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# Vestibular assessment with Balance Quest Normative data for children and young adults

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**Summary**

*Objective:* The purpose of the present study was to compare equilibrium pattern in 12-year-old children with 20-year-old young adults and to obtain normative data for the BQ in both groups.
*Methods:* Mean stability percentages and synthesis ratios of 29 healthy children aged 12 years were compared to those of 68 young adults aged 20 years, using BQ.
*Results:* The mean stability percentages for children were significantly lower than for young adults. Vestibular ratios were lower in children compared to young adults, whereas somesthesic ratios were similar for the two groups. Visual dependence was significant higher in children.
*Conclusions:* Children unlike young adults had lower stability percentages when visual information was not available or was incorrect. Ratio synthesis pattern was different in the two groups. Our results on BQ partially confirms previous results obtained in children assessed with Equitest CDP. This study also provides BQ normative data for these two age groups.

## 1. Introduction and purpose

The efficiency of postural control has been closely associated with the ability to correctly perceive the environment through peripheral sensory systems. The sensory information that is responsible for this control is somatosensory, visual, and vestibular in origin. In order to maintain postural control under a

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variety of environmental conditions, motion information from sensory systems must be organized by the central nervous system.

Computerized Dynamic Posturography (CDP) through the Equitest (Neurocom International, Clackamas, OR) has been world widely accepted for the assessment of balance control. An extensive literature has confirmed the contribution of CDP in the diagnosis of balance disorders [1—6].

During Equitest CDP testing the subject stands on a movable, dual forceplate with rotation (toes up-down) and translation (forward—backward) capabilities to measure the vertical forces exerted by the patient's feet under the precise control of a computer. The subject is asked to maintain normal standing balance during varying conditions by altering the visual field of the subject and/or the support surface on which the subject is standing. CDP can impose varying conditions on the subject, simulating the varying conditions one might encounter in the environment, and record the resulting postural responses. The computer processes signals from the force-sensing support surface to quantify the subject's postural stability under modified sensory conditions and the motor reactions to unexpected perturbations. The result is an objective measurement of the subject's balance system through the evaluation of three parameters: 1 — Sensory Analysis (SA) with Sensory Organization Test (SOT); 2 — Motor Control Test (MCT); 3 — Adaptation Test (ADT). The SA objectively identifies problems with postural control by assessing the patient's ability to make effective use of (or suppress inappropriate) visual, vestibular, and proprioceptive information. The MCT assesses the patient's ability to quickly and automatically recover from unexpected external perturbations. The ADT assesses the patient's ability to modify motor reactions and minimize sway when the support moves unpredictably in the toes-up or toes-down direction.

Micromedical Technologies (Chatham, IL) has developed the Balance Quest (BQ) (so called Multitest Equilibre, Framiral, Cannes France). It is a diagnostic medical technology designed to mimic the natural range of motion available in the human body more closely than other systems currently available. According to Micromedical Technologies, "when the platform center support is released from its static position, it essentially floats on a spring suspension allowing dynamic motion with 6 degrees of freedom of movement. BQ platform allows linear movement in X (forward/backward); Y (side to side); and Z (up/down) planes. There are three axes of angular movement allowed: Yaw (twist clockwise/counter clockwise); Pitch (tilt forward/backward); Roll (tilt left/right). The Balance Quest software measures center of pressure in the X, Y, and Z planes plus pitch and roll axes for unparalleled information about the direction and amplitude of sway" (http://www.micromedical.com/quest.htm).

Visual surround motion is controlled by a full field optokinetic ball projector which is able to turn horizontally leftward and rightward.

This platform allows an assessment of the vestibular influence on postural stability (stability

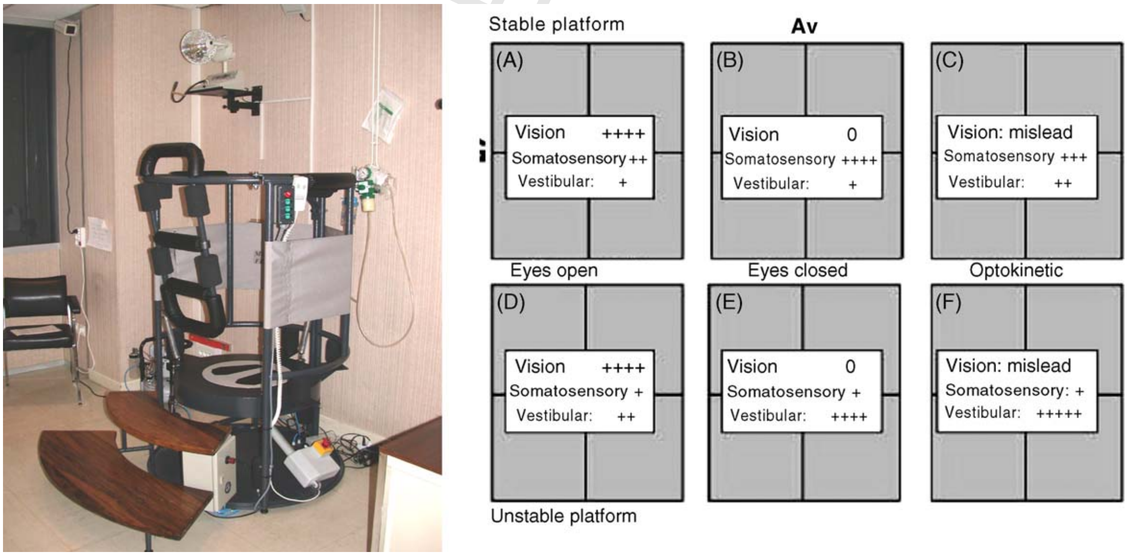

**Fig. 1** Balance Quest System and scheme with the six sensory conditions; Algorithms. Algorithms used to calculate Synthesis ratios — provided by Framiral, Cannes, France — http://perso.wanadoo.fr/framiral/multi_gb.htm. Somatosensory = (surface A/surface B) *k*1 (*); visual = (surface A/surface D) *k*2 (*); vestibular = (surface A/surface E) *k*3 (*); visual dependence = [(surfaces C + F/surfaces B + E) *k*4] — 1 (*), where *k*1, *k*2, *k*3, *k*4 are the coefficients provided by manufacturer; (*) except in case of fall.

scores) with and without the influence of vision and perturbing proprioception and, therefore, to assess the synthesis sensorial ratios. Photography of the BQ is provided in Fig. 1 together with the six assessment conditions scheme.

While Equitest CDP was been used extensively in balance assessment and normative data are available [7—10], little to no normative data are available for BQ, particularly for children. Therefore, the purpose of this study was to compare equilibrium pattern provided by BQ, in children aged 12 years with young adults of 20-year old, in whom vestibular system maturation is presumed to be complete.

## 2. Methods

### 2.1. Population and enrollment

Twenty-nine children (12 females and 17 males) aged between 11 and 12 years (11.9 ± 0.1) and with normal ear status were recruited for enrollment. Normal health and hearing status were assessed by the school medical staff. All of the children followed their course work in a regular classroom. Mean height and weight (mean ± S.E.) were 148.60 ± 5.4 cm and 45.1 ± 3.0 kg, respectively.

Sixty-eight healthy young adults with normal ear status were recruited for enrollment (40 females and 28 males). All of the young adults were students at the Medical University of the Hospital. Mean age was 20.1 ± 0.2, mean height was 170.5 ± 1.1 cm and mean weight 62.5 ± 3.1 kg (Table 1). The study was approved by the Ethical Committee.

All included subjects met the same inclusion criteria used by Neurocom when provided normative data for Equitest: 1 — no current or past medical diagnosis or injury affecting balance; 2 — no use of medication affecting the CNS or known to affect balance/coordination; 3 — no symptoms of dizziness or light-headedness; 4 — no symptom suggestive of vestibular or neurological disorders; 5 — no psychological disorders including depression; 6 — no history of two or more unexplained falls within the past 6 months; 7 — normal vision with or without glasses.

**Table 1** Characteristics of the two studied groups (mean ± S.D.)

| | Group 20-year old | *p* | Group 12-year old |
|---|---|---|---|
| Age | 20.1 ± 0.2 | <0.0001 | 11.9 ± 0.1 |
| Height (cm) | 170.4 ± 1.1 | <0.0001 | 148.6 ± 5.4 |
| Weight (kg) | 62.5 ± 3.1 | <0.0001 | 45.1 ± 3.0 |

S.D.: standard deviation.

If the subject responded to these criteria, he or she was eligible for the study, the details of the study were described, and written informed consent was obtained.

### 2.2. Testing procedures

A standardized history was obtained to verify if criteria for the two enrolled groups were respected. Since it is known that otitis media in children could affect postural stability, actual otological data were collected prior vestibular assessment [10]. Normal hearing status was assessed by otoscopy and by recording Transiently Evoked Otoacoustic Emissions (TEOAEs). Subjects were excluded if one of the seven inclusion criteria was lacking or if TEOAEs were abnormal.

Dynamic Posturography was performed using the BQ. The platform was placed in a room large enough to prevent acoustic spatial orientation. The subject was positioned on the platform with feet aligned parallel and shoulder-width apart (between 10 and 32 cm) and was instructed on safety procedures and equipment on the BQ. Recordings was performed in quiet standing position during six standard conditions: A — eyes open, stable platform (SP); B — eyes closed (SP); C — visual disorientation (optokinetic field) (SP); D — eyes open, unstable platform (UP); E — eyes closed (UP); F — visual disorientation (optokinetic field) (UP). "stable platform" refers to the conditions where the BQ dynamic platform is maintained in a static, stable position. During this condition, the subject received no additional or incorrect information to their somatosensory system while maintaining their balance. "unstable platform" refers to the conditions where the BQ platform is allowed to free-float in all axes during the completion of that section of the balance assessment protocol. The platform responded to changes in weight transfers and shifts in the subject's center of pressure (COP) while the subjects attempted to maintain their balance. This condition increased the demand on the subject's visual and vestibular systems to maintain balance (scheme Fig. 1). Trials in B and E conditions, were conducted in complete darkness. For conditions C and F, optokinetic stimulation was performed in a horizontal direction moving 15 s to the left and 15 s to the right. The optokinetic stimulation was projected on a wall at a distance of 250 cm from the subject's eyes. Optokinetic ball projector turned with 15° per second angular speed. Visual reference including room's geometry (e.g. corners, light spots under the door) was not allowed. Completion of one assessment session included the successful completion of one trial for each of the six conditions listed above. Each condition lasted for the duration of 30 s with a 15 s rest between each condition. Subjects' stability and primary gaze position were monitored by an infrared camera placed overhead in a superior and lateral position.

## 2.3. Data analysis

For each of the six recording conditions, the following parameters were calculated for the two groups: 1 — percentage stability. On the Balance Quest platform the percentage stability ($\theta$) for each condition is computed using this formula: $\theta = [(100 - \sigma x)/100] \times [(100 - \sigma y)/100]$ where $x$, $y$ represents the subjects deviations in anterior—posterior and lateral direction and $\sigma x$, $\sigma y$ vary from 0 to 100. The results were expressed as percentages, with 0 indicating sway exceeding the limit of stability (fall) and 100% indicating perfect stability; 2 — the average speed of center of pressure (COP) sway (cm/s); 3 — the surface area of the COP displacement ($\text{cm}^2$); 4 — sensory synthesis: the respective percentage of somatosensory, visual, and vestibular sensory inputs involved in balance control throughout the six conditions. These ratios were computed as follows (Fig. 1):

$$\text{Somatosensory} = \frac{\text{surface A}}{\text{surface B}} \times k1$$

$$\text{Visual} = \frac{\text{surface A}}{\text{surface D}} \times k2$$

$$\text{Vestibular} = \frac{\text{surface A}}{\text{surface E}} \times k3$$

$$\text{Visual dependence} = \left(\frac{\text{surface C} + \text{surface F}}{\text{surface B} + \text{surface E}} \times k4\right) - 1,$$

where $k1$, $k2$, $k3$, $k4$ are normative data coefficients provided by the manufacturer after performing assessments on 100 healthy adults. According to Balance Quest's manufacturer, these coefficients are available for all subjects weighting 25—100 kg.

**Table 2** Normative values in the two studied groups (mean ± S.D.)

| | Age (year) | | |
|---|---|---|---|
| | 20 | 12 | |
| Condition A | | | |
| Stability percentage | 95.4 ± 0.2 | 94.8 ± 0.6 | ns |
| Sway speed | 0.1 ± 0.008 | 0.08 ± 0.002 | ns |
| Surface area of COP | 0.67 ± 0.8 | 0.97 ± 0.3 | ns |
| Condition B | | | |
| Stability percentage | 94.9 ± 0.3 | 94.2 ± 0.5 | ns |
| Sway speed | 0.2 ± 0.01 | 0.14 ± 0.02 | ns |
| Surface area of COP | 0.94 ± 0.1 | 1 ± 0.2 | ns |
| Condition C | | | |
| Stability percentage | 93.5 ± 1.4 | 87.8 ± 1.8 | $p = 0.02$ |
| Sway speed | 0.2 ± 0.02 | 0.5 ± 0.15 | $p = 0.01$ |
| Surface area of COP | 1.2 ± 0.2 | 7.2 ± 3.0 | $p = 0.003$ |
| Condition D | | | |
| Stability percentage | 93.8 ± 0.3 | 90.3 ± 0.7 | $p < 0.0001$ |
| Sway speed | 0.2 ± 0.02 | 0.2 ± 0.04 | ns |
| Surface area of COP | 1.3 ± 0.1 | 2.5 ± 0.4 | $p = 0.0005$ |
| Condition E | | | |
| Stability percentage | 84.4 ± 1.0 | 80.2 ± 1.5 | $p = 0.02$ |
| Sway speed | 1.2 ± 0.1 | 1.2 ± 0.3 | ns |
| Surface area of COP | 9.4 ± 1.1 | 13.6 ± 2.1 | ns ($p = 0.06$) |
| Condition F | | | |
| Stability percentage | 84.9 ± 1.2 | 73.4 ± 3.1 | $p < 0.0001$ |
| Sway speed | 0.9 ± 0.1 | 1.4 ± 0.4 | ns ($p = 0.09$) |
| Surface area of COP | 10.0 ± 1.9 | 28.1 ± 6.9 | $p = 0.0007$ |
| Synthesis ratios | | | |
| Somatosensory | 74.6 ± 3.7 | 85.5 ± 4.5 | ns |
| Visual | 97.9 ± 1.4 | 100.0 ± 0.0 | ns |
| Vestibular | 88.9 ± 2.7 | 82.3 ± 5.7 | ns |
| Visual dependence | 50.6 ± 8.5 | 73.3 ± 4.2 | $p = 0.009$ |

These coefficients are not height-dependent (http://perso.wanadoo.fr/framiral/multi_gb.htm last web access 11/25/05). The visual dependence represents the degree to which a patient relies on visual information to maintain balance, even when the information is incorrect. ''visual dependence'' in BQ synthesis analysis has the same clinical significance as ''visual preference'' within Equitest sensory analysis. However, seen the differences between the algorithms, 100% visual preference signifies a very good visual integration with Equitest, while 100% visual dependence within BQ, represents a poor visual cue efficacy in the balance control.

## 3. Results

All subjects have successfully pass the BQ assessment. Equilibrium parameters (mean ± S.D.) recorded during the six conditions for the two groups are given in Table 2 and Fig. 2, respectively. There was no significant difference between the stability percentages obtained in conditions A and B, although 12-year-old children recorded lower values (Fig. 2). Results were significantly different between the two groups in conditions C, D, E, and F where 12-year-old children obtained lower percentage stability than the 20-year-old adults ($p = 0.02$, $p < 0.0001$, $p = 0.02$, and $p < 0.0001$, respectively).

Sway velocity recorded during the six conditions in the two groups are shown in Fig. 3. Results were significantly different between the two groups only in condition C, that is, the 12-year-old children had higher sway velocity than the young adults ($p = 0.01$). Results did not reach significance in condition F, although in children sway values tended to be higher than in young adults ($p = 0.09$).

Surface area for the COP displacement during the six conditions in the two groups is shown in Fig. 4. The children had significantly higher COP surfaces in conditions C, D, and F ($p = 0.003$, 0.0005 and 0.0007, respectively) and the analysis approach significance for E condition (0.06).

Sensory synthesis data are presented in Fig. 5. Compared to 20-year-old adults, the children had higher somatosensory and visual ratios but lower vestibular performance, though not significant. Visual dependence score was statistically greater in children ($p = 0.009$).

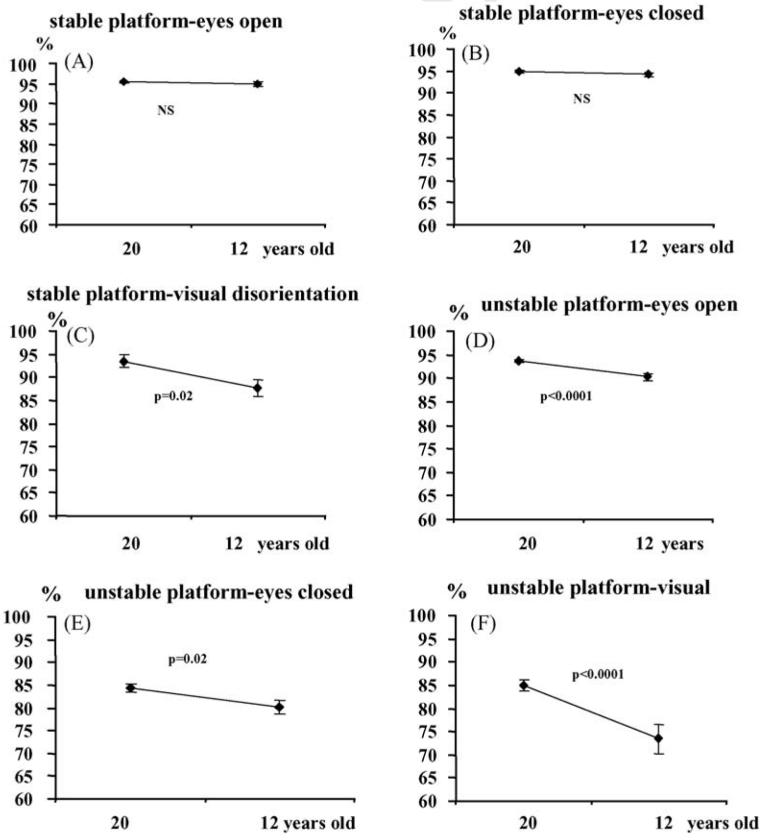

**Fig. 2** Stability percentages (%) (mean ± S.E.) of each age group in each condition (S.E.: standard error). (A) Stable platform — eyes open; (B) stable platform — eyes closed; (C) stable platform — visual disorientation; (D) unstable platform — eyes open; (E) unstable platform — eyes closed; (F) unstable platform — visual.

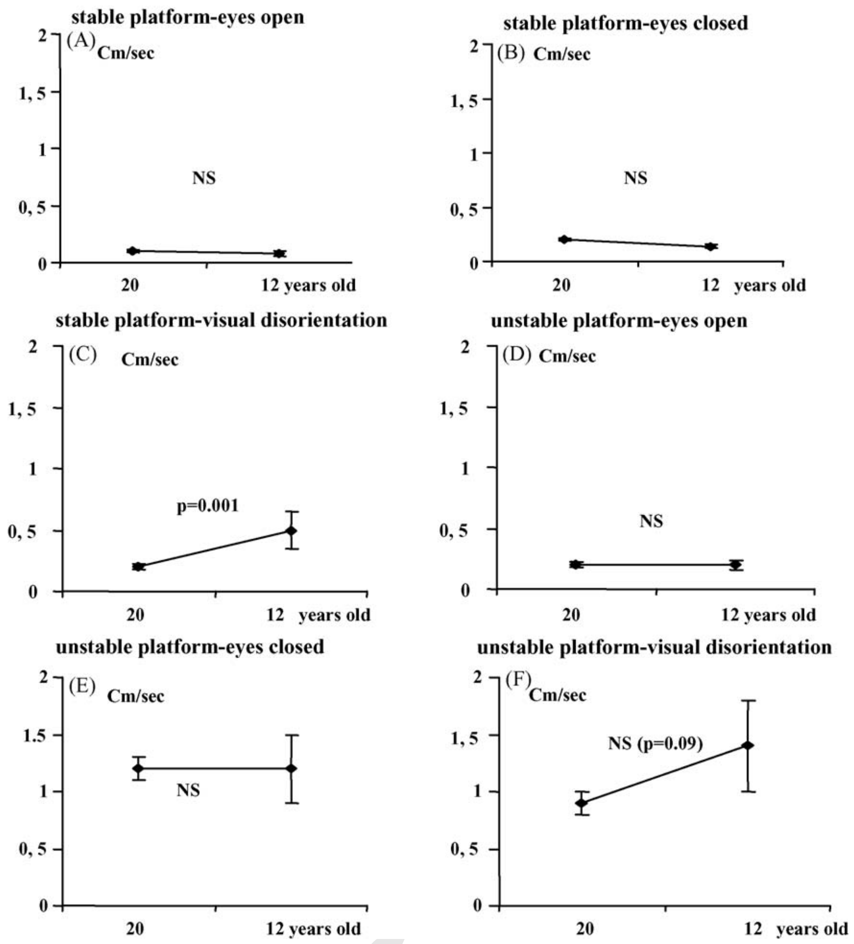

**Fig. 3** Sway velocity (cm/s) (mean ± S.E.) of each age group in each condition. (A) Stable platform — eyes open; (B) stable platform — eyes closed; (C) stable platform — visual disorientation; (D) unstable platform — eyes open; (E) unstable platform — eyes closed; (F) unstable platform — visual disorientation.

## 4. Discussion

BQ device evaluates globally the postural balance in static and dynamic conditions. Although BQ differs in some ways with the Equitest CDP device (e.g., in conditions C and F vision is not sway referenced) the use of this platform has some advantages. First in unstable conditions all degrees of freedom are allowed on the BQ platform which is acting as a force platform and should be more sensitive than other similar devices. Second, the optokinetic field projections in conditions C and F represent a strong stimulus for the peripheral vision which is thought to be involved in balance control, especially in children [11—15].

In summary, there are three main differences between the two devices: (1) for the last three conditions of the assessment, the BQ platform is free floating in all planes of the space, whereas the Equitest platform is sway referenced in anterior—posterior and up-down directions only; (2) the conflicting vision condition on the BQ is provided by randomly moving lights projected in front of the patient while for the same condition on the Equitest platform the patient's vision is completely sway referenced; (3) vestibular parameters on the two platforms are *not* computed using the same algorithms: Equilibrium scores on Equitest are calculated from the maximum anterior and posterior angle sway compared to the theoretical limits of stability (8.25° anterior, 4.25° posterior) [16,17] while on BQ stability percentages ($\theta$) are computed as given in "data analysis". Furthermore, while within Equitest Sensory Analysis is computed using equilibrium scores (%), the BQ algorithm use sway displacements (cm$^2$) to obtain its specific synthesis ratios.

CDP is often used together with other clinical tests to identify sensory input deficit in adults, but its use in children has not been widely reported. Moller et al. [18] have used posturography to identify sensory-based balance in children suffering

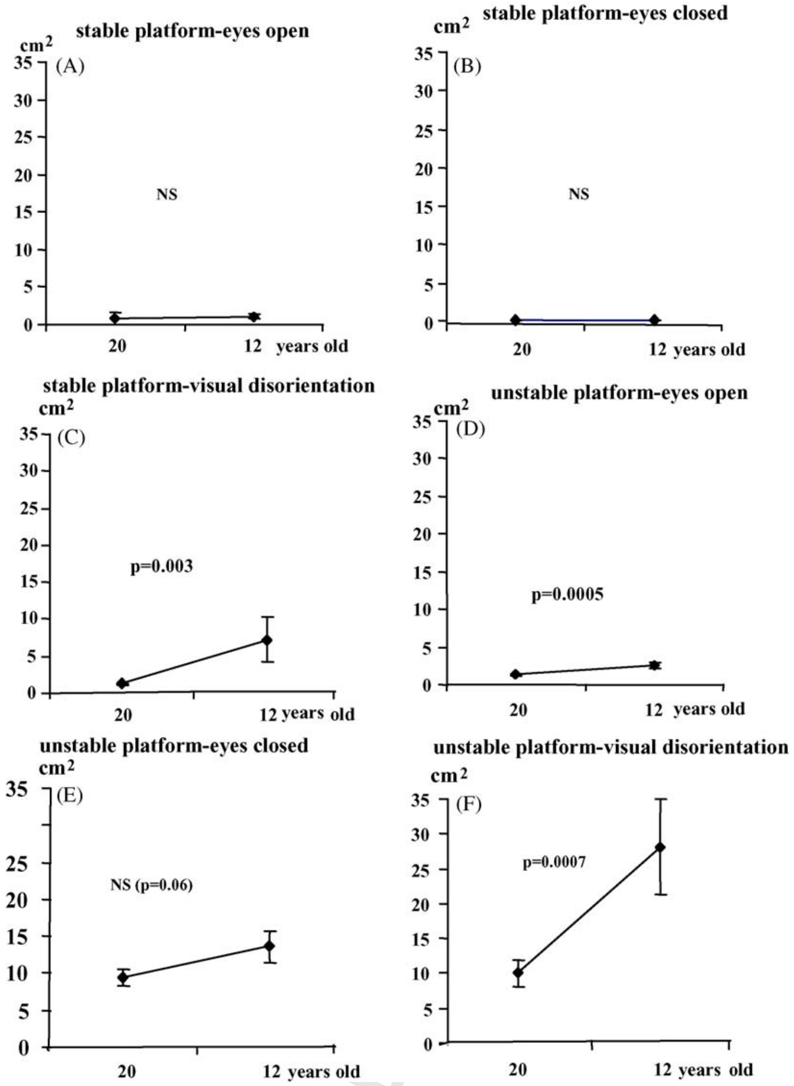

**Fig. 4** Surface area for COP displacement ($cm^2$) (mean ± S.E.) for each age group in each condition. (A) Stable platform — eyes open; (B) stable platform — eyes closed; (C) stable platform — visual disorientation; (D) unstable platform — eyes open; (E) unstable platform — eyes closed; (F) unstable platform — visual disorientation.

from Usher's syndrome (congenital syndrome including profound hearing loss, absence of vestibular response and retinis pigmentosa). In this study, children were compared to adult subjects because normative data were not available for children tested with the Equitest. Foudriat et al. [8] completed Equitest CDP testing on children aged 3—6 years. These authors concluded that the transition to adult-like balance responses is not complete for all sensory condition by age six. They also emphasized that in children visual inputs predominate over somatosensory information. Therefore, they speculated that, unlike adults, in children afferent contributions of the somesthetic system are seriously limited when visual information is available. Similar conclusions were reached by Cherng et al. [19] when comparing young adults (19—23-year old) to children (7—10-year old) equilibrium scores on Equitest. According to these authors, functional efficiency of the vestibular system in children of 10 years of age is still developing.

Hirabayashi and Iwasaki [9] compared sensory organization control through groups of children from the first grade of kindergarten (3 or 4 years of age) to the third grade of junior high school (14—15 years of age) to that of adults (20—60-year old). The lower equilibrium scores he observed in children were interpreted as reflecting immaturity of the basic neuro-muscular mechanisms involving both the sensory and motor processes. They stressed that: 1 — children aged 3—4 years showed levels of somatosensory function equivalent to the adults; 2 — the visual function develops more slowly, the children aged 14—15 years having the same levels as the

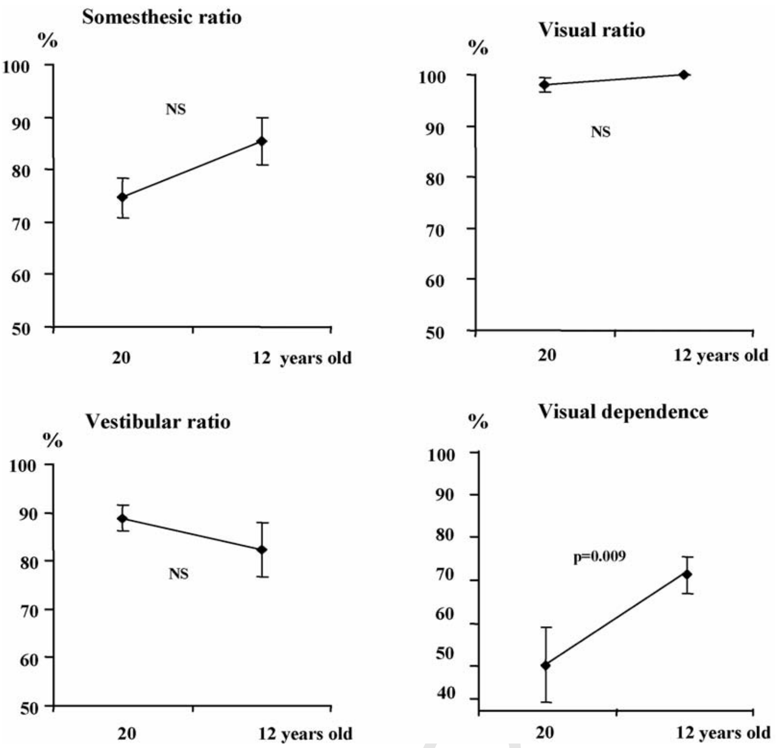

**Fig. 5** Synthesis ratios (%) (mean ± S.E. of each age group).

adults; 3 — the vestibular function develops more slowly than visual function, so even at the age of 14—15 years tested subjects did not completely reach the adults levels.

Shumway-Cook and Woolacott [20] using a movable platform capable of antero-posterior (A-P) displacements, proposed that at the age of 7—10 years the response pattern became close to that of adults, suggesting that by this age maturation of organization process required to integrate sensory inputs had occurred.

Recently, Hatzitaki et al. [21] using another platform force device, in a study which included 50 children, considered that 11—13-year-old boys have the ability to select varying balance strategies just like adults.

Despite's the inadvertences between the results of these five studies, we could expect that transition to an adult-like vestibular pattern may occur through the age of 12—13 years. This is the reason we choose to evaluate with the BQ vestibular parameters in 12-year-old children and to compare to 20-year-old subjects vestibular performances.

In the present work, children demonstrated lower stability scores (conditions C, D, E and F), remarkable highs mean values for the visual ratio (100 ± 0%) but also greater visual dependence than adults. It is known that in case of an inter-sensory conflict, the vestibular system acts as a referential function by suppressing input not congruent with vestibular information [9]. Due to a presumed mature vestibular function, even with misleading visual information, adults may improve their postural control. This leaded us to speculate that still may be an incomplete development of the balance control in children up to age 12. Therefore, it can be postulated that children by age 12 are still not able to select and process misleading visual information, which could be overcome in the adult group. Following Hirabayashi and Iwasaki [9] our results suggest that such a maturation process occurs more slowly, and continues throughout childhood, at least through the age of 12 years.

Despite technological differences between the two devices, our preliminary results on Balance Quest confirm those previously reported on Equitest: younger children often lose their balance under conflicting sensory conditions. This fact was reflected in our 12-year-old group by normal visual ratios (even higher than in adults) associated to a strong visual dependence. This predominant visual involvement in balance control in children needs to be investigated further since it has been shown that in children, ocular disorders are often responsible for balance abnormalities [22]. The authors reported that 5% from 523 children referred during 5 years for vestibular testing had no pathologic findings other than ocular disorders. For this reason, children with vertigo or dizziness but with normal neurological findings, and no obvious vestibular or otological disorders after vestibular testing should undergo complete ocular testing before performing cerebral MRI.

## 5. Conclusions

In our study the 12-year-old children showed globally lower stability percentages compared to young adults. Although visual and somatosensory stability percentage and sensorial ratios are as good in children as in young adults, their sensory organization was different. While visual ratios were very similar, in children the somatosensory ratio was greater while vestibular ratio was lower. Children were obviously more visual dependent than adults. Although still immature at age 12, it can be speculated that: 1 — children preferred visual inputs to vestibular information in achieving their postural equilibrium; 2 — between three sensory inputs in children, vestibular system seems to be the less effective in postural control. Despite various differences between the two platforms, our results obtained with the BQ platform strengthen previous authors' conclusions on Equitest, that in the balance sensorial control hierarchy somatosensory inputs are primary in adults while vision predominates in children. This study also provides BQ normative data for 12-year-old children and 20-year-old adults, which has not been reported previously.

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