Normative Values of Saccades and Smooth Pursuit in Children Aged 5 to 17 Years

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Abstract

Background Pediatric oculomotor function can be evaluated via videonystagmography. Adult normative data for saccades and smooth pursuit tests cannot be used as a benchmark for pediatric patients because children's peripheral and central systems continue to mature throughout adolescence.

Purpose The purpose of this study was to establish normative data for saccade and smooth pursuit tests that can be used clinically in the assessment of vestibular and neurological disorders in children, and to investigate the effect of age and eye movement direction (left/right) on tests parameters.

Research Design The present study is prospective cross-sectional study.

Study Sample A total of 120 healthy children were recruited and equally distributed according to age and gender to each of the following groups: 5-8, 9-11, 12-14, and 15-17 years old. Participants had to pass a comprehensive otological and neurological assessment prior to inclusion in the study. Each subject underwent saccade and smooth pursuit testing.

Data Collection and Analysis Saccade latency, velocity and accuracy/precision, and smooth pursuit gain were analyzed across groups using a two-way repeated measure multivariate analysis of variance (MANOVA).

Results Saccadic latency was longer in the youngest group aged 5-8 years old (305 ± 48 msec) in comparison to children aged 9-11 years old (276 ± 22 msec) ($P = 0.017$), 12-14 years old (252 ± 34 msec) ($P = 0.001$) adolescents 15-17 years (256 ± 33 msec) ($P = 0.001$). Age did not affect the results of saccadic velocity and accuracy/precision. Saccade parameters (latency, velocity, accuracy/ precision) were not affected by oculomotor direction (left vs. right). Smooth pursuit gain increased from 0.63 in children aged 5-8 years old to 0.85 in children aged 15-17 years

Keywords
- maturation
- pediatric
- saccade
- smooth pursuit
- videonystagmography

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($P = 0.0001$). The percentage of gain asymmetry was significantly different in the youngest two groups.

Conclusion Saccade latency decreased as age increased. Smooth pursuit gains increased with increased age. Saccade velocity and accuracy/precision did not change significantly from ages 5-8 to 15-17 years of age. These data provide normative values for pediatric oculomotor evaluation and suggest that saccade and pursuit pathways may mature at different rates.

Introduction

The oculomotor system is considered as the system of choice to explore the neural reflexes and to track brain maturation and development (Luna et al[26]). Saccade and smooth pursuit tests have been demonstrated to be beneficial not only for visual testing and vestibular diagnosis but also for a wide range of psychopathologies (e.g., attention-deficit/hyperactivity disorder and autism) and musculoskeletal disorders that are linked to neurodevelopmental basis in children (Everling and Fischer[12]; Sweeney et al[41]; Lion et al[25]).

Saccades are voluntary rapid eye movements that bring an object of interest to the fovea of the eye, enabling clear vision for fast-moving targets. They are quantified by latency, velocity, and accuracy/precision. Latency is the interval of time between the presentation of the target and the beginning of the saccadic eye movement intended to acquire that target. The normal range of latency in adults is 170-350 msec (Findlay[13]). The reaction time might be affected by different factors such as age and attentive state (Meyer et al[28]). Long latency in an adult can be associated with the presence of lesion(s)/abnormalities in the basal ganglia, brainstem, cerebellum, peripheral oculomotor nerves, or eye muscles (Mekki[27]). Velocity refers to the peak velocity obtained during the saccadic eye movement, and it may range from 50° to 700°/second in adults. Velocity is affected by the size of the eye movement (Leigh and Zee[24]), and a mean value >230°/second is considered within the normal range. Saccadic accuracy reflects the precision of creating appropriate eye movement displacements. A score >70-80% (gain) is considered normal (Bucci et al[5]; Ruckenstein and Davis[36]). Abnormal saccadic accuracy/precision includes hypometric saccades (i.e., undershooting: meaning that initial saccades are too small) or hypermetric saccade (i.e., overshooting: meaning initial saccades are too large). Hypometria refers to a lesion in the cerebellar flocculus and hypermetria refers to a lesion in the cerebellar vermis (Mekki[27]). However, hypometria and hypermetria should not be considered an abnormal finding unless they are repetitive and consistent because they may occur occasionally in normal individuals, keeping in mind that poor vision and attentiveness can affect the saccadic accuracy/precision as well. Saccades are present at birth (Luna et al[26]) and saccade origins are based on the direction of movement (a) the horizontal movement is generated at the medullar point of the reticular formation, close to the abducens nucleus and (b) the vertical movement is generated at the medium rostral reticular formation for the oculomotor nuclei (Mezzalira et al[29]). For the purpose of the present study, only horizontal saccades will be discussed.

Smooth pursuit is a slow eye tracking movement that aims to stabilize the image of a slow-moving target on the fovea of the eye. Smooth pursuit is quantified by gain and asymmetry. The gain of smooth pursuit eye movement in normal healthy adults is usually >0.8 (Wuyts and Boniver[45]). However, normative data suggest deterioration with age (elderly in comparison with adult) (Moschner and Baloh[30]).

Bilateral abnormal gain of smooth pursuit can be related to aging or to the presence of diffuse cortical, basal ganglia, or cerebellar anomalies (Mekki[27]). In these cases, the eyes lag behind the target and catch-up saccades are noted. Moreover, the eye movement should be conjugate. An asymmetric defect indicates the presence of focal lesions involving the ipsilateral cerebellar hemisphere, brainstem, or parieto-occipital region. Smooth pursuit eye movement can be detected within the first two months of a child's life (von Hofsten and Rosander[44]). Neural pathways responsible for the smooth pursuit movement start at the occipital cortex, the temporal and parietal cortex, corpus callosum, pons, and bulb and finally reaching the cerebellum (Mezzalira et al[29]). The pursuit system is immature at birth. In the first few weeks, pursuit tracking happens through optokinetic nystagmus (Rosander[33]), and at two months, this becomes a slow inaccurate saccadic movement (Rosander and von Hofsten[34]). By six months of age, the saccadic aspect of pursuit remains with continued maturation of the pursuit system until later in adolescence (Ross et al[35]).

The gold standard to record oculomotor function clinically is videonystagmography (VNG). Specifically, the oculomotor portion of VNG testing, which includes saccade and smooth pursuit testing provides information regarding (a) the integrity of the central vestibular system (namely the brainstem and cerebellum) and (b) the structures of the eyes and corresponding muscles and ligaments and their concomitant physiological and neurological functions (Doettl et al[10]). Both saccade and smooth pursuit tests are predicated on a comparison with adult normative data, often embedded in VNG software. Pediatric test results cannot be directly compared with adult normative data because of incomplete maturation of the peripheral and central vestibular systems in pediatric population until adolescence, resulting in poorer performance in children than adults when testing using VNG (Cyr et al[7]; Fukushima et al[15]; Salman, Sharpe, Lillakas, et al[39]; Salman, Sharpe, Eizenman, et al[38]; Valente[42]; Doettl et al[10]).

Despite its clinical importance, there are few published normative data in children. Some explored younger age-groups (aged 4-6 years) (Doettl et al[10]) or older children (aged 7-19 years) (Accardo et al[1]; Salman, Sharpe, Eizenman, et al[38]); thus, the primary aim of this study was to fill this gap by collecting pediatric normative data for the oculomotor components used in VNG, namely, the saccade and smooth pursuit tests for children aged from 5 to 17 years. The outcome of the present study will improve the diagnostic accuracy and enhance the assessment of oculomotor and vestibular disorders, in the pediatric population.

Methods

This prospective analytic cross-sectional study was conducted over a period of 24 months at the Audiology and Balance Center at the American University of Beirut Medical Center after approval from the Institutional Review Board (part of AUB IRB #: OTO.KS.05).

Participants

A total of 120 healthy children were included in the study and segregated into 4 groups: 5-8, 9-11, 12-14, and 15-17 years old. Each age-group included 15 boys and 15 girls. The parent (or guardian) of each child signed a consent form approving the participation of their child in the present study. ►**Figure 1** describes the flowchart of the protocol followed to include the participants in the present study.

Case History

Using the audiology and balance center case history intake form, parents were asked a set of questions to confirm that the child had a "healthy" medical history at the time of participation and was fit to join the present study. The child was excluded from the study if the parent reported any history of otitis media, hearing loss, previous ear surgery, vision problems (based on pediatric vision screening performed by the child pediatrician during the academic year using Snellen visual acuity testing), general disorders (e.g., metabolic, neurological or vestibular, or genetic), skeletal malformation, meningitis, immune-deficiency disorders, delays in developmental milestones, cancer, or other relevant health issues.

Outer and Middle Ear Evaluation

The child was excluded from the study and referred to an otolaryngologist if the otoscopic examination showed any ear canal or tympanic membrane abnormalities (e.g., perforation, otitis externa, and otitis media). Because the previous literature described the effect of middle ear effusion and otitis media on balance in children (Golz et al[17]), immittance testing was performed. Only children with normal tympanic membrane mobility and presenting ipsilateral and contralateral acoustic reflexes at 500, 1000, and 2000 Hz were included in the study (GSI TympStar Middle Ear Analyzer v.2; Grason-Stadler, Eden Prairie, MN).

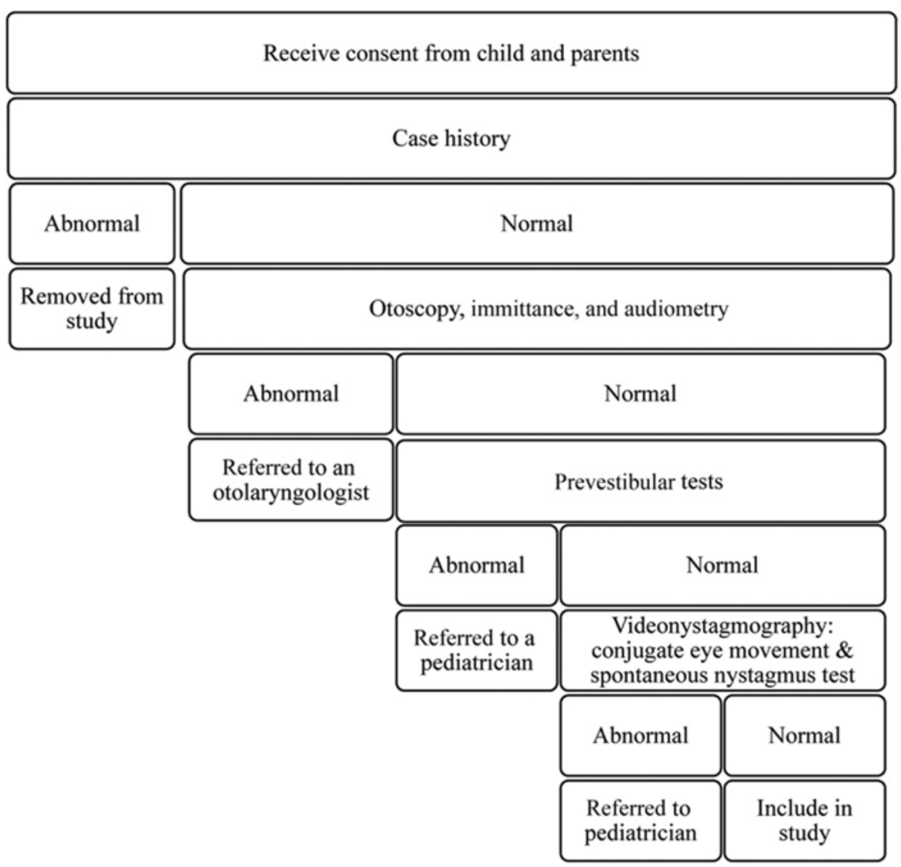

Fig. 1 Protocol followed.

Hearing Level Evaluation

A hearing screening was performed according to the clinical guidelines of the American Academy of Audiology for childhood hearing screening (American Academy of Audiology[2]). Because hearing loss can be associated with balance disorders (Cushing[6]) and prolonged latencies in saccade testing can be detected in hearing-impaired children (Selz et al[40]), any participant with hearing thresholds >15 dBHL across the frequencies (500, 1000, 2000, and 4000 Hz) or a significant air-bone gap was excluded from the study. Pure-tone air and bone-conduction thresholds were recorded (MADSEN Astera-2 audiometer; GN Otometrics, Copenhagen, Denmark) with insert earphones in a sound-treated booth.

Prevestibular Assessment

A prevestibular screening was conducted to verify that the child had a good overall balance. Four simple tasks were performed by the participant: (a) Romberg stance (children kept their feet close together, their arms at their sides, and their eyes open initially and then their eyes closed), (b) rapidly alternating movement evaluation, (c) point-to-point evaluation, and (d) tandem gait. Any deficit in performing these tasks might suggest a neurological or vestibular deficiency, and thus, the child was excluded from the study and referred to his/her pediatrician.

Vestibular Assessment

To evaluate vestibular weakness at the time of the study, bilateral caloric testing was performed afterward. The child was excluded if any unilateral or bilateral weakness was noted in the caloric results and referred to the otolaryngologist for further assessment.

VNG Calibration

The conjugate eye movement test was conducted. The camera was placed on the right eye except in cases when the participant indicated the "better eye" to be the left. VNG was recorded (Synapsys™ VNG system, Goggles Flex; VNS3X monocular camera; and Ulmer™ software, Marseille, France). The goggle had infrared sensors built in the mask. The child was seated on a chair 1.2 m away from a television screen that showed the projection, and the height of the chair was adjusted for the child to be at the center in front of the screen. Instructions were given and repeated to children before every subtest; they were asked not to reposition the goggles and to stay still during testing while following the white square with their eyes only. Some children were excluded from the study because of improper weight and size of the goggle (i.e., too big for them), failure to perform the calibration, or lack of cooperation. In case the examiner found that the tracking curve was inadequate, the child was reinstructed and the test repeated.

The first step in testing was to conduct calibration using a fixed saccade task to convert eye movement into a digital representation that can be analyzed by the computerized system and to calculate the conversion factor. Any error in this step would cause inaccuracy in measuring the amplitude of the eye movements and would affect all the other tests. The stimulus used for calibration was at 0.3 Hz frequency and 33° amplitude for a total of 30 seconds. Calibration was repeated in case of accidental removal of the goggle.

The second step was the gaze test, during which the child was asked to look at the center, right, and left at 30° angles for 30 seconds at each position. This task was repeated but with the vision denied (i.e., spontaneous nystagmus test) and followed by fixation (red light) to ensure the absence of central nystagmus. This test was considered normal if no nystagmus was recorded. If spontaneous nystagmus was detected, the examination was discontinued and the child was excluded from the study and referred back to his/her pediatrician.

Saccadic Eye Movement

Saccadic eye movement was evaluated using a random saccade test. The stimulus used for the randomized saccade was a horizontal visual target presented randomly at different angles in the range of 0-40° (to the left and right) and at a random frequency (maximum 0.3 Hz) for a duration of 30 seconds. Measurement parameters included saccadic latency, velocity, and accuracy/precision (►**Figure 2**).

Smooth Pursuit Eye Movement

The smooth pursuit stimulus used was a visual sinusoidal target moving horizontally from side to side at 0.3 Hz and recorded for 30 seconds (►**Figure 2**). The parameters studied in this test are velocity gain and asymmetry: gain is calculated as the ratio of the peak eye velocity over the peak target velocity. The gain of "one unit" indicates an eye velocity equal to the target velocity. Asymmetry is evaluated as the difference in velocity gain between the eyes while the eyes move toward the right and toward the left (expressed in percentage). If the child moved his/her eyes ahead of the target, the child was reinstructed and the test repeated until obtaining two full cyclic tracings.

Asymmetry between the right and left was computed in percentage for all parameters ofsaccades and smooth pursuit using the following formula: (right side value − left side

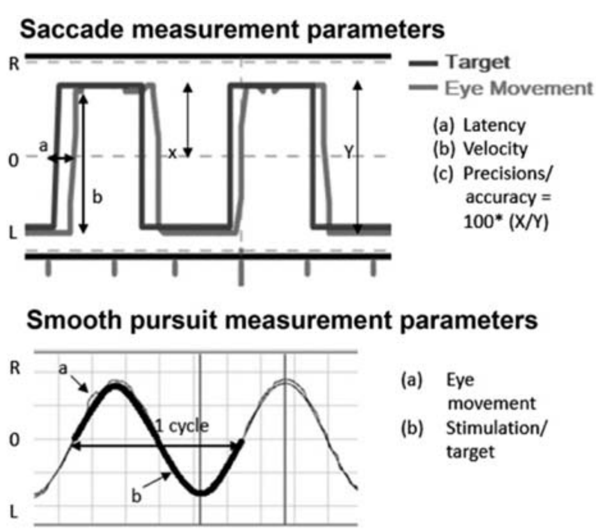

Fig. 2 Saccade and smooth pursuit measurement parameters.

Table 1 Normative Data of Oculomotor Tests in Children Aged 5-17 Years (Mean [± Standard Deviation])

		5-8 Years	9-11 Years	12-14 Years	15-17 Years
Saccade latency	Left	302.70 (±40.16)	274.63 (±19.86)	251.57 (±34.25)	255.73 (±34.23)
	Right	307.67 (±48.20)	277.40 (±24.01)	253.97 (±35.54)	257.53 (±33.77)
Saccade velocity	Left	332.57 (±51.92)	329.87 (±54.67)	332.47 (±67.20)	323.23 (±64.37)
	Right	336.80 (±55.87)	333.07 (±36.55)	335.63 (±55.69)	324.30 (±52.66)
Saccade accuracy	Left	95.13 (±5.91)	94.03 (±6.22)	93.40 (±5.15)	94.60 (±4.45)
	Right	95.03 (±6.28)	94.43 (±4.92)	92.77 (±5.87)	94.63 (±3.18)
Smooth pursuit gain	Left	0.63 (±0.15)	0.76 (±0.11)	0.78 (±0.13)	0.86 (±0.10)
	Right	0.63 (±0.17)	0.76 (±0.11)	0.76 (±0.11)	0.83 (±0.08)

value)/(total of both side). Other frequencies were not examined in the present study because of the lengthy time of our research protocol that might fatigue the participating children.

Statistical Analysis

Frequency means and standard deviation were used to describe the study sample. A two-way repeated measure multivariate analysis of variance was used to compare oculomotor findings across different age-groups. The independent variables included four different age-groups and the direction of stimulus (i.e., left and right). The dependent variables included saccadic latency, velocity and accuracy, and smooth pursuit gain. A p-value <0.05 was considered significant, and in case of significance, post hoc analysis including paired comparisons (i.e., Bonferroni correction) was conducted to analyze the differences across these age-groups. All statistical analyses were conducted using SPSS software V25 (IBM Corp., Armonk, NY).

Results

The findings in children aged 5-17 years for different saccades and smooth pursuit parameters are shown in ►**Table 1**. ►**Figures 3-5** show and summarize the effect of age and direction on the latency, velocity, and accuracy/precision parameters of the saccadic recordings, respectively. Statistical analysis of all the examined parameters across different age-groups showed significant findings only for saccadic latency. The mean latency changed across age-groups as shown in ►**Figure 3**. The comparison between groups showed a statistically significant difference between groups ($F = 12.77$, $p = 0.001$). Children of age-group 5-8 years had the longest latency compared with all the other age-groups (p for 9-11 years $= 0.017$, p for 12-14 years $= 0.001$, and p for 15-17 years $= 0.001$). Moreover, when comparing the middle groups (9-11 and 12-14 years old), the difference was also statistically significant ($p = 0.013$). No difference was noted when comparing the older groups (12-14 versus 15-17 years old). Direction left versus right had no significant effect on saccadic latency ($F = 2.143$, $p = 0.15$, partial $\eta^2 = 0.06$). Saccadic latency asymmetry ranged between 0% and 19%, and it was the same across age-groups ($p = 0.24$).

Results showed no significant effect of age ($F = 0.45$, $p = 0.50$, partial $\eta^2 = 0.01$) and direction (right versus left) ($F = 0.33$, $p = 0.79$, partial $\eta^2 = 0.03$) on saccadic velocity (►**Figure 4**), as well as no significant effect of age ($F = 0.04$, $p = 0.82$, partial $\eta^2 = 0.00$) and direction ($F = 0.95$, $p = 0.42$, partial $\eta^2 = 0.09$) on

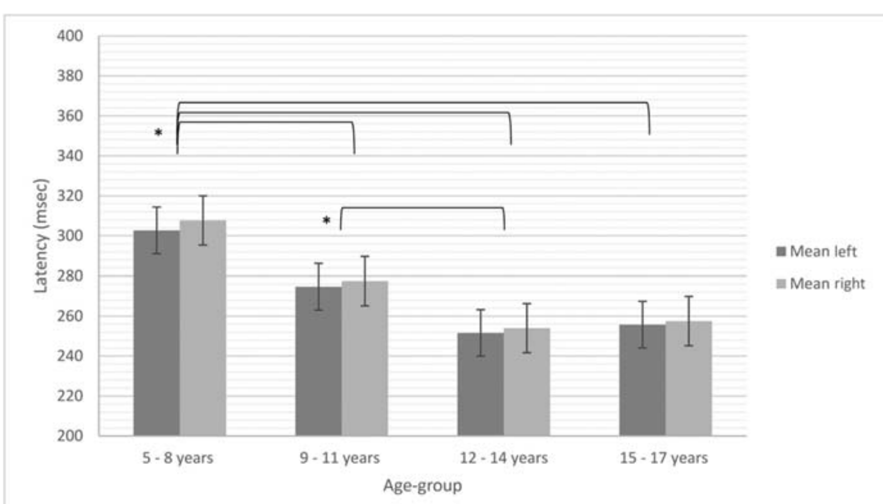

Fig. 3 Mean saccade latency values for the left and right for different age-groups (*represent statistically significant).

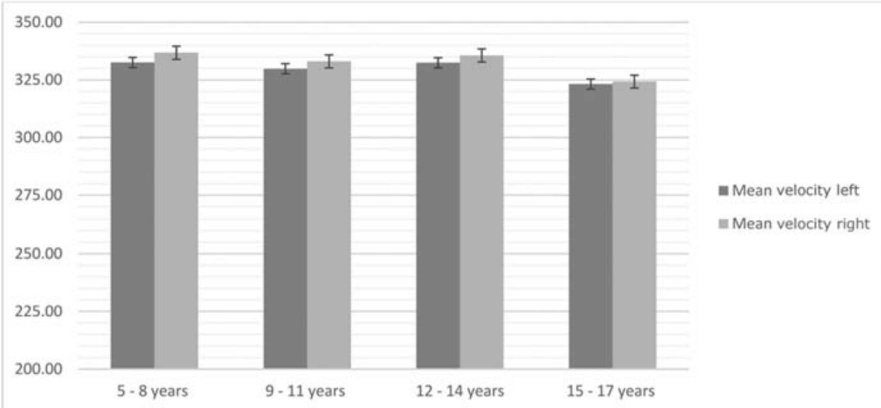

Fig. 4 Mean saccade velocity values for the left and right for different age-groups.

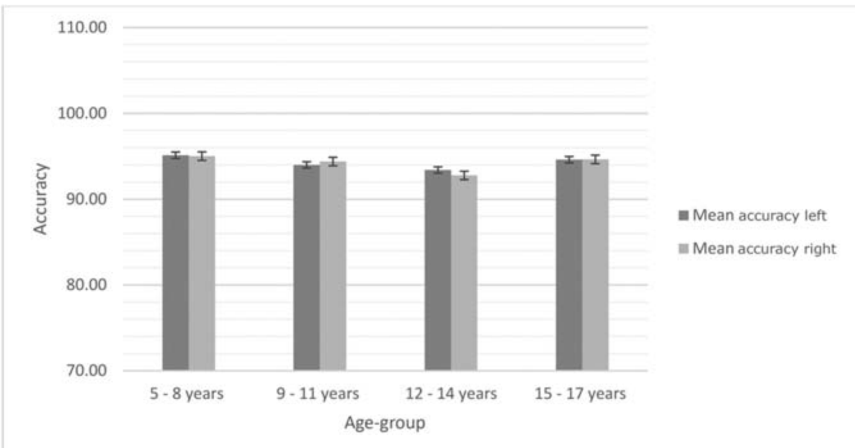

Fig. 5 Mean saccade accuracy values for the left and right for different age-groups.

saccadic accuracy (►**Figure 5**). Saccadic velocity asymmetry ranged between 0% and 20%, with the older group having the highest asymmetrical value (X^2 =17.73, $p = 0.001$). However, this age-group difference for asymmetry was not noted for saccadic accuracy/precision ($p = 0.292$).

►**Figure 6** shows and summarizes the effect of age and direction (left and right eye movement) on the gain parameter of the smooth pursuit recordings. Age had a significant effect on smooth pursuit gain ($F = 18.875$, $p < 0.001$, partial $\eta^2 = 0.67$), but direction did not have a significant effect ($F = 2.017$, $p = 0.16$, partial $\eta^2 = 0.06$). The youngest group (aged 5-8 years) also had a significantly lower mean gain compared with each of the other age-groups (p for 9-11 years $= 0.016$, p for 12-14 years $= 0.001$, and p for 15-17 years $= 0.001$). The 9-11 years old group and the 12-14 years old group were not significantly different ($p = 0.142$). In

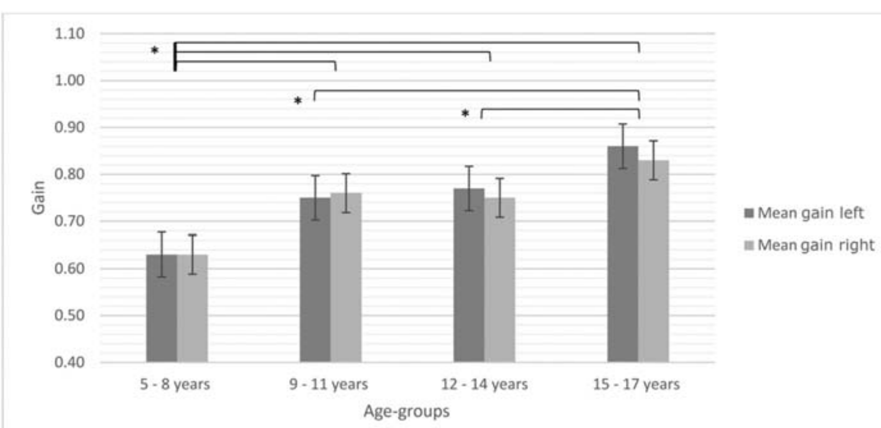

Fig. 6 Mean smooth pursuit gain values for the left and right for different age-groups.

addition, the smooth pursuit mean gain of the 15-17 years old group was significantly larger than the mean gain of the 9-11 years old group ($p = 0.02$) and larger than the mean gain of the 12-14 years old group ($p = 0.014$). The percentage of gain asymmetry varied from 0% to 26% across different groups, with the youngest having the highest percentage ($X^2 = 10.27$, $p = 0.016$). The difference between direction (left/right) was significantly different between the first two groups ($F = 4.49$, $p < 0.001$). Further statistical analysis using the chi-squared test showed that the left side was weaker than the right side in all age-groups except the 9-11 years old group ($X^2 = 7.946$, $p < 0.05$).

In summary, saccade parameters (latency, velocity, and accuracy/precision) were not affected by oculomotor direction (left versus right). Age affected the saccadic latency only but had no effect on velocity and accuracy/precision. Saccadic latency was longer in the group (aged 5-8 years) compared with the older children. Smooth pursuit gain was affected by age and increased from 0.63 to 0.85 but was not affected by direction.

Discussion

Infants have longer saccadic latencies of about 500 msec (Aslin and Salapatek[3]) that decreases from birth to adolescent and stabilizes throughout adulthood (Fukushima et al[15]; Irving et al[20]). In the present study, latency was longer with 307302 msec from 5-8 years of age to 257-255 msec for 15-17 years of age, similar to Doettl et al[10] who found that saccadic latencies were longer in pediatric participants (right 293 msec ± 45 and left 288 msec ± 54) in comparison with adults (right 246 msec ± 27, left 247 msec ± 36). The saccadic latency reached its lowest value in the age-group (12-14 years old), suggesting a possible maturation ofthe saccadic structures around mid-adolescence. This finding is similar to the suggested maturation age range for the saccadic structures reported in the literature: 12 years old (Fukushima et al[15]) and 14 years old (Irving et al[20]). The slight increase in saccadic latency that was found in the group (15–17 years old) was remarked by Salman et al[38] (saccade), who believed that adult normative values are not reached until the age of 19 years. It was hypothesized in the literature that the reason for the delayed development of saccadic latency can be beyond the oculomotor system (muscles and nerves) and possibly due to the central nervous system development such as the speed of neural processing that continues to undergo maturation and myelination later in childhood, as well as the long duration needed for the cerebral cortex to reach full development (Luna et al[26]). In addition to contributions from the development of the visual system, prefrontal function and cerebral cortex (Fukushima et al[15]; Klein and Foerster[22]; Yang et al[46]; Doettl and McCaslin[9]).

Anatomically, the burst neurons and omnipause neurons in the brainstem determine saccade velocity (Leigh and Zee[24]). The pattern of velocity in children is controversial compared with adults. In infancy, saccades are slower in comparison with adult values (Hainline et al[18]). Some studies have reported in children, saccadic peak velocities are higher than adults (Fioravanti et al[14]). Other studies found no change in saccadic velocity across different age-groups (Munoz et al[31]; Fukushima et al[15]; Luna et al[26]). Findings of Irving et al[20] showed an increase in peak velocity from 446°/second to 610°/second in children aged 3-14 years and assumed that it peaked around the age of 10-15 years then continues to decrease till the age of 86 years. However, Salman et al[38] (saccade) supported the idea that peak velocity approaches adult values at an earlier age and stays stable after that. The saccadic velocity noted has been previously explained because of naso-temporal differences and eye dominance (Vergilino-Perez et al[43]).

Saccadic accuracy/precision was not affected by age in the present study, suggesting an early maturation of the neural components responsible for saccadic accuracy/precision or at least minor changes in maturation across different age-groups. In infancy and early childhood, hypometria has been observed (Aslin and Salapatek[3]; Fioravanti et al[14]; Munoz et al[31]), but other studies showed that it stabilizes post-maturation at the age of ten years (Fioravanti et al[14]; Munoz et al[31]; Irving et al[20]).

Smooth pursuit movement improves throughout the early years of the child's life (Ross et al[35]). Rutsche et al[37] described an increase in smooth pursuit gain in children up to six years of age. This is possibly due to continued maturation of the temporal and cortical regions of the brain (Rütsche et al[37]). Accardo et al[1] reported a lower gain for children aged 7-12 years compared with adults (0.83 versus 0.95 at 0.4 Hz). A similar finding was reported by Doettl et al. Smooth pursuit gain was around 0.71 at 0.3 Hz in children aged 4-6 years in comparison with 0.91 in adults (Doettl et al[10]). In the population of the present study, smooth pursuit gain improved with age from 0.63 to 0.86. Smooth pursuit gain provides information regarding the integration of the cortical and cerebellar circuitries supporting the predictive processes (Rosander[33]). However, the maturation age of the smooth pursuit system is still not very clear and controversial. Katsanis et al[21] reported that smooth pursuit gain reaches adult values around 17-18 years of age, whereas Langaas et al[23] reported that children aged 5-7 years had adult gain value of 0.97 at 0.3 Hz. Finally, Salman et al[39] (smooth pursuit) hypothesized that mean smooth pursuit gain approaches adult values in mid-adolescence.

Anatomically, most aspects of oculomotor control (saccade and fixation system) continue to develop throughout childhood (Helo et al[19]). Development of structures involved in the saccade system starts in prenatal period and continues to mature until late adolescence. The different elements involved in the saccade circuits are extraocular muscles, cranial nerves 3: oculomotor (CN3) and cranial nerves 6: abducens (CN6), frontal eye field (FEF), dorsolateral prefrontal cortex, paramedian pontine reticular formation, caudate nucleus, superior colliculus, thalamus, parietal cortex, and visual cortex. The smooth pursuit track is adjacent to the saccade system track and overlaps in oculomotor muscles and nerves, visual cortex, and vestibular system (Fukushima et al[16]). Other pursuit areas include the cerebellar floccular region, dorsal vermis, caudal fastigial nucleus, medial superior temporal cortical area, caudal FEF, and dorsolateral pontine nucleus (Fukushima et al[16]).

The development of the extraocular muscles begins at three to four weeks of gestation age (GA) and are in their final anatomical positions by six months GA but do not mature until three to four months postnatal (da Silva Costa et al[8]). The somatic efferent cranial nerves CN3, derived from the basal plate of the embryonic midbrain, and CN6, rising from the basal plate of the embryonic pons, form during the fifth- and sixth-week GA and myelinate around six months GA and continue maturation up to two years ofage. The brainstem and cerebellum are almost fully developed and myelinated around the age of ten years (Barkovich[4]). However, the frontal, temporal, and posterior parietal cortices and the cerebral hemispheres continue to myelinate beyond adolescence until early adulthood (Barkovich[4]). The FEF effects are seen shortly after birth. However, the dorsolateral prefrontal cortex undergoes a prolonged maturation that lasts until adulthood. A mature caudate nucleus is established within the first week postpartum, and the lamination of the superior colliculus begins to emerge by 11 weeks GA and matures to full function by 20 weeks GA (Qu et al[32]).

Anatomical maturation is not the only influence on oculomotor test parameters. The difference (or drop) seen across parameters between the age-group 12-14 years and 15-17 years can be due to puberty at the physical level or the behavioral changes and attention maturation at this particular age (Fukushima et al[15]). Uncooperative participants and normal visual acuity (no correction needed) were recruitment challenges in the present study because of the increased prevalence of using spectacles to correct decreased visual acuity in children (Ertekin et al[11]). This increased prevalence of using spectacle in these children could be due to high school demands at this age or could be caused by the increased time of using computers and other technologies. Therefore, caution must be taken when applying the normative data reported in the present study on children with vision problems.

Conclusion

Saccade and smooth pursuit pediatric normative values help to interpret VNG results and facilitate diagnosis of different disorders (visual, vestibular, postural, neurological, and behavioral). Based on the methodology used (specific stimulus and VNG manufacturer) and on the normative data collected, a list of criteria is now considered by the authors for deciding the normality of random saccades in children: (a) saccadic latency within norms (217-355 msec age specific [Table 1]), keeping in mind that saccadic latency decreased with age; hence, any slow saccade should be reported as a possible indicator of central pathology or visual impairment; (b) fast saccadic velocity (>400°/second) or slow saccades (<200°/second) suggests the need for further assessment; (c) clean tracing with no clear asymmetrical saccadic movement to the left or the right with minimal overshoot/hypermetria or undershoot/hypometria repeated throughout the test, and in case of abnormality or an asymmetry, the test must be repeated after reinstructing the child. Abnormality in tracing is only reported if reproducible. Similar to the saccades criteria, the pediatric smooth pursuit tracing should be free of saccadic intrusions, spontaneous nystagmus, or asymmetry left/right. Abnormality is only reported when reinstructed result shows reproducible abnormal result. Moreover, the smooth pursuit gain should be age specific knowing that in our sample the gain increased with age.

Abbreviations

FEF	frontal eye field
GA	gestation age
VNG	videonystagmography

Notes

Partial data relevant to this research paper were presented as a poster titled “Normative Data of Saccades Test and Smooth Pursuit Test in Children Between 9 and 17 years of Age” during the 30th American Academy of Audiology Annual Conference, AAA 2018 in Nashville, TN, April 20, 2019.

Conflict of Interest

None declared.

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