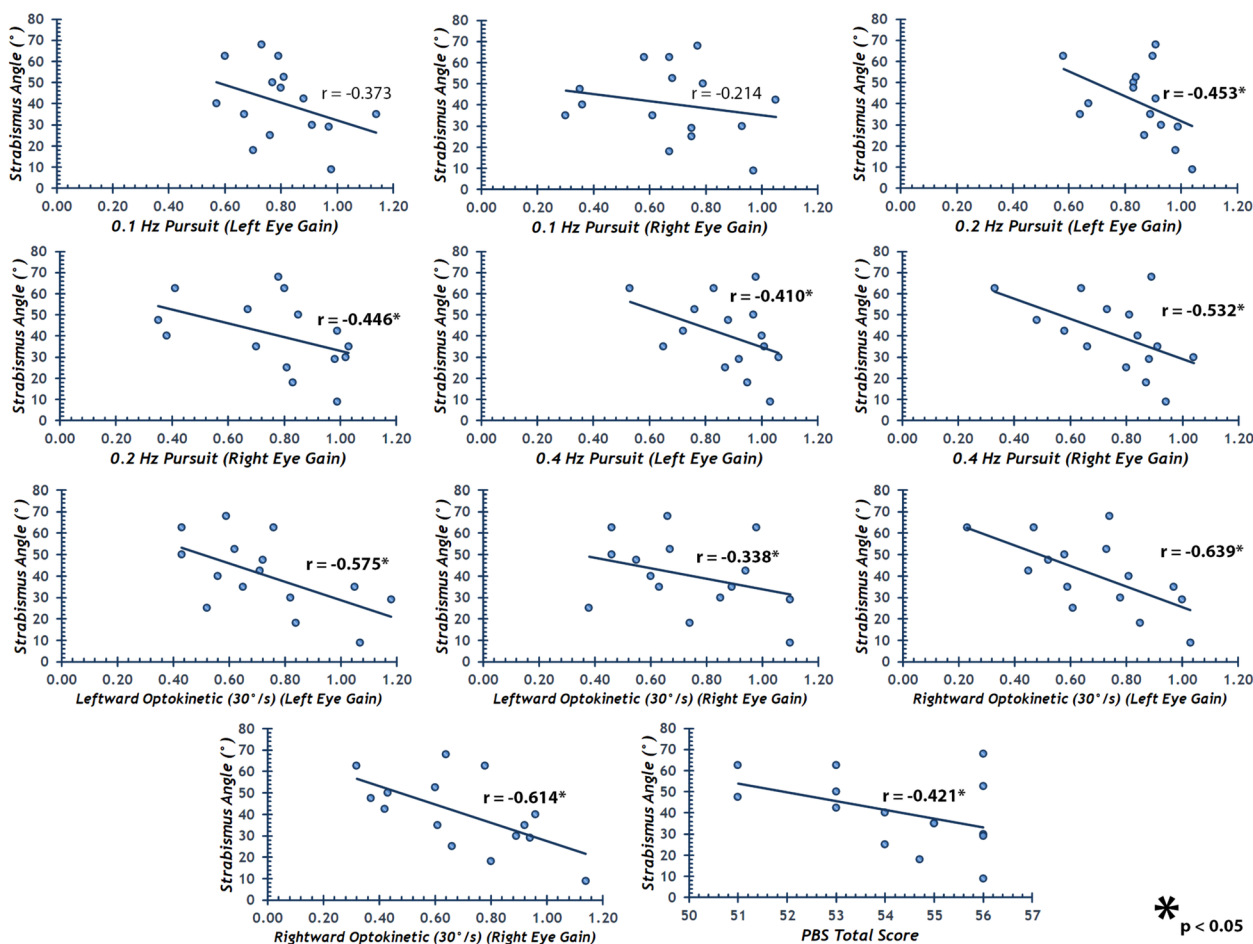
their descriptive statistics are not presented in the table below (Table 7). The mean scores for PBS items 3, 9, 10, 11, 13, and 14, and the PBS total scores obtained from the study and control groups are shown in Table 7. A statistically significant difference was found between the strabismus and control groups with the strabismus group scoring lower on PBS item 10 (turning 360°) (*p* = 0.027) and the total score (*p* = 0.029).

Correlation analysis revealed statistically significant negative correlations between the strabismus angle and optokinetic test gains, pursuit test gains, and PBS total scores, with correlation coefficients ranging from -0.639 to -0.338 (*p* < 0.05). The detailed results of the correlation analysis are presented in Fig. 1.

**Discussion**

The formation of saccadic eye movements involves the visual cortex, parietal cortex, frontal cortex, superior colliculus, and brainstem. Motor impulses generated and mediated by these structures reach the extraocular muscles to initiate saccadic movements. Saccadic eye movements, which can be voluntary or reflexive, are rapid shifts from one target to another [27]. Bucci, Seassau [28] stated that saccade latency decreases with age, and saccade maturation is completed by the age of 12. Many studies have reported that the mean saccade latency in children is longer compared to adults [29, 30]. It has been reported that saccade latency tends to be longer in children with strabismus compared to typically developing children, but this difference is significant only on an individual basis [31]. In our study, no significant difference was found between the strabismus and control groups regarding saccade latency (*p* > 0.05). Based on these latency findings, the saccadic system functions of the strabismus group appear to be similar to those of the control group, suggesting that the effects of strabismus on the saccadic system are well compensated. However,





**Fig. 1** Correlation analysis results between strabismus angle and VNG subtest results and PBS total scores

the high standard deviations in the strabismus group imply a more individualistic phenomenon underlying this finding. We believe that the underlying factor affecting this standard deviation is the strabismus angle, which we will discuss later in this section.

Hypermetric saccades are mostly associated with cerebellar pathologies [32]. In our study, hypermetric saccades were not observed in any child. Kapoula, Bucci [33], reported that hypometric saccades were observed in eccentrically located targets in both typically developing and strabismic children. Similarly, in our study, hypometric saccades were observed in some children in both the strabismus and control groups, with no statistically significant difference in their frequency between the groups ( $p > 0.05$ ). These findings suggest that the hypometric saccades observed in both groups are likely not related to pathology but rather to the natural functioning of the saccadic system.

Studies have suggested that the brainstem connections controlling the peak velocity of saccades are well developed by the age of 6 years [28, 30, 34]. In our study, no

significant difference was found between the saccadic peak velocities of children in the strabismus and control groups ( $p > 0.05$ ). This suggests that the development of the saccadic firing generator in the brainstem is comparable in both groups.

The pursuit mechanism stabilizes moving objects on the fovea by providing retinal shift through open-loop and closed-loop systems [35]. Studies have reported that pursuit gains are lower in children with strabismus compared to typically developing children [18]. In our study, pursuit test gains in the strabismus group (except for the left eye gain at 0.4 Hz) were statistically significantly lower than those in the control group ( $p < 0.05$ ).

The pursuit system relies on binocular coordination to stabilize images on the fovea. Failure to achieve this coordination results in asymmetries [36]. Lions et al. [37], reported that binocular pursuit coordination is impaired in children with strabismus. In our study, pursuit asymmetries (except for right eye asymmetry at 0.4 Hz) were significantly higher in the strabismus group compared to the control group ( $p < 0.05$ ). Furthermore, since there

were no central lesions in the strabismus group, it is suggested that the observed pursuit asymmetries are likely attributable to strabismus itself.

The pursuit system is crucial for maintaining dynamic balance. However, pursuit stimuli not associated with dynamic balance activities cause retinal flow unrelated to movement, increasing postural oscillation and limiting balance skills [38]. In our study, the lower pursuit gains and higher asymmetries in the strabismus group compared to the control group ( $p < 0.05$ ) suggest that the pursuit mechanism struggles to stabilize images on the fovea in children with strabismus. Consequently, the retinal shift following movements involving the pursuit mechanism may not adapt to peripheral motion, causing the target image to remain outside the fovea. Given that pursuit stimuli negatively impact dynamic balance even in typically developing individuals [38], it is suggested that strabismus-related impairments in the pursuit system may adversely affect dynamic balance.

Optokinetic eye movements stabilize gaze when the visual scene is variable and the viewer's body movements are constant [32]. In our study, no statistically significant difference was found between the strabismus and control groups in optokinetic nystagmus gains ( $p > 0.05$ ). However, the strabismus group exhibited much higher standard deviations compared to the control group. Due to the high standard deviations in strabismus angles within the strabismus group, this variability may have masked any statistically significant differences in optokinetic nystagmus scores between the two groups. This suggests that strabismus may have varying individual effects on optokinetic nystagmus gains depending on the strabismus angle.

We found that an increase in strabismus angle negatively affects pursuit system gains, optokinetic system gains, and the total scores of the PBS, with varying correlation strengths ( $p < 0.05$  and  $-0.639 < r < -0.338$ ) (Fig. 1). Specifically, the correlations indicate that larger strabismus angles are associated with lower gains in both the pursuit and optokinetic systems, as well as lower overall balance performance as measured by the PBS. These findings suggest that the severity of strabismus can have a significant impact on multiple aspects of visual and balance function, highlighting the importance of considering individual variability in clinical assessments and interventions.

Some studies have reported worse balance and optokinetic function in children diagnosed with strabismus compared to their typically developing peers [12, 18]. However, to our knowledge, there is no study in the literature that analyzes the correlation between strabismus angle and oculomotor or balance function. Our study contributes to the literature by providing this

analysis, which suggests a negative correlation between strabismus angle and oculomotor and balance functions. Nevertheless, more studies are needed to further substantiate this claim.

The Pediatric Balance Scale (PBS) has been used in the literature to assess functional balance skills in daily activities across various pathologies, including visual impairment, and in typically developing pediatric populations [39–42]. In one study, the balance skills of children with strabismus were evaluated using PBS, and a statistically significant difference in the total PBS score was found between the strabismus group and an age-matched control group [12]. In our study, consistent with the literature, the strabismus group had a statistically significantly lower total PBS score compared to the control group ( $p = 0.029$ ). Specifically, in the 360° rotation activity of the 10th item on the PBS, the strabismus group scored significantly lower than the control group ( $p = 0.027$ ). This may be associated with dysfunctions in the pursuit mechanism. Rotation around oneself primarily involves the optokinetic nystagmus (OKN) mechanism. However, optokinetic stimulation is known to coordinate not only the OKN system but also the pursuit system [32]. Consequently, it is suggested that children with strabismus may struggle to stabilize their balance under conditions where target objects or the individual move excessively or rapidly.

## Conclusions

The results of our study evaluating oculomotor functions in children with strabismus showed that gaze, spontaneous nystagmus, saccade, and optokinetic functions were similar between typically developing children and those with strabismus. However, children with strabismus exhibited lower gains and higher asymmetry in the pursuit system compared to their typically developing peers. These disturbances in oculomotor functions due to strabismus may adversely affect balance skills in daily living activities.

Further studies with larger sample sizes are needed to establish clinical evaluation standards for children with strabismus. Additionally, the effects of possible oculomotor dysfunctions on the balance system in preschool children with strabismus should be investigated in detail. Rehabilitation programs that can strengthen the balance system should be developed and implemented.

## Acknowledgements

Not applicable.

## Authors' contributions

Contributions with respect to CRediT taxonomy are listed below: Fatma Telci: conceptualization (equal), formal analysis (equal), investigation (equal), methodology (equal), project administration (equal), writing—original draft (equal), writing—review and editing (equal). Figen Karabekiroğlu: conceptualization

(equal), formal analysis (equal), investigation (equal), methodology (equal), project administration (equal), supervision (equal), writing—review and editing (equal). Leyla Niyaz: conceptualization (equal), formal analysis (equal), methodology (equal), supervision (equal). Talha Cogen: formal analysis (equal), visualization (lead), writing—original draft (equal), writing—review and editing (equal).

#### Funding

No financial or other support has been received.

#### Availability of data and materials

The datasets analyzed during the current study are available from the corresponding author upon reasonable request. The data will be available within 6 months to 2 years after the article is published. Declarations.

#### Declarations

##### Ethics approval and consent to participate

This study was approved by Ondokuz Mayıs University Clinical Research Ethics Committee (number: B.30.2.ODM.0.20.08/1774–1790). The study was conducted in accordance with the ethical principles stated in the Declaration of Helsinki. Voluntary consent forms were obtained from all participants and their caregivers.

##### Consent for publication

Not applicable.

##### Competing interests

The authors declare that they have no competing interests

Received: 8 June 2024 Accepted: 13 September 2024

Published online: 02 October 2024

#### References

- Peterka RJ (2018) Sensory integration for human balance control. *Handb Clin Neurol* 159:27–42. <https://doi.org/10.1016/b978-0-444-63916-5.00002-1>
- Grace Gaerlan M, Alpert PT, Cross C, Louis M, Kowalski S (2012) Postural balance in young adults: the role of visual, vestibular and somatosensory systems. *J Am Acad Nurse Pract* 24(6):375–381. <https://doi.org/10.1111/j.1745-7599.2012.00699.x>
- Horak FB, Nashner LM, Diener HC (1990) Postural strategies associated with somatosensory and vestibular loss. *Exp Brain Res* 82(1):167–177. <https://doi.org/10.1007/bf00230848>
- Zipori AB, Colpa L, Wong AMF, Cushing SL, Gordon KA (2018) Postural stability and visual impairment: assessing balance in children with strabismus and amblyopia. *PLoS One* 13(10):e0205857. <https://doi.org/10.1371/journal.pone.0205857>
- O'Connell C, Mahboobin A, Drexler S, Redfern MS, Perera S, Nau AC et al (2017) Effects of acute peripheral/central visual field loss on standing balance. *Exp Brain Res* 235(11):3261–3270. <https://doi.org/10.1007/s00221-017-5045-x>
- Black FO, Wall C 3rd, Nashner LM (1983) Effects of visual and support surface orientation references upon postural control in vestibular deficient subjects. *Acta Otolaryngol* 95(3–4):199–201. <https://doi.org/10.3109/00016488309130936>
- Paulus WM, Straube A, Brandt T (1984) Visual stabilization of posture. Physiological stimulus characteristics and clinical aspects. *Brain* 107(Pt 4):1143–1163. <https://doi.org/10.1093/brain/107.4.1143>
- Redfern MS, Yardley L, Bronstein AM (2001) Visual influences on balance. *J Anxiety Disord* 15(1–2):81–94. [https://doi.org/10.1016/s0887-6185\(00\)00043-8](https://doi.org/10.1016/s0887-6185(00)00043-8)
- Torp-Pedersen T, Boyd HA, Skotte L, Haargaard B, Wohlfahrt J, Holmes JM et al (2017) Strabismus incidence in a Danish population-based cohort of children. *JAMA Ophthalmol* 135(10):1047–1053. <https://doi.org/10.1001/jamaophthalmol.2017.3158>
- Von Noorden GK, Campos EC (2002) Binocular vision and space perception. In: *Binocular vision and ocular motility*, 6th edn. Mosby Inc., London, p 7–35
- Cotter SA, Varma R, Tarczy-Hornoch K, McKean-Cowdin R, Lin J, Wen G et al (2011) Risk factors associated with childhood strabismus: the multi-ethnic pediatric eye disease and Baltimore pediatric eye disease studies. *Ophthalmology* 118(11):2251–2261. <https://doi.org/10.1016/j.ophtha.2011.06.032>
- Jayakaran P, Mitchell L, Johnson GM (2018) Peripheral sensory information and postural control in children with strabismus. *Gait Posture* 65:197–202. <https://doi.org/10.1016/j.gaitpost.2018.07.173>
- Bucci MP, Soufi H, Villeneuve P, Colleville L, Bui-Quoc E, Lions C (2016) Importance of proprioceptive information for postural control in children with strabismus before and after strabismus surgery. *Front Syst Neurosci* 10:67. <https://doi.org/10.3389/fnsys.2016.00067>
- Ezane MD, Lions C, Bui Quoc E, Milleret C, Bucci MP (2015) Spatial and temporal analyses of posture in strabismic children. *Graefes Arch Clin Exp Ophthalmol* 253(10):1629–1639. <https://doi.org/10.1007/s00417-015-3134-8>
- Lions C, Colleville L, Bui-Quoc E, Bucci MP (2016) Importance of visual inputs quality for postural stability in strabismic children. *Neurosci Lett* 617:127–133. <https://doi.org/10.1016/j.neulet.2016.02.008>
- Matsuo T, Narita A, Senda M, Hasebe S, Ohtsuki H (2006) Body sway increases immediately after strabismus surgery. *Acta Med Okayama* 60(1):13–24. <https://doi.org/10.18926/amo/30754>
- Furman JM, Goldstein A (2017) Vertigo. In: Swaiman KF, Phillips J (eds) *Swaiman's pediatric neurology principles and practice*, 6th edn. Elsevier, Edinburgh, p 52–8
- Hepokur M, Mutlu B, Güneş M, Topçu MT, Mutlu A, Oğuz H et al (2022) The effect of different types of convergent strabismus on horizontal eye movements. *Int Ophthalmol* 42(12):3951–3961. <https://doi.org/10.1007/s10792-022-02379-2>
- Cohen J (1988) *Statistical power analysis for the behavioral sciences*, 2nd edn. Routledge Member of the Taylor and Francis Group, New York
- Jerger J (1970) Clinical experience with impedance audiometry. *Arch Otolaryngol* 92(4):311–324. <https://doi.org/10.1001/archotol.1970.04310040005002>
- Tusa RJ (2014) History and clinical examination. In: Herdman SJ, Clendaniel RA (eds) *Vestibular rehabilitation*. F. A. Davis Company, New York
- Hullar T, Minor LB (2005) The neurotologic examination. In: Jackler RK, Brackmann DMD (eds) *Neurotology*. Elsevier, Philadelphia, p 215–227
- Akpınar Z (2005) Vestibüler testler ve yorumu. *Türkiye Klinikleri Tıp Bilimleri Dergisi* 25(5):724–731
- Zaidi SH, Sinha A. *Vertigo: A Clinical Guide*. Springer, Berlin, 2013
- Whitney SL, Herdman SJ (2014) Physical therapy assessment of vestibular hypofunction. In: Herdman SJ, Clendaniel RA (eds) *Vestibular rehabilitation*. F. A. Davis Company, New York
- Franjoine MR, Gunther JS, Taylor MJ (2003) Pediatric balance scale: a modified version of the berg balance scale for the school-age child with mild to moderate motor impairment. *Pediatr Phys Ther* 15(2):114–128. <https://doi.org/10.1097/01.Pep.0000068117.48023.18>
- Heywood S, Churcher J (1981) Direction-specific and position-specific effects upon detection of displacements during saccadic eye movements. *Vision Res* 21(2):255–261. [https://doi.org/10.1016/0042-6989\(81\)90119-X](https://doi.org/10.1016/0042-6989(81)90119-X)
- Bucci MP, Seassau M (2012) Saccadic eye movements in children: a developmental study. *Exp Brain Res* 222(1–2):21–30. <https://doi.org/10.1007/s00221-012-3192-7>
- Doettl SM, Plyler PN, McCaslin DL, Schay NL (2015) Pediatric oculomotor findings during monocular videonystagmography: a developmental study. *J Am Acad Audiol* 26(8):703–715. <https://doi.org/10.3766/jaaa.14089>
- Fukushima J, Hatta T, Fukushima K (2000) Development of voluntary control of saccadic eye movements. I. Age-related changes in normal children. *Brain Dev* 22(3):173–180. [https://doi.org/10.1016/s0387-7604\(00\)00101-7](https://doi.org/10.1016/s0387-7604(00)00101-7)
- Bucci MP, Kapoula Z, Yang Q, Brémond-Gignac D (2006) Latency of saccades, vergence, and combined movements in children with early onset convergent or divergent strabismus. *Vision Res* 46(8–9):1384–1392. <https://doi.org/10.1016/j.visres.2005.06.035>



32. Leigh RJ, Zee DS (2006) *The neurology of eye movements*, 4th edn. Oxford University Press, New York
33. Kapoula Z, Bucci P (2002) Distribution-dependent saccades in children with strabismus and in normals. *Exp Brain Res* 143(2):264–268. <https://doi.org/10.1007/s00221-002-1018-8>
34. Munoz DP, Broughton JR, Goldring JE, Armstrong IT (1998) Age-related performance of human subjects on saccadic eye movement tasks. *Exp Brain Res* 121(4):391–400. <https://doi.org/10.1007/s002210050473>
35. Krauzlis RJ, Lisberger SG (1994) Temporal properties of visual motion signals for the initiation of smooth pursuit eye movements in monkeys. *J Neurophysiol* 72(1):150–162. <https://doi.org/10.1152/jn.1994.72.1.150>
36. Bogousslavsky J, Regli F (1986) Pursuit gaze defects in acute and chronic unilateral parieto-occipital lesions. *Eur Neurol* 25(1):10–18. <https://doi.org/10.1159/000115980>
37. Lions C, Bui-Quoc E, Wiener-Vacher S, Seassau M, Bucci MP (2013) Smooth pursuit eye movements in children with strabismus and in children with vergence deficits. *PLoS One* 8(12):e83972. <https://doi.org/10.1371/journal.pone.0083972>
38. Thomas NM, Dewhurst S, Bampouras TM, Donovan T, Macaluso A, Vannozzi G (2017) Smooth pursuits decrease balance control during locomotion in young and older healthy females. *Exp Brain Res* 235(9):2661–2668. <https://doi.org/10.1007/s00221-017-4996-2>
39. Abuin-Porras V, Villafañe JH, Jiménez-Antona C, Palacios A, Martínez-Pascual B, Rodríguez-Costa I (2018) Relationship between attention and balance: a dual-task condition study in children. *J Exerc Rehabil* 14(3):349–355. <https://doi.org/10.12965/jer.1836142.071>
40. Seung Mi Y, Ji Young L, Hye Yeon S, Yun Sik S, Jeong YK (2019) Factors influencing motor outcome of hippotherapy in children with cerebral palsy. *Neuropediatrics* 50(3):170–177. <https://doi.org/10.1055/s-0039-1685526>
41. Verbecque E, Vereeck L, Van de Heyning P, Hallemans A (2017) Gait and its components in typically developing preschoolers. *Gait Posture* 58:300–306. <https://doi.org/10.1016/j.gaitpost.2017.08.012>
42. Zylka J, Lach U, Rutkowska I (2013) Functional balance assessment with pediatric balance scale in girls with visual impairment. *Pediatr Phys Ther* 25(4):460–466. <https://doi.org/10.1097/PEP.0b013e31829ddbc8>

### Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.