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Maturation of Subjective Visual Vertical in Children

*†‡Michel Toupet, †§Christian Van Nechel, and ‡||Alexis Bozorg Grayeli

**Centre d'Explorations Fonctionnelles Otoneurologiques, Paris, France; †Institut de Recherche Oto-Neurologique (IRON), Paris, France; ‡Otolaryngology Department, Dijon University Hospital, and Burgundy University, Dijon, France; §Neurological Rehabilitation Department, Brugmann University Hospital, and Clinique des Vertiges, Brussels, Belgium; and ||CNRS, UMR-6306, Electronic, Image and Computer Research Laboratory, Dijon, France*

Objective: The attraction of the subjective visual vertical (SVV) to the side of initial rod presentation has already been described in adults. The aim of this study was to evaluate this phenomenon in children and to analyze the effect of sex and maturation in this population.
Study Design: Retrospective cross-sectional study.
Setting: Tertiary referral center.
Patients: Six hundred and one individuals aged between 4 and 19 years.
Intervention: All subjects underwent a complete balance workup. SVV was measured by presenting a laser line 12 times in total darkness with a 45 degrees deviation from the vertical alternatively on the left and the right. The patient was seated and asked to replace the bar vertically with a remote control.
Results: On average, SVV was tilted to the side of the rod presentation at each iteration. The cumulative tilt to the side of presentation after 12 measures was higher in the 4 to 7 years age group and decreased progressively with age (25 ± 2.2 degrees in 4–7 years, $n = 109$ versus 5 ± 1.4 in 15–19 years, $n = 204$, $p < 0.001$, analysis of variance [ANOVA]). The cumulative tilt was higher in girls than in boys in the 15 to 19 years group (8 ± 2.5 degrees, $n = 104$ versus 2 ± 1.2, $n = 100$, respectively, $p < 0.001$, ANOVA). This phenomenon appeared independent from the type of vestibular disorder.
Conclusion: Young children are highly attracted to the side of rod presentation during SVV measurements. This phenomenon gradually disappears with maturation, faster in boys than in girls. **Key Words:** Behavioral maturation—Central nervous system development—Sex difference—Visual dependency—Visuomotor tasks.

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Subjective visual vertical (SVV) is routinely used to assess the otolithic function (1–3). But this function encompasses a larger integrative function implicating proprioception and central processing mechanisms (4). Visuomotor tasks implicating the judgment of object or line orientation such as SVV appear to be under the influence of sex hormones (5–7). Women are reported to perform poorer in these tasks and to be more dependent on their visual context (8). Although many studies suggest that children have also a lower capacity in these tasks, due probably to the immaturity of their central nervous system, the influence of sex at early ages is unclear (8,9).

In a previous study, we showed that VVS was attracted to the side of bar presentation and this effect varied with age and sex (10). This phenomenon is probably related to short-term visual memory and similar to visual dependency at rod-and-frame test. We defined the effect as visual attraction, and showed that it was higher in children, teenagers, and senior patients in comparison to middle-aged adults (10). We also observed a higher attraction in women versus men. However, the relatively small number of children at early ages did not allow analyzing the possible influence of sexes. In this study, we studied a large number of pediatric patients to precise the effect of sex on the phenomenon in children before and after the age of puberty.

MATERIALS AND METHODS

Population

This retrospective study included 601 consecutive children and teenagers (age ranging between 4 and 19 years) admitted to a tertiary referral center for dizziness or for a balance test before job application between 2005 and 2015. The study was conducted according to the university ethical committee recommendations and a written consent was obtained in all cases from patients or their parents. The population comprised 317 boys and 284 girls (sex ratio: 1.11). The mean age was 12 ± 4.3 years. All patients underwent a thorough clinical examination including audiometry, postural control and positional testing, caloric, and rotatory tests, in addition to the evaluation of oculomotor function (gaze, saccades, pursuit). Diagnostic categories were based on patient's history and the above tests.

Address correspondence and reprint requests to Alexis Bozorg Grayeli, M.D., Ph.D., Dijon University Hospital, Otolaryngology Department, 2 Boulevard Maréchal Lattre de Tassigny, 21000 Dijon, France; E-mail: alexis.bozorggrayeli@chu-dijon.fr
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Concerning the job application group, French legislation requires that specific categories of workers performing on elevated positions undergo medical examination including vestibular tests. This category represented 19 individuals without any complaints and underwent all routine tests described above.

Similarly to other reports (11), unilateral loss or weakness was defined by a reduction of at least 30% of the maximal slow phase velocity of the nystagmus during the two caloric tests (44 and 30 °C) on one side in comparison to the contralateral ear. Bilateral loss was defined by a the maximal slow phase velocity of the nystagmus <3 degrees/s for all four caloric tests on both sides and for the rotatory chair.

The diagnosis of otolithic disorder was based on patients' descriptions (sensation of linear acceleration or displacement, of body takeoff, body penetration into the ground, out-of-body experience, room tilt illusion), and average SVV tilt without caloric deficit or abnormalities on clinical examination.

Ménières disease in this population mainly concerned teenagers (Table 1) and was based on American academy of Otolaryngology–Head and Neck surgery (AAO-HNS) diagnostic criteria and categorized as probable Ménière's disease in all cases. BPPV was diagnosed on typical diagnostic maneuvers and normality of all other clinical and vestibular tests. Benign paroxysmal vertigo of childhood (BPVC) was defined as an isolated recurrent vestibulopathy, a normal vestibular testing, and audiometry. Fainting, stress, and idiopathic categories were defined according to the description of the child and the parents. In these cases, audio-vestibular testing and clinical examination were normal.

Subjective Visual Vertical Tilt Measurements

The SVV tilt measurements consisted of presenting a red laser line measuring 1 m on a screen placed 2 m in front of a seated child in complete darkness. The child's head was not supported and he or she was instructed to keep the head straight. The line was presented with a 45 degrees deviation from the vertical, alternatively on the left and the right 12 times, beginning on the left. The patient was asked to place the line at the vertical each time using a remote control. The remote was held by the subject and there was no alignment between the interface and the line. The angle precision of the control was 0.1 degree. The subject remained in the dark between iterations. The 12 measures were completed in less than 5 minutes. Deviations of the rod from the vertical to the right were considered as positive, and those to the left as negative. The cumulative SVV tilt was defined as the algebraic sum of tilts between two consecutive SVV tilt measurements (in degrees) and calculated by:

$$\sum_{n=12}^{n=2}(\mathrm{SVV}_n - \mathrm{SVV}_{n-1}),$$

where n represents the iteration. The visual attraction index (VAI) was defined as the cumulative SVV tilt after 12 measures. A positive index indicated an average attraction toward the side of the initial presentation and a negative value an inverted effect.

Statistical Tests

Data were analyzed by Prism (Graphpad Inc., San Diego, CA, U.S.A.). Values were expressed as mean ± SD. Continuous variables were analyzed by two-way analysis of variance (ANOVA) followed by a Bonferroni or a Dunnett's posttest. A linear regression analysis was conducted for the cumulative SVV tilt. Slopes and intercepts were compared with an *F* test.

RESULTS

SVV Measurements and Population Characteristics

SVV measures were within the normal limits described for adults (0 ± 2.8 degrees including three standard

TABLE 1. *Diagnostic categories and subjective visual vertical tilt in children*

Etiology Categories	n (%)	Sex Ratio	Age	SVV Tilt
Perpheral disorders				
Caloric weakness	33 (7%)	0.94	11 ± 4.7	Right: 1.2 ± 2.12 (10) Left: −3.1 ± 2.45 (11)*** Bilat.: 0.1 ± 0.94 (4)
Cured BPPV	30 (6%)	1.31	12 ± 4.4	0.0 ± 1.26
Ongoing BPPV	18 (4%)	0.5	15 ± 3.3	Right: −0.5 ± 1.69 (4) Left: −0.2 ± 1.35 (8)
Otolithic syndrome	12 (2%)	2.00	12 ± 4.6	0.7 ± 2.93
BPVC	27 (6%)	0.69	8 ± 2.4	0.0 ± 1.95
Ménière	25 (5%)	2.12	14 ± 3.5	Right: 0.8 ± 0.71 (10) Left: 0.2 ± 1.11 (8)
Hearing loss	52 (10%)	0.73	10 ± 3.5	0.0 ± 1.60
Non peripheral disorders				
Migraine	115 (23%)	0.62	12 ± 3.7	0.1 ± 1.66
Head trauma	14 (3%)	0.55	11 ± 3.6	−0.3 ± 2.38
Fainting	28 (6%)	0.56	15 ± 2.4	0.4 ± 1.34
Stress	13 (3%)	0.62	14 ± 4.5	−0.3 ± 1.49
Idiopathic	30 (6%)	1.5	12 ± 4.4	0.0 ± 1.73
Miscellaneous	22 (4%)	0.47	11 ± 5.6	0.5 ± 1.74
Normal	73 (15%)	1.43	12 ± 4.4	−0.1 ± 1.30
Total	492	0.87	12 ± 4.3	−0.02 ± 1.64

Diagnostic was available in only 492 cases (82%). BPPV, benign positional paroxysmal vertigo; BPVC, benign paroxysmal vertigo of childhood; SVV, subjective visual vertical.

***$p < 0.001$, unpaired *t* test.

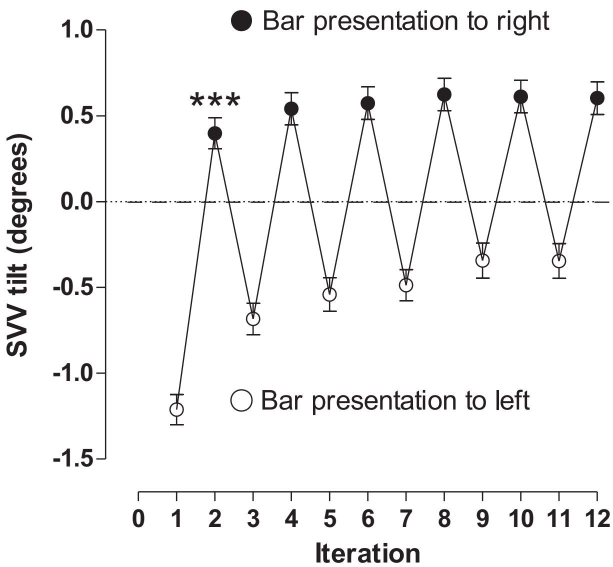

FIG. 1. Subjective visual vertical (SVV) measurements as a function of iteration. SVV was measured by presenting the bar alternatively to the left (*open circles*) and the right (*black circles*) 12 times. Negative values represent deviations to the left and positive to the right. SVV was tilted to the side of the bar presentation ($p < 0.001$, paired t test for right versus left presentation, n = 601).

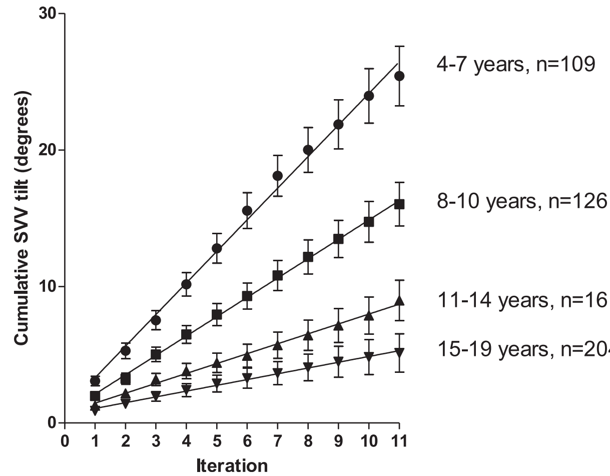

FIG. 2. Cumulative (SVV) tilt as a function of iteration in four age groups. Cumulative SVV tilt increased linearly in all four groups: $y = 2.3x + 1.0$, n = 109 for 4 to 7 years, $y = 1.4x + 0.7$, n = 126 for 8 to 10 years, $y = 0.7x - 0.7$, n = 161 for 11 to 14 years; and $y = 0.4x + 0.6$, n = 204 for 15 to 19 years, $R = 0.99$ for all regression lines. The progression of cumulative tilt with iteration was faster in younger children ($p < 0.001$, F test for comparison of slopes).

deviations [12]). Average SVV values did not vary with age in the diagnostic category designated as ''normal'' (Table 1): 0.3 ± 1.6 degrees (n = 14) for 4 to 7 years old, −0.3 ± 1.2 (n = 12) for 8 to 10; −0.3 ± 1.3 (n = 25) for 11 to 14; and 0.1 ± 1.2 (n = 22) for 15 to 19 (not significant, ANOVA). This normality was observed in all etiology categories except for unilateral weakness where SVV was tilted to the side of the weakness as expected (Table 1). Average SVV measures did not differ between boys and girls regardless of etiology (0.1 ± 1.56, n = 317 versus −0.13 ± 1.71, n = 284 respectively, not significant, unpaired t test).

Tilt Toward the Side of Bar Presentation

On average, SVV was tilted to the side of the rod presentation at each iteration (Fig. 1). This effect persisted up to 12 iterations and the cumulative SVV tilt progressed linearly with iterations in all age groups and in both sexes suggesting that the effect does not fade with iteration (Fig. 2). The linear progression was faster in young children in comparison to teenagers (Fig. 2): the highest VAI was observed in the 4 to 7 years group and decreased progressively with age (25 ± 2.2 degrees in 4–7 years group, n = 109; 16 ± 1.6 degrees in 8–10, n = 126; 9 ± 1.5 degrees in 11–14, n = 159 and 5 ± 1.4 degrees in 15–19, n = 204, $p < 0.001$, one-way ANOVA).

In the two younger groups (4–7 and 8–10 years), VAI was similar between the two sexes (26 ± 3.8 degrees, n = 48 for girls versus 26 ± 3.1, n = 61 for boys between 4 and 7 years; and 14 ± 2.2, n = 65 for girls versus 18 ± 2.4, n = 61 for boys in the 8–10 years group, not significant, unpaired t test, Fig. 3). But in older children and teenagers, VAI was higher in girls than in boys (11 ± 2.0 degrees, n = 99 for girls versus 4 ± 1.9 degrees, n = 60 for boys in the 11–14 group and 8 ± 2.5 degrees, n = 104 in girls versus 2 ± 1.2 degrees n = 100 in boys, $p < 0.05$, unpaired t test, Fig. 3). It should also be pointed out, that in the 8 to 10 years group, the regression line for boys had a steeper slope than for girls ($p < 0.01$, F test, Fig. 3) even if the VAI and the cumulative tilt values did not differ (not significant, unpaired t test). This suggests a tendency for these boys to have higher cumulative tilt values than girls. VAI was neither influenced by the etiology (one-way ANOVA, not significant, Table 2), nor by the average SVV (simple regression analysis, data not shown).

DISCUSSION

In this study, we showed that SVV estimation was largely influenced by the side of bar presentation in children, and that this influence did not decrease with 12 iterations. The effect was predominant in young children between 4 and 7 years of age and decreased in older age groups. The etiology of dizziness did not seem to interfere with this phenomenon. There was a significant difference between boys and girls in terms of visual attraction: although, in young children there was no influence of sex on the visual attraction, in teenagers this effect became prominent in girls. It should be pointed out that our population, which was a heterogeneous cohort does not represent children with normal vestibular function.

A phenomenon equivalent to visual attraction has been largely studied by the ''rod-and-frame'' test (5,10). The position of a tilted frame constantly present on the screen

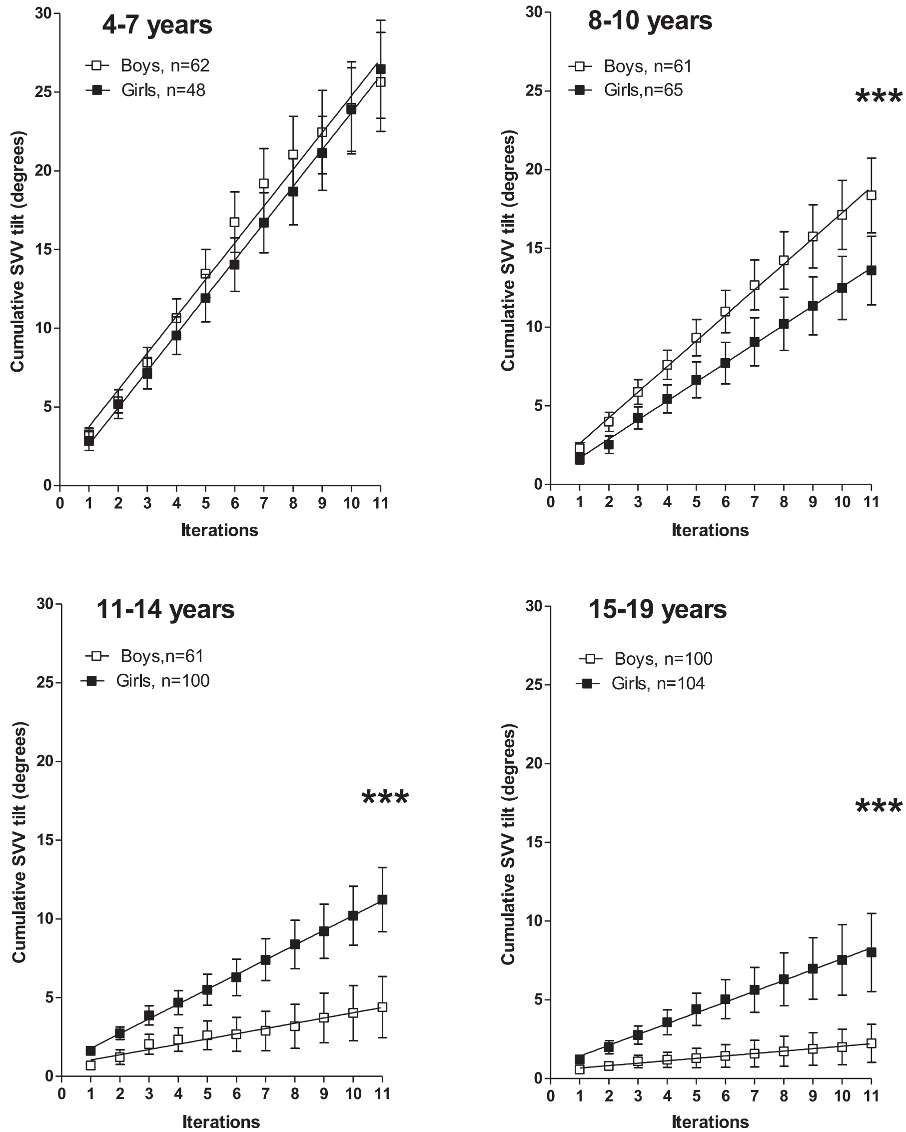

FIG. 3. Cumulative SVV tilt as a function of sex in the four age groups. Cumulative SVV tilt progressed equally in both sexes in 4 to 7 age group ($Y = 2.3X + 1.4$, $R = 0.99$, n = 62 for boys and $Y = 2.3X + 0.3$, $R = 0.99$, n = 48 for girls, not significant for comparison of slopes, F test). It progressed faster in boys than in girls in the 8 to 10 years age group ($Y = 1.6X + 1.0$, $R = 0.99$, n = 61 for boys and $Y = 1.2X + 0.5$, $R = 0.99$, n = 65 for girls, $p < 0.0001$, F test for comparison of slopes). For older age groups, the opposite occurred and cumulative SVV increased faster in girls than in boys (for 11–14 years, $Y = 0.3X + 0.7$, $R = 0.98$, n = 61 for boys and $Y = 0.9X + 0.8$, $R = 0.99$, n = 100 for girls, $p < 0.0001$, F test for comparison of slopes, and for 15 to 19 years, $Y = 0.2X + 0.5$, $R = 0.99$, n = 100 for boys and $Y = 0.7X + 0.7$, $R = 0.99$, n = 104 for girls, $p < 0.0001$, F test for comparison of slopes).

influences the estimation of the vertical and is defined as visual dependency. In our protocol, the initial position of the bar does not persist physically. Hence, the visual attraction can be explained by the fact that the initial position of the rod is memorized and interferes with the estimation of the vertical. The short-term visual memory appears as the most plausible mechanism of the visual attraction effect in SVV measurement (for review see [13]).

The effect of age on visual dependency has already been reported: children rely more heavily on the visual frame of reference for processing spatial orientation cues. However, the influence decreases with age without reaching the expected adult values (6).

The effect of sex on visuomotor skills has also been documented. The role of sex has been advocated in inter individual differences of the short-term visual memory and visiomotor tasks (8,13). Evaluation of tasks involving visual capacity by the mirror box illusion test (14), mental rotation test (15), judgment of line orientation (16) also provide arguments in favor of sex differences in terms of visuomotor capacities.

Rod-and-frame test, or the body-steadiness test (standing steady in the presence of an unstable visual field),

TABLE 2. *VAI in different etiologies*

Etiology Categories	N (%)	Sex Ratio	Age	VAI
Peripheral disorders				
Caloric weakness	33 (7%)	0.94	11 ± 4.7	14 ± 16.9
Cured BPPV	30 (6%)	1.31	12 ± 4.4	5 ± 29.4
Ongoing BPPV	18 (4%)	0.5	15 ± 3.3	8 ± 17.0
Otolithic syndrome	12 (2%)	2.00	12 ± 4.6	10 ± 18.7
Ménière	25 (5%)	2.12	14 ± 3.5	2 ± 9.2
Hearing loss	52 (10%)	0.73	10 ± 3.5	25 ± 25.1
Non peripheral disorders				
Migraine	115 (23%)	0.62	12 ± 3.7	12 ± 19.4
BPVC	27 (6%)	0.69	8 ± 2.4	17 ± 22.3
Head trauma	14 (3%)	0.55	11 ± 3.6	15 ± 19.0
Fainting	28 (6%)	0.56	15 ± 2.4	7 ± 13.4
Stress	13 (3%)	0.62	14 ± 4.5	17 ± 21.7
Idiopathic	30 (6%)	1.5	12 ± 4.4	15 ± 20.9
Miscellaneous	22 (4%)	0.47	11 ± 5.6	15 ± 26.9
Normal	73 (15%)	1.43	12 ± 4.4	11 ± 23.6
Total	492	0.87	12 ± 4.3	12 ± 21.3

BPPV indicates benign positional paroxysmal vertigo; BPVC, benign paroxysmal vertigo of childhood; VAI, visual attraction index.

show that women are more field dependent than males and more affected by the context in which the item is presented during childhood (8–17 years) but also in adults (5).

By exploring the visual dependency by a rod-and-frame test in large cohort of children from 7 to 12 years old, Bagust et al. (6) showed that at corresponding ages, women tended toward larger alignment errors than males. This effect appeared to be independent from the age in their study. By increasing the age span in our study, and by using the visual attraction index, we could observe that differences between boys and girls for this visuomotor task appear and increase gradually with age.

In a previous study (10), we reported the influence of age and sex in a large population ($n = 6{,}931$) predominantly composed of adult patients (mean age 55 years). We showed that the phenomenon of visual attraction was maximal in both age extremes and that in young and mid-aged adults (20–50 years) the attraction was negligible in both sexes. This observation suggested that the capacity of eliminating the visual attraction is slowly acquired with age and readily lost after the age of 60 years. But in the first report, we could not observe an influence of sex on the visual attraction in children due to the small size of our samples. The present study provides us with additional information on the influence of sex and age in a large group of children: we observed that girls appear to reduce their visual attraction more slowly than boys after the age of 11.

The etiology did not seem to influence VAI even in the otolithic disorder category defined clinically (Table 2). Since this cohort covers a 10-year period, oVEMP and cVEMP were not performed in earlier cases and this could represent a limitation. Another explanation for not having systematic oVEMP and cVEMP was the young age of our patients and technical difficulties in obtaining reliable results in this population.

The exact pathophysiological mechanisms of sex influence on visuomotor tasks are still unclear. Several studies in adults suggest a role of progesterone and/or estrogen impregnation in these capacities and the modulation of these cerebral performances by the hormone levels during the menstrual cycle (15–17). Other observations on mental rotation tasks are in favor of differences between sexes appearing as early as 3 months after birth and persisting during the lifespan and point toward sex-related mechanisms other than sex hormones (18). Although differences between sexes in visuomotor tasks are small if present during childhood (6), the visual attraction index seems to differ largely between boys and girls appearing at the age of puberty.

In conclusion, SVV is highly influenced by the side of the rod presentation. This phenomenon, which we defined as the visual attraction did not fade with iteration. Girls appeared to have higher visual attraction than boys between 11 and 19 years. Visual attraction index decreased with maturation in both sexes.

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