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ORIGINAL ARTICLE

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The effects of maturation on self-induced dynamic body sway frequencies of girls performing acrobatics or classical dance

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Abstract We investigated the effects of maturation on the dynamic body sways of healthy girls. Prepubertal and postpubertal girls practising professional physical activities requiring a good ability to maintain equilibrium (acrobats and dancers) were asked to stand on a free seesaw platform and the results compared to those for untrained age-matched girls. This platform (stabilometer) allows self-induced body sways. Stabilograms were obtained by a double integration of the angular acceleration from the recordings of the platform sways made with an accelerometer. Fast Fourier transform processing of stabilograms allowed spectral frequency analysis. The total spectrum energy and the energies of three frequency bands (0–0.5 Hz, 0.5–2 Hz, 2–20 Hz) were determined. ANOVA showed that, for all groups of different equilibrium activity and independent of visual input, prepubertal girls had higher energy values than postpubertal girls in the 0- to 0.5-Hz band whereas the opposite was true for 0.5- to 2-Hz band. Ballet dancers were more dependent than acrobats on visual inputs for the regulation of their postural control but were less dependent than untrained girls at both ages. Maturation seemed to shift body sways towards higher frequencies and the utilization of the cues of postural control was different according to the type of equilibrium activity practised by the subjects.

Key words Equilibrium · Body sway frequencies · Dynamic balance · Physiological maturation · Professional classical dancers · Acrobats

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Introduction

There have been few studies dedicated to the neurophysiological characteristics of the dynamic equilibrium of adolescents. With servo-controlled unstable platforms, Müller et al. (1992) studied the influence of various "postural sets" on stance-stabilizing electromyographic (EMG) responses in children aged 1–10 years. They found that the basic organization of stance-stabilizing responses and their modification by postural sets remain invariable during development. These authors suggested that the relevant organizational principles are present as soon as a child is able to stand upright, and are not further developed by motor learning. The only significant change in the organizational pattern of long-latency EMG responses is a decline in the amplitude and duration in the older age groups (9–10 years). Similar findings were reported by Shumway-Cook and Woollacott (1985). A similar, but improved, organization of long-latency responses was also found by Berger et al. (1985). These studies consisted of subjecting a given postural system to a transient external disturbance, and analysing the resulting reactive responses. We used a different approach to study equilibrium control, an approach which is less invasive for children because it does not involve recording an EMG. Our method (Bessou et al. 1988) is based on the postural activities in response to self-induced body oscillations on a free, unstable platform. This method is simple and allows the longitudinal study of postural control for each year of growth in adolescence. Nevertheless, the present study, like previous studies, is cross-sectional because it is a preliminary investigation with this approach. To assess the effect of maturation on dynamic postural control and to specify differences between different professional activities requiring a good ability to maintain equilibrium, we studied prepubertal and postpubertal untrained and athletic girls. Only girls were studied to avoid gender-related effects, which have been previously described (Golomer and Monod 1995).

Methods

Subjects

To study maturational effects, two groups of different ages were used: 46 11-year-old prepubertal girls and 35 18-year-old postpubertal girls. An age of 18 years was selected as being representative of the postpubertal phase, consistent with a previous study which showed a delay in equilibrium maturation in ballet dancers (Golomer 1995). The two groups of girls were further subdivided into three categories: untrained subjects, dancers and acrobats. The untrained subjects, in good health (without acute or chronic abnormalities of locomotor and/or neural systems), were age matched with dancers and acrobats and are considered as control subjects. The mean (SD) ages, heights and body mass were: 10.8 (1.1) years, 143.7 (7.2) cm, 39.2 (8.5) kg for the 12 prepubertal girls, and 19.7 (2.6) years, 166.4 (6.7) cm, 57.9 (7.5) kg for the 11 postpubertal girls. The dancers were students of classical dance with 1 or 2 years of professional training [18 prepubertal girls: 11.9 (1.1) years, 148.8 (7.3) cm, 36.1 (5.1) kg], or professional dancers with the Paris Opera with 1 year of professional activity [16 postpubertal: 17.4 (1.1) years, 165.0 (4.6) cm, 47.0 (4.7) kg]. The acrobats were trampoline athletes with 2 years of national training [16 prepubertal: 12.5 (1.5) years, 147.3 (9.4) cm, 39.8 (7.8) kg] and international trick riding and "acrosport" athletes [8 postpubertal: 18.1 (3.1) years, 161.0 (5.6) cm, 55.6 (5.4) kg].

Biomechanical factors linked to age (particularly mass and height) were tested for correlation with each dynamic equilibrium variable to verify if these factors were involved in the postural control.

Experimental design

The dynamic balance conditions were assessed by asking the subject to stand upright on the platform of a seesaw (stabilometer); a photograph of the subject-platform system has been published previously (Golomer and Monod 1995). The stabilometer consisted of a platform (40 cm × 40 cm) with a cylindrical curved base (radius of base curvature, $r = 55$ cm). This base contacts the ground via a 40-cm segment of line called the "pivot" (generator of the cylinder). The equilibrium established is dynamic because the pivot is not fixed to the ground at any point. On this stabilometer, the subject cannot stand still but has to adjust their posture continuously to maintain balance. Body sways are considered self-induced because the geometrical conception of the platform creates a natural instability without any exterior perturbation: the support area becomes a line and the centre of gravity of the examined subject is above the centre of rotation of the platform (55 cm). The platform is free and consequently the subject is responsible for both its unsteadiness and its steadiness. In order to avoid falling, several body modules are used to balance. Body adjustments involve the main articulations: neck, hip and ankle, according to the postural control of both visual, vestibular and proprioceptive systems.

Four experimental conditions were studied: two visual (eyes open versus eyes closed), for each of two positions (anteroposterior versus lateral tilts). As the stabilometer has only one degree of movement liberty, subjects have two positions. When the frontal plane of the subject is perpendicular to the pivot of the platform, lateral body oscillations can be analysed and when their frontal plane is parallel to the pivot platform, anteroposterior body oscillations are tested. The subject, with straight legs and with arms placed alongside their body, stood in the middle of the platform, with their feet positioned at the centre of gravity of the platform. Heels were separated by a distance of 4 cm to increase instability. During the test, the subject was instructed to maintain the platform as horizontal as possible. During eyes-open tests, the subjects looked at an eye-level target at a distance of approximately 2 m. Only one trial without recordings was allowed for each subject prior to the first test to minimize the learning effect, as described in similar experiments by Costes-Salon (1987).

Recordings and data analysis

The tilts of the platform performed by the subject were recorded every 10 ms by an angular accelerometer. For each test, body sways were recorded for 25.6 s (the period the computer could process is short but sufficient in view of the difficulty of the test in term of mental concentration). Linear displacements of the pivot were obtained by double integration of the angular acceleration of the platform. The graphical representation of these displacements plotted against time constitutes the stabilogram. The total length of the pivot displacement (PDL) of the platform (total distance rolled by the cylinder along the ground) was calculated as the absolute value of the sum of pivot elementary displacements. This variable correlates with the amplitudes and sway frequencies of the platform (Costes-Salon 1987; Dupui et al. 1990).

The frequency spectrum of the platform oscillations was calculated from 0 Hz to 20 Hz (total energy of power spectrum, volts^2) by a Fast Fourier transform (FFT). Horack and Nashner (1986) showed different muscular latencies according to different strategies of postural sway. This led Dupui et al. 1990 to divide the total energy of the power spectrum into three bands, i.e. 0–0.5, 0.5–2 and 2–20 Hz, to facilitate the attribution of the observed values to the main regulation loops involved in the postural control. The PDL and frequency values were subjected to an appropriate variance analysis (ANOVA) to compare the different experimental conditions. Four-factor ANOVA was used: the factors were age (two levels: pre and postpubertal), equilibrium activity (three types: untrained, dancers and acrobats), position on the platform (two levels with repeated measures: anteroposterior and lateral sways), vision (two levels with repeated measures: eyes open and eyes closed).

Multiple correlation techniques were used to test for correlations between equilibrium variables and anthropometrical characteristics linked to age (height and weight).

Results

Correlations

Equilibrium variables did not correlate with anthropometric characteristics; this result shows that height and mass do not modify the postural control. As the prepubertal groups of acrobats or dancers are both selected on the basis of their professional status and as the height and mass are not involved, differences in postural control between age groups were due to body maturation.

PDL values

The PDL values were linked to the visual input: PDL values were significantly higher when the eyes were closed than when open ($F = 632$, $P < 0.001$). The values were independent of the position of the subject on the platform and of the degree of maturity. There were no differences between the three groups for equilibrium activity ($F = 3.2$, $P < 0.05$).

The power spectrum

The total energy of the power spectrum was independent of the position of the subject on the platform. For this parameter, the effects of the eyes being open or closed and the differences between the equilibrium activity groups were statistically significant ($F = 374$, $P < 0.001$ and $F = 16.7$, $P < 0.001$ respectively). Independently of whether the eyes were open or closed, the results for the equilibrium activity groups were significantly different: the acrobats had the lowest values and the untrained subjects the highest. The interaction between vision and equilibrium activity was statistically significant ($F = 52$, $P < 0.01$). The dependence on vision of the regulation of equilibrium by the dancers was less than that of the untrained subjects, but more than that of the acrobats. By contrast, the degree of maturity had no significant effect on the total energy of the power spectrum. The analysis of this parameter measured for the anteroposterior sway showed the same results.

The energy for the 0- to 0.5-Hz band

Figure 1 shows the values of the lateral sway energy for the spectral band of 0–0.5 Hz for the equilibrium activity of prepubertal and postprepubertal girls. The results for equilibrium activity groups were significantly different ($F = 13.2$, $P < 0.001$): the values for the untrained subjects were higher than those of the dancers, and the acrobats' values were lower than those of the dancers. The degree of maturity had a poorly significant effect: only $P < 0.05$ and $F = 5.7$ in isolation. The visual factor had a large effect ($F = 266$, $P < 0.001$), which interacted with the degree of maturity and the equilibrium activity. There was a significant interaction between vision and age ($F = 4.2$, $P < 0.05$) – this result showed that the effect of the visual input was greater in prepubertal subjects than in postpubertal girls in all equilibrium activity groups. The significant interaction between vision and equilibrium activity ($F = 8.4$, $P < 0.001$) showed that the effect of the visual input was more pronounced in untrained girls than in girls who regularly practised a physical activity. Similar results were found for the anteroposterior sway measurements.

The energy for the 0.5- to 2-Hz band

Figure 2 shows the average energy measured in lateral sway experiments for the 0.5- to 2-Hz band for the three equilibrium activity groups at the two different ages (values were statistically similar for the two positions). For all equilibrium activity groups and both visual input conditions, age had a significant effect ($F = 7.4$, $P < 0.01$): prepubertal group values were lower than postpubertal group values. The visual factor had a highly significant effect ($F = 245$, $P < 0.001$) that was dependent on both the degree of maturity and equilibrium activity. There was a significant interaction between the visual input and age ($F = 5.9$, $P < 0.05$): the difference caused by having the eyes closed or the eyes open was greater in prepubertal than in postpubertal girls, in all the equilibrium activity groups. The visual input significantly interacted with training ($F = 7.3$, $P < 0.05$) such that the difference caused by having the eyes closed or open was most pronounced for untrained subjects.

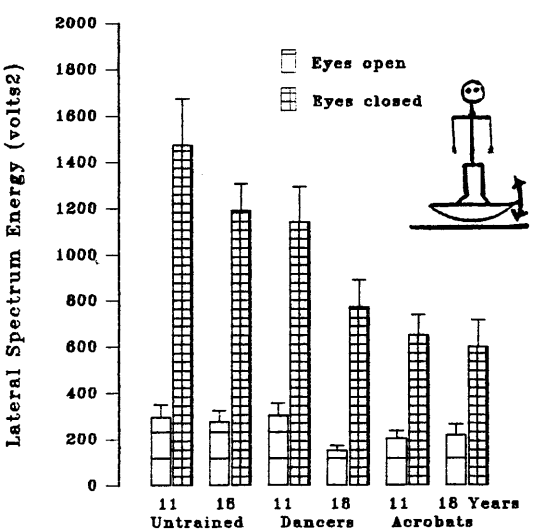

Fig. 1 Means (SD) of energy (volts^2) for the 0- to 0.5-Hz frequency band, under eyes-open and eyes-closed conditions, in lateral sway experiments, for the groups of 11-year-olds, i.e. untrained girls ($n = 12$), dancers ($n = 18$) and 15 acrobats ($n = 15$) and the groups of 18-year-olds, i.e. untrained girls, ($n = 11$), dancers ($n = 16$) and acrobats ($n = 8$)

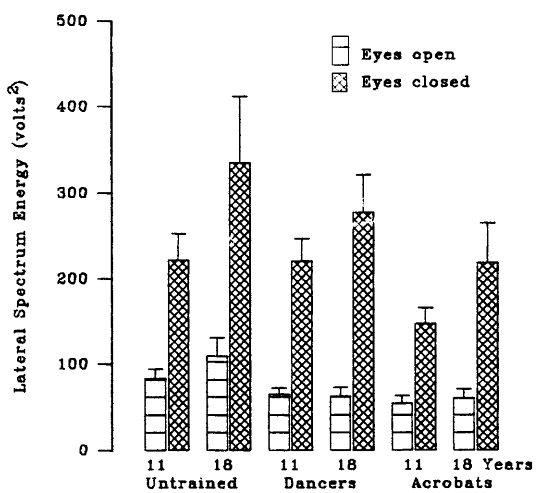

Fig. 2 Means (SD) of energy (volts^2) for the 0.5- to 2-Hz frequency band, under eyes-open and eyes-closed conditions, lateral sway experiments, for the groups of 11-year-olds, i.e. untrained girls ($n = 12$), dancers ($n = 18$) and acrobats ($n = 15$) and for the groups of 18-year-olds, i.e. untrained girls ($n = 11$), dancers ($n = 16$) and acrobats ($n = 8$)

The energy for the 2- to 20-Hz band:

Maturation had no direct effect on this variable and there were no significant differences between groups (not shown).

Discussion

Influence of maturation

For all frequency bands and for the three groups of equilibrium activity, the effect of the visual input was greater for the prepubertal girls than for the postpubertal girls. This implies that visual cues are more important for children than for adults, as Hertogh et al. (1994) have shown in static equilibrium experiments. The unstable platform used in our study can be considered as a device inducing proprioceptive perturbation, showing that children are more sensitive than adults to somesthesic perturbations (Hytönen et al. 1993). In the frequency band from 0 to 0.5 Hz, the spectrum energy was higher for prepubertal than postpubertal girls, whereas in the frequency band from 0.5 to 2 Hz prepubertal group values were lower than postpubertal group values. Thus, for girls standing under unstable conditions, the main sway frequency is lower before puberty than after. In terms of postural control, a low frequency of sway indicates that children use long-loop reflexes until puberty and that maturation shortens such loop responses, with a consequent increase of body sway frequency. This is consistent with the findings of Berger et al. (1985), who analysed the EMG responses of the leg muscles following perturbations of stance and gait in children aged between 1 and 8 years. They thereby assessed the development of the reflex systems involved in the compensatory movements necessary to maintain body equilibrium. From 4 years old, the polysynaptic reflex response became shorter and a reciprocal mode of leg muscle activation developed with a consequently more rapid and effective compensation for perturbations.

Postural control and different equilibrium activities

The effects of maturation were better appreciated in terms of frequency analysis and the differences in postural control in girls practising different types of equilibrium activities were better assessed in terms of total spectrum energy, which is independent of age. Prepubertal female acrobats had lower values than dancers, which reveals that the former group has lower amplitude body movements. As this was a cross-sectional study, this result may be due to two factors: heredity or training. Assuming training to be responsible, the early age at which training starts (5 or 6 years old) for at least 1 h a week, and the type of training (beam exercises) are presumably the main factors that improve the ability to maintain equilibrium. These exercises involve using the equilibrium systems of the whole body, from the ankle upwards, to avoid falls and improve postural control. Alternatively, perhaps young acrobats who have inherited a good ability to maintain equilibrium choose this sport for this reason. The equilibrium of prepubertal dancers was less good than that of acrobats possibly because classical dance requires prolonged training on tiptoe (pointes), but working on equilibrium only from the age of 9 or 10 years (because of osteo-muscular maturity) (Golomer 1995). Dancers are more dependent than acrobats on vision possibly because they use several visual targets and watch their body in a mirror during training.

Physical activities and unstable platforms

With a servo-controlled platform, Debu and Woollacott (1988), unlike our study, confirmed that there was an improvement in the maintenance of equilibrium in older but not in young gymnasts, but for neck muscles not leg muscles. Perrin et al. (1989) found that the latency response of the soleus muscle is shorter in gymnasts than in other athletes. This result is at variance with the study of Debu and Woollacott (1988). These divergent results may be due to the combination of EMG and a preprogrammed unstable platform being unsuitable for assessing the differences between the types of sports training among adolescent girls. In contrast, the free stabilometer method allows the sway frequencies, which are linked to proprioceptive input (Golomer et al. 1994), to be assessed both for differences linked to the type of physical activity and also the effects of maturation upon the whole dynamic postural control system of girls.

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