Gait and Posture 15 (2002) 187–194
www.elsevier.com/locate/gaitpost

Judo, better than dance, develops sensorimotor adaptabilities involved in balance control

Philippe Perrin [a,b,c,*], Dominique Deviterne [a,d], Francine Hugel [a], Cyril Perrot [a]

[a] *Equilibration et Performance Motrice, UFR STAPS, University Henri Poincaré – Nancy 1, 30 rue du Jardin Botanique, 54 600 Villers-les-Nancy, France*
[b] *National Institute for Health and Medical Research (INSERM), U420, Faculty of Medicine, 54 500 Vandoeuvre-les-Nancy, France*
[c] *Department of Otorhinolaryngology, University Hospital, Nancy, France*
[d] *IUFM of Lorraine, Nancy, France*

Received 9 May 2000; accepted 7 June 2001

Abstract

Objectives: Training allows sportsmen to acquire new balance control abilities, possibly differing according to the discipline practised. We compared, by means of static and dynamic posturographic tests, the postural skills of high-level judoists, professional dancers and controls, in order to determine whether these sports improved postural control. *Results:* With eyes open, judoists and dancers performed better than controls, indicating a positive effect of training on sensorimotor adaptabilities. Yet, with eyes closed, only judoists retained a significantly better stance. *Conclusions:* These data indicate that the practice of a high-skill activity involving proprioceptive afferences especially improves both performance and balance control.

Keywords: Postural strategies; Sports training; Vision; Proprioception; Transfer

1. Introduction

The performance of high-level motor tasks during sport learning and training or competition implies to master simultaneously both static and dynamic balance [1–3]. Sportsmen involved in such movements therefore must adopt appropriate physiological and biomechanical attitudes as well as a specific psychological perception.

Proper balance control in the achievement of motor skills is mainly based on muscular synergies that minimise the displacements of the centre of gravity while maintaining upright stance, proper orientation, adapted locomotion and adequate gestures, figures or techniques imparted to the sport practised [4,5]. Choice of the sensorimotor strategy most appropriate to the task [6,7] and mental abilities thus rely on the sensory information perceived and integrated in the past by the sportsman, such as during training [8–11].

Learning a sport and training it over a long period of time appear to improve the efficiency of both static and dynamic postural control in daily life activities [1,3,11–14]. Several authors have suggested that such improvement was independent from the experimental conditions imposed to test balance control, i.e., by removing major visual and/or somatosensory cues [2,9,15–17].

In Judo, competitors have to efficiently control their dynamic posture because the techniques of this martial art are mainly based on constant displacements aiming at disturbing the balance of the opponent in order to make him fall. Then, during fights (i.e. randori), each judoist learns to use unstable dynamic situations to turn them to his advantage [4], using the stimulation of muscular, articular and cutaneous mechanoreceptors to adapt to the constant modifications of posture, support, ground and partner contact [3,4].

Conversely, the morphocinetical actions of Classical Ballet dancing, involving static balance as well as complex chained dynamic choreographic figures, suggest that this art is a physical activity where balance control

* Corresponding author. Tel.: +33-383-905-627; fax: +33-383-902-842.
E-mail address: philippe.perrin@staps.uhp-nancy.fr (P. Perrin).

0966-6362/02/$ - see front matter
PII: S0966-6362(01)00149-7

is essential [1,12,13] and mostly relies on visual afferences. Classical Ballet dancers work in a stable environment, either in front of a mirror or on stage, with unwavering visual spatial referential [1].

Because Judo relies most on proprioceptive signals [3,4,15,18] and Ballet dancing preferentially on visual inputs [1], it may therefore be postulated that Judo and Dance might impact differently on balance control.

Here, we analysed static and dynamic posturographic performances of high-level judoists and professional dancers, in terms of sensorimotor strategies and adaptabilities, in order to determine which of these sports appeared to mostly improve balance control in unexpected situations.

2. Subjects and methods

2.1. Subjects

Body sway was measured using a vertical force platform for 73 healthy adults between 20 and 35 years of age.

Fourteen female dancers of the National Ballet of Nancy and Lorraine (mean age 22.1 ± 4.5 years old, range 20–34) agreed to participate in this study. On average, they had 10 to 15 years of training in Classical Ballet and on-stage experience as professionals. All reported that they had not presented any acute articular injuries during the past 6 months.

Seventeen male high-level judoists (black belts, mean age 24.8 ± 4.5 years old, range 20–34) involved in national and international athletic tournaments, also agreed to take part in this experiment. All had a minimum number of six years of practice (20 years for the best competitors) and no mechanical or functional instability consecutive to ligamentous, articular or muscle trauma or injury in the past 3 months. None of these subjects suffered obvious retinal lesions (which may be secondary to intense efforts or to vascular strangling), neurological pathology or plantar sole contact irritant dermatitis.

Finally, 21 women and 21 men (mean age 23.9 ± 4.2 years old, range 20–35) formed the control group. None of them held a sports license nor practised leisure physical activities at a level liable to modify their postural control. Nervous lesions or orthopaedic pathologies were not disclosed in any of them.

All subjects gave informed consent prior to the study.

2.2. Experimental set-up

A vertical force platform, fitted with four strain gauges (Toennies, GmbH, Freiburg, Germany) was used to perform posturographic recordings in a sound proof room. Each subject, standing upright on the platform, barefooted, arms along the body, was instructed to stare straight ahead at a white dot located at eye level two meters away. The feet were 10 cm apart. Static and dynamic tests were then performed in the same session.

In the static test, displacements of centre of foot pressure (CFP) are recorded over 20 s, with eyes open, then with eyes closed. The resulting statokinesigrams allow to measure the sway path, or way (W), and area (A) travelled by the CFP, as well as anterior–posterior (AP) and lateral (Lat) oscillations (Fig. 1). Low values for sway path and area parameters are representative of good posture control. The role of visual afferences was evaluated individually with the Romberg's quotient comparing data obtained with eyes open (EO) or closed (EC), e.g. W_{EC}/W_{EO} ratio.

In a second test, the subjects were submitted to slow rotational oscillations of the support with a 4° amplitude, at a frequency of 0.5 Hz, for 20 s, in EO and EC conditions. The graphs obtained (Fig. 2), by recording CFP displacements over time, can be analysed by comparison with the sinusoid yielded by the movement of the platform and as fast Fourier transformations (FFT) as reported elsewhere [9,19–23].

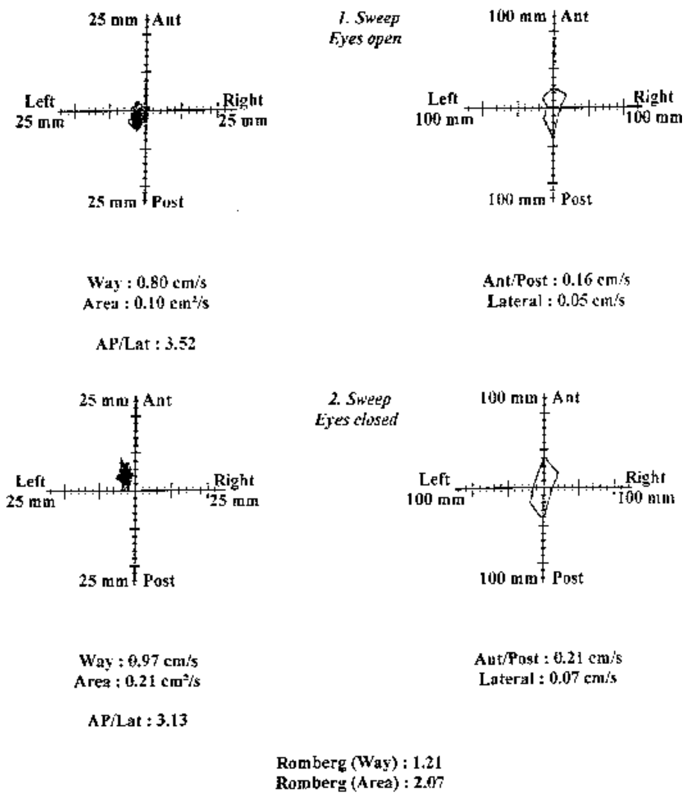

Fig. 1. Statokinesigram recordings from static tests performed with eyes open (top) or closed (bottom) and providing the sway path (way) and the area of CFP displacements (left) as well as anterior–posterior and lateral displacements (right).

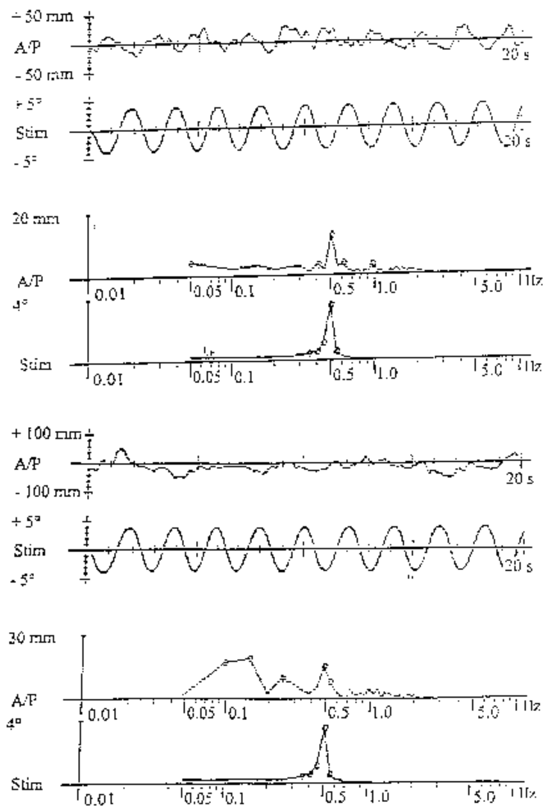

Fig. 2. Typical recordings of centre of foot pressure (CFP) displacements and fast Fourier transformations (FFT) consecutively to a slow sinusoidal movement of the platform (Stim: 4°, 0.5 Hz, 20 s) in the anterior–posterior plane (A/P). Upper part: Type 1 graph; lower part: Type 2 graph.

FFT graphs were analysed in determining frequencies and amplitudes of the different peaks [24–26], and partitioned in three groups. For this partition, the presence of high frequency peaks, whatever the amplitude yielded, was not taken into account, as it is considered that they do not reflect the level of instability of the subject.

The three groups were:

- Group 1: major peak at 0.5 Hz, with lower frequency peaks of no more than 75% the amplitude of the major peak;
- Group 2: major 0.5 Hz peak associated with peaks at lower frequencies reaching more than 75% of the major peak's amplitude;
- Group 3: major peak occurring at lower frequency than 0.5 Hz.

Group 1 characteristics revealed stable balance control and were designed Type 1. Groups 2 and 3 characteristics revealed unstable balance control and were designed Type 2.Type 1 recordings, indicating great stability of the subject during the test, correspond to a bottom-up regulation model, the body oscillating like an inverted pendulum [27]. Type 2 recordings convey the instability of the subject. This pattern corresponds to a top-down regulation model, favouring visual anchorage and vestibular referential, and involving movements of the main joints [27].

The same instructions given to dancers, judoists and controls induced sufficiently similar behaviour that inter-individual comparisons were possible.

2.3. Statistics

One-way analysis of variance was made in order to evaluate the effects of sex-factor (comparison between 21 male and 21 female in the control group) and of the sport practice factor (comparison between 17 judoists, 14 dancers and 42 controls) for all measures in static tests. This analysis was completed by a repeated measures ANOVA, including 2 factors (3×2): (i) the between-subjects factor concerned the sport practised and had three modalities (none, judo and dance), (ii) the within-subjects factor (repeated measures) concerned the visual condition and had two modalities (eyes open – eyes closed). Then, for each statistically significant value of F, 2 by 2 comparisons were made between mean values using the Fisher test of the Protected Least Significant difference (Fisher PLSD).

These tests were applied only after verification of the normal distribution of data by graphic method.

A Chi squared test was used to compare the frequency distributions of the types of patterns used to regulate the dynamic equilibrium: (i) in the males and females of the control group; (ii) in the three groups of subjects (judoists, dancers and controls).

A 0.05 significance level was used for all analyses.

3. Results

3.1. Influence of sex factor

Data were first analysed by examining the possible influence of sex on static and dynamic balance control by comparing in the control group 21 female versus 21 male subjects. No sex-related differences were noted both in static and dynamic tests for all the parameters studied (Table 1).

3.2. Influence of high-level sport practice

3.2.1. Static tests

One way ANOVA analysis demonstrated significant differences between the three groups (Table 2). In EO condition, the grading observed was judoists, dancers, controls: for way and area parameters, judoists performed a significantly better balance regulation than controls. In EC condition, the grading observed was judoists, controls, dancers: for way and area parameters, dancers and controls displayed a significantly

Table 1
Comparison between males and females in the control group for static and dynamic tests, performed in EO or EC condition

		Males ($n=21$)	Females ($n=21$)	
Static test				
		m (SD)	*m* (SD)	Student's *t* (*P*)
Way/s (cm)	EO	0.89 (0.20)	0.82 (0.21)	1.12 (NS)
	EC	1.41 (0.46)	1.27 (0.61)	0.81 (NS)
Area/s (cm^2)	EO	0.32 (0.28)	0.26 (0.18)	0.86 (NS)
	EC	0.63 (0.50)	0.48 (0.27)	1.23 (NS)
AP/s (cm)	EO	0.14 (0.04)	0.14 (0.05)	0.25 (NS)
	EC	0.28 (0.10)	0.30 (0.22)	0.47 (NS)
Lat/s (cm)	EO	0.08 (0.02)	0.08 (0.05)	0.12 (NS)
	EC	0.10 (0.06)	0.08 (0.03)	0.44 (NS)
RQ way		1.58 (0.26)	1.57 (0.45)	0.08 (NS)
RQ area		2.32 (1.16)	2.07 (1.07)	0.73 (NS)
Dynamic test				
		% (*n*)	% (*n*)	χ^2 test
Type 1	EO	100 (21)	95 (20)	$\chi^2=1.02$ df = 1, NS
	EC	52 (11)	43 (9)	$\chi^2=1.02$ df = 1, NS

worse balance regulation than judoists, and for lateral oscillation parameter, dancers displayed significantly more instability than both other groups.

Repeated measures ANOVA demonstrated differences in the influence of vision on balance control between the three groups: the switch from EO to EC condition resulted in a significant increase of W, A, Lat, AP values (Table 3: repeated measures). The level of that increase differed between the three groups (Table 3: interaction groups x repeated measures), the Romberg quotient parameters (Table 2: RQ way and RQ area) evidencing the following grading: from the lowest to the highest value, judoists, controls and dancers.

3.2.2. Dynamic tests

In EO condition, all subjects of the three groups, except 1 of the 42 controls, displayed a type 1 strategy (Table 4). In EC condition, the frequency of type 1 responses dropped for the three groups. This decrease was significantly more important for the dancers and controls compared to the judoists (Partial Chi squared, Table 4).

4. Discussion

In this study, comparing the balance control of highly skilled judoists, dancers and controls, we show that only judoists were able to maintain a better balance control than controls in all circumstances, i.e., with or without sensory deprivation (eyes closure) or external perturbation (movement of the support). The good results of these sportsmen both in static and dynamic tests confirm the hypothesis formulated in several studies of a redistribution of postural control processing developed by Judo practice [3,4,15].

Given the absence of differences between sexes in balance regulation in our young control population, we hypothesised that the differences observed between the three groups tested were not related to sex but to sport

Table 2
One-way ANOVA in judoists, dancers and controls during the static test performed in EO or EC condition

		Groups: *m* (SD)				One-way ANOVA		
		Judoists (J)	Dancers (D)	Controls (C)	*F* test	Fisher's PLSD		
		$n=17$	$n=14$	$n=42$		J/C	D/C	J/D
		m (SD)	*m* (SD)	*m* (SD)	*F* value (*P*)	*P*	*P*	*P*
Way/s (cm)	EO	0.72 (0.13)	0.80 (0.16)	0.85 (0.21)	3.01 (0.05)	0.02	NS	NS
	EC	1.07 (0.26)	1.53 (0.50)	1.34 (0.54)	3.70 (0.03)	0.05	NS	0.01
Area/s (cm^2)	EO	0.16 (0.10)	0.23 (0.10)	0.29 (0.24)	3.14 (0.05)	0.02	NS	NS
	EC	0.22 (0.15)	0.58 (0.46)	0.56 (0.40)	5.33 (0.01)	0.003	NS	0.01
AP/s (cm)	EO	0.11 (0.04)	0.13 (0.04)	0.14 (0.05)	2.16 (NS)	NS	NS	NS
	EC	0.21 (0.10)	0.25 (0.12)	0.29 (0.17)	1.91 (NS)	NS	NS	NS
Lat/s (cm)	EO	0.09 (0.06)	0.08 (0.05)	0.08 (0.04)	0.03 (NS)	NS	NS	NS
	EC	0.09 (0.06)	0.16 (0.10)	0.09 (0.05)	8.48 (0.01)	NS	0.001	0.02
RQ way		1.50 (0.30)	1.90 (0.42)	1.57 (0.36)	5.51 (0.01)	NS	0.005	0.003
RQ area		1.66 (0.70)	2.85 (2.43)	2.19 (1.11)	2.81 (0.05)	NS	NS	0.02

Table 3
Effects of the within-subjects factor (repeated measures: EO/EC) and interaction of this factor with the between-subjects factor (groups: judoists/dancers/controls) on four parameters in static test (way, area, anterior–posterior and lateral oscillations)

	Two ways ANOVA with repeated measures		
	Groups F (P)	Repeated measures (EO/EC) F (P)	Groups × repeated measures F (P)
Way/s (cm)	3.48 (0.04)	131,94 (0.0001)	4.00 (0.02)
Area/s (cm^2)	5.00 (0.009)	50.82 (0.0001)	4.44 (0.02)
Anterior–posterior/s (cm)	2.38 (0.10)	77.34 (0.0001)	1.13 (NS)
Lat/s (cm)	3.63 (0.03)	8.47 (0.005)	11.21 (0.0001)

practice. This hypothesis of absence of sex-effect is sustained by the part of the data of Kollegger et al. [28] concerning the same range of age (21–35 years) as ours. Ekdalh et al. [29] evidenced better standing balance in women than in men, but within a population including older subjects (20–64 years old) than our sample. These results suggest the importance of relating the test-data not only to sex but also to age.

The use of a particular sensorimotor strategy, implied in the regulation of static and dynamic balance, would depend on the choice of sensory cues (visual, vestibular or proprioceptive) privileged to detect divergences between the posture planned and that really adopted. This choice is influenced by prior experiences [30,31].

Our results also confirm that Judo or Ballet dancing learning and training, respectively practised barefooted or with special Ballet shoes, tend to improve orthostatic balance control in EO condition. In both cases, the foot constitutes a full organ of balance control in a context involving both external information (position relative to the ground) and internal constraints (sense of position) [32,33]. As suggested by Bessou et al. [34] and Kavounoudias et al. [35], superficial plantar mechanoreceptors provide the CNS with information relative to the position of the body with respect to the vertical reference [35], which relies on gravitational forces, reaction forces from the supporting surface and shear forces. This postural regulative function of the plantar sole therefore allows sportsmen to perform better than controls in EO condition, suggesting that proprioception plays a major role in maintaining a stable upright stance [3,9,15,36]. With eyes closed, dancers display the worst balance control. This could be due to the fact that training in Classical Ballet develops specific modalities of balance, which are not transferable to posture control in our test situations [1].

Our results are in accordance with those of Golomer et al. [12] indicating that ballet dancers were more dependent than acrobats on visual inputs for the regulation of postural control but differing from those indicating that they were less dependent than untrained subjects, both for females [12] and for males [17]. Dance training strengthens the accuracy of proprioceptive inputs, in a lower way than in judo and acrobatics, but shifts with difficulty sensorimotor dominance from vision to proprioception, according to our results. Dancers do not efficiently compensate visual suppression, because this input is not used in their practice to solve the task, but to take landmarks [37]. The direction of the gaze is important for artistic expression and also to perceive the surrounding. In dance, during high-speed rotations, body rotations are regular while those of the head occur in fits and starts, with short periods of fixation on an environmental target at each turn. Moreover, gaze fixation allows to avoid post rotatory nystagmus [38,39].

In this study, the combination of closed eyes and a moving support in dynamic tests are two new situations unusual in Dance. The vestibular capacities to decode new somesthetic solicititation would appear not to efficiently compensate the simple loss of visual cues, which is consistent with data from Pailhous and Bonnard [40]. By contrast, the good performance of judoists in all experimental conditions, suggests a low reliance on visual inputs for balance control in this discipline. Similar results were obtained by Hain et al. [14] in Tai Chi.

The difference of balance modalities involved in Judo and Dance likely relies on the very different training and practice of these two sports. Dancers train for long hours in a very stable environment (in front of a mirror, holding a ramp), then perform freely but in an unmoving space (either in the training room or on stage). They voluntarily generate their own imbalance during their complex chained dynamic choreographic figures. Conversely, both in training and in competition, judoists are constantly subjected to unexpected movements imposed by their opponent in order to make them fall on soft ground (tatami). Therefore, the good performances of judoists in unusual situations, could be due to the fact that training in martial arts develops sensorimotor adaptabilities transferable to posture control in other circumstances. In Judo practice, the CNS acts to control the position of the body's centre of gravity relative to the feet and organises postural patterns in this balance task as a function of available sensory information and biomechanical constraints [41–43].

Table 4
Comparison between judoists, dancers and controls for the frequency distributions in two types of strategies in EO and EC conditions during the dynamic test

		Type 1			Type 2		Type 1 vs Type 2
		Group 1 % (n)	Group 2 % (n)	Group 3 % (n)	% (n)		
EO	Judoists	100 (17)	0 (0)	0 (0)	0 (0)	100 (17)	Global χ^2 (J/D/C) = 0.75, df = 2, NS; Partial χ^2 (J/C) = 0.41, df = 2, NS; Partial χ^2 (D/C) = 0.34, df = 2, NS; Partial χ^2 (J/D) = 0.00, df = 2, NS
	Dancers	100 (14)	0 (0)	0 (0)	0 (0)	100 (14)	
	Controls	98 (41)	0 (0)	2 (1)	2 (1)	100 (42)	
EC	Judoists	76 (13)	12 (2)	12 (2)	24 (4)	100 (17)	Global χ^2 (J/D/C) = 5.89, df = 2, $P = 0.05$; Partial χ^2 (J/C) = 4.09, df = 1, $P = 0.04$; Partial χ^2 (D/C) = 0.60, df = 1, NS; Partial χ^2 (J/D) = 5.24, df = 1, $P = 0.02$
	Dancers	36 (5)	21 (3)	43 (6)	64 (9)	100 (14)	
	Controls	48 (20)	14 (6)	38 (16)	52 (22)	100 (42)	

In fact, the improvement of postural control concurrent to Judo training appears to be the consequence of a better mastery of the common postural strategies available in the controls'repertoire and especially those based on somatosensory inputs [2,9,19,44]. Blind subjects can also reach a high level of practice in judo.

In controls, balance control may rather depend on a multisensory evaluation of imbalance, without a clear prevalence of any sensory input [2,45].

Finally, the hypothesis must be raised that the subjects we tested practised Judo or Classical Ballet because of their innate sensory abilities, and that we did not really measure the influence of their sport's training and practice. Predisposition can effectively facilitate learning, but in the judoist or in the dancer group, we cannot affirm that there are no individuals predisposed to the first or to the latter practice and in the same way that in the control group, there are no individuals predisposed to one of both sports.

In conclusion, our results confirm that high-level sportsmen display improved balance control in relation with the requirements of each discipline. Because the visual afference is a major input used by Ballet dancers to achieve a better balance regulation, they are likely to fare less well than controls in daily life situations where this afferent is missing. Conversely, Judo training leads to the best performances in terms of maintaining a stable stance in all circumstances as the result of privileging somatosensory afferences as an essential component of balance control, abilities likely to have a positive bearing in current activities. The balance strategies and techniques learned by high-level judoists should be carefully analysed to determine if they could be incorporated into treatment programs for injured subjects or non sportsmen with balance instability.

References

[1] Hugel F, Cadopi M, Kohler F, Perrin Ph. Postural control of ballet dancers: a specific use of visual input for artistic purposes. Int J Sports Med 1999;20:86–92.

[2] Mesure S, Amblard B, Crémieux J. Effect of physical training on head-hip co-ordinated movements during unperturbated stance. Neuro Report 1997;8:3507–12.

[3] Perrot C, Deviterne D, Perrin Ph. Influence of training on postural and motor control in a combative sport. J Hum Mov Studies 1998;35:119–36.

[4] Barrault D, Brondani JC, Rousseau D. Médecine du Judo. Paris: Masson, 1991.

[5] Winearls J. Posture: its function in efficient use of the human organism as a total concept. Agressologie 1972;13B:99–102.

[6] Nashner LM. Strategies for organization of human posture. In: Igarashi M, Black FO, editors. Vestibular and visual control on posture and locomotor equilibrium. Basel: Karger S, 1985:1–8.

[7] Horak FB, Nashner LM. Central programming of postural movements: adaptation to altered support-surface configuration. J Neurophysiol 1986;55:1369–81.

[8] Handford C, Davids K, Bennett S, Button C. Skill acquisition in sports: some applications of an evolving practice ecology. J Sports Sci 1997;15:621–40.

[9] Perrin Ph, Schneider D, Deviterne D, Perrot C, Constantinescu L. Training improves the adaptation to changing visual conditions in maintaining human posture control in a test of sinusoidal oscillation of the support. Neurosci Lett 1998;245:155–8.

[10] Proteau L. On the specificity of learning and the role of visual information for movement control. In: Proteau L, Elliott D, editors. Vision and motor control. Amsterdam: Elsevier, 1992:67–102.

[11] Lavisse D, Deviterne D, Divry M, Perrin Ph. Mental information processing in motor skill acquiring by able-bodied and motor-handicapped subjects. J Hum Mov Studies 1995;29:149–69.

[12] Golomer E, Dupui Ph, Monod H. The effects of maturation on self-induced dynamic body sway frequencies of girls performing acrobatics or classical dance. Eur J Appl Physiol 1997;76:140–4.

[13] Mouchnino L, Aurenty R, Massion J, Pedotti A. Coordination between equilibrium and head-trunk orientation during leg movement: a new strategy built up by training. J Neurophysiol 1992;67:1587–98.

[14] Hain TC, Fuller L, Weil L, Kotsias J. Effects of Tai Chi on balance. Arch Otolaryngol Head Neck Surg 1999;125:1191–5.

[15] Mesure S, Crémieux J. The effect of judo training on postural control assessed by accelerometry. In: Brandt Th, editor. Proceeding of the Xth International Symposium on Disorders of Posture and Gait. New York: Stuttgart, 1992:302–6.

[16] Crotts D, Thompson B, Nahom M, Ryan S, Newton RA. Balance abilities of professional dancers on select balance tests. J Orthop Sports Phys Ther 1996;23:12–7.

[17] Golomer E, Crémieux J, Dupui Ph, Isableu B, Ohlmann. Visual contribution to self-induced body sway frequencies and visual perception of male professional dancers. Neurosci Lett 1999;267:189–92.

[18] Perrot C, Mur JM, Mainard D, Barrault D, Perrin Ph. Influence of trauma induced by judo practice on postural control. Scand J Med Sci Sports 2000;10:292–7.

[19] Diener HC, Dichgans J, Guschlbauer B, Mau H. The significance of proprioception on postural stabilization as assessed by ischemia. Brain Res 1984;186:103–9.

[20] Diener HC, Dichgans J. On the role of vestibular and somatosensory information for dynamic postural control in humans. In: Pompeiano O, Allum JHJ, editors. Progress in brain research, vol. 76. Amsterdam: Elsevier, 1988:253–62.

[21] Perrin Ph, Béné MC, Perrin C, Durupt D. Ankle trauma significantly impairs posture control: a study in basketball players and controls. Int J Sports Med 1997;18:387–92.

[22] Ferdjallah M, Harris GF, Wertsch JJ. Instantaneous postural stability characterization using time-frequency analysis. Gait Posture 1999;10:129–34.

[23] Corna S, Tarantola J, Nardone A, Giordano A, Schieppati M. Standing on a continously moving platform: is body inertia counteracted or exploited. Exp Brain Res 1999;124:331–41.

[24] Perrin Ph, Jeandel C, Perrin C, Béné MC. Influence of visual control, conduction and central integration on static and dynamic balance in healthy older adults. Gerontol 1997;43:223–31.

[25] Perrin Ph, Gauchard G, Perrot C, Jeandel C. Effects of physical and sporting activities on balance control of elderly people. Br J Sports Med 1999;33:121–6.

[26] Gauchard G, Lascombes P, Kühnast M, Perrin Ph. Influence of different types of progressive idiopathic scoliosis on static and dynamic postural control. Spine 2001;26:1052–8.

[27] Perrin Ph, Perrin C. Exploration des afférences sensorielles et du contrôle moteur de l'équilibration par la posturographie statique et dynamique. Ann Otolaryngol Chir Cervicofac 1996;113:133–46.

[28] Kollegger H, Baumgartner C, Wober C, Oder W, Deecke L. Spontaneous body sway as a function of sex, age, and vision: posturographic study in 30 healthy adults. Eur Neurol 1992;32:253–9.
[29] Ekdalh C, Jarnlo GB, Andersson SI. Standing balance in healthy subjects. Evaluation of a quantitative test battery on a force platform. Scand J Rehabil Med 1989;21:187–95.
[30] Horak FB, Shupert CL, Dietz V, Horstmann G. Vestibular and somatosensory contributions to responses to head and body displacements in stance. Exp Brain Res 1994;100:93–106.
[31] Massion J. Movement, posture and equilibrium: interaction and coordination. Prog Neurobiol 1992;38:35–56.
[32] Magnusson M, Enbom H, Johansson R, Pyykkö I. The importance of somatosensory information from the feet in postural control in man. In: Brandt Th, Paulus W, Dieterich M, Krafczyk S, Straube A, editors. Disorders of Posture and Gait. Stuttgart: Georg Thieme Verlag, 1990:190–3.
[33] Okubo J, Watanabe I, Baron JB. Study on influences of the plantar mechanoreceptor on body sways. Agressologie 1980;21D:61–9.
[34] Bessou M, Dupui P, Séverac A, et al. Le pied, organe de l'équilibration. In: Villeneuve Ph, editor. Pied, équilibre et posture. Paris: Frison-Roche, 1996:21–32.
[35] Kavounoudias A, Roll R, Roll JP. The plantar sole is a 'dynamometric map' for human balance control. Neuro Report 1998;9:3247–52.
[36] Bles W, De Wit G. Study of the effects of optic stimuli on standing. Agressologie 1976;17:1–5.
[37] Pailhous J. Evolution du rôle des indices visuels avec l'apprentissage dans l'exécution d'un mouvement morphocinétique. Can Psychol 1980;23:99–106.
[38] Perrin Ph, Perrot C, Deviterne D, Ragaru B, Kingma H. Dizziness in discus throwers is related to motion sickness generated while spinning. Acta Otolaryngol (Stockh) 2000;120:390–5.
[39] Teramoto K, Sakata E, Ohtsu K. Use of the visual suppression test using post-rotatory nystagmus to determine skill in ballet dancers. Eur Arch Otorhinolaryngol 1994;251:218–23.
[40] Pailhous J, Bonnard M. Locomotor automatism and visual feedback. In: Proteau L, Elliott D, editors. Vision and motor control. Amsterdam: Elsevier, 1992:339–419.
[41] Allum JHJ, Bloem BR, Carpenter MG, Hulliger M, Hadders-Algra M. Proprioceptive control of posture: a review of new concepts. Gait Posture 1998;8:214–42.
[42] Buchanan JJ, Horak FB. Emergence of postural patterns as a function of vision and translation frequency. J Neurophysiol 1999;81:2325–39.
[43] Dietz V, Trippel M, Ibrahim IK, Berger W. Human stance on a sinusoidally translating platform: balance control by feedforward and feedback mechanisms. Exp Brain Res 1993;93:352–62.
[44] Gauchard G, Jeandel C, Tessier A, Perrin Ph. Beneficial effect of proprioceptive physical activities on balance control in elderly human subjects. Neurosci Lett 1999;273:81–4.
[45] Debu B, Woollacott M. Effects of gymnastics training on postural responses to stance perturbations. J Motor Behav 1988;20:273–300.