ORIGINAL ARTICLE

Do sensorial manipulations affect subjects differently depending on their postural abilities?

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Objectives: To examine whether sensorial manipulation affects subjects differently according to their postural performance and the strategies used. The literature showed that the level of competition of soccer players influences their postural performance and strategy.
Methods: Eight high-level (HL) professional soccer players and nine regional-level (RL) soccer players were tested (1) in a reference condition and (2) in a manipulated sensorial condition (MAN). The MAN condition consisted of perturbing the proprioceptive and exteroceptive information. For each postural condition, balance was assessed by measuring the centre of foot pressure using a force platform during a test of bipedal standing posture.
Results: The postural control was less perturbed in the HL than in the RL players in the two postural conditions. Moreover, the group–condition interaction showed that the postural control was less disturbed in the HL than in the RL players when the sensory information was manipulated.
Conclusions: The HL soccer players probably possessed a better internal model of verticality than the RL players. Subjects who had a better postural control level were less disturbed by sensorial manipulation than the others in postural regulation.

Postural regulation requires the integration of proprioceptive and exteroceptive information. When this information is perturbed or manipulated, postural control is altered. Indeed, cutaneous sensory disturbance by hypothermic anaesthesia,[1] myotendinous interference by muscle vibration,[2] pain by stimulation of skin thermoreceptors,[3] electromyostimulation,[4] galvanic vestibular stimulation[5] or visual manipulation by stroboscopic light[6] affects postural stability in healthy subjects. Keshner *et al*[7] showed that combined disturbances (ie, visual, proprioceptive, vestibular) caused greater disturbance than any one presented alone. However, combined perturbations might not disturb all subjects in the same way. We do not know whether subjects who present a better postural performance level counteract differently to the effects of manipulating proprioceptive and exteroceptive information in postural regulation than the others. Moreover, the postural strategy—that is, preferential involvement of short (visuovestibular contribution) or long (myotatic participation) neuronal loops in postural regulation—can also influence the effects of sensorial perturbation. To study this, sportsmen at different levels of competition should be studied.

Indeed, the level of competition influences the postural performance: the higher the level of competition, the more stable the posture.[8 9] The level of competition also influences the preferential use of the different neuronal loops involved in balance regulation as Paillard *et al*[9] showed with soccer players. Hence, one can wonder (1) whether high-level soccer players can preserve better postural control than players at a lower level when their proprioceptive and exteroceptive informations are disturbed and (2) whether these two categories of players are differently affected by sensorial manipulation.

The aim of this work was to compare the postural behaviour between high-level soccer players and players at a lower level in two different postural conditions. The first condition was the reference (no sensorial perturbation), whereas in the second condition proprioceptive and exteroceptive information was disturbed.

METHODS

Subjects

Eight male professional soccer players who played at a national championship (high level or HL group) and nine male amateur soccer players who played at a regional level (regional level or RL group) participated in the study. The subjects' morphological characteristics (table 1) showed no difference between the two groups (one-factor analysis of variance (ANOVA)). All the subjects had practised soccer for at least 6 years. None of the subjects had ankle, knee or hip injuries in the past 4 months. HL players train almost every day and RL players twice a week. The experiment was conducted at the middle of the competition season. The subjects signed a written informed consent according to the declaration of Helsinki.

Measurements

We asked the subjects to stand as still as possible, with their arms along the body, on two legs barefoot on a force platform (PostureWin, Techno Concept, Cereste, France; 40 Hz frequency, 12 bit A/D conversion), which recorded the displacements of the centre of foot pressure (COP) with three strain gauges. The subjects were placed according to precise marks. Their legs were tended and their feet formed a 30° angle relative to each other (inter-malleolar distance of 5 cm). They were tested (1) in the reference condition (REF) and (2) in a manipulated sensorial condition (MAN). For the two conditions, the test lasted 51.2 s first with eyes open (EO) then with eyes closed (EC). In the EO situation, the subjects looked at a fixed level target 2 m away. In the EC situation, they were asked to keep their "gaze" in a straight-ahead direction.

COP signals were smoothed using a second-order Butterworth filter with a 6 Hz low-pass cut-off frequency. The COP surface area (90% confidence ellipse) evaluates the

Abbreviations: ANOVA, analysis of variance; COP, centre of foot pressure; EC, eyes closed; EO, eyes open; HL, high level; LF, low frequency; MAN, manipulated sensorial condition; REF, reference condition; RL, regional level

Table 1 Comparison of the subjects' morphological characteristics between the two groups (one-factor analysis of variance)

	HL group (n = 8)	RL group (n = 9)	Statistics
Age (years)	24 (3)	23 (2)	NS
Height (cm)	181 (6)	175 (6)	NS
Weight (kg)	77 (6)	66 (7)	NS

HL, high level; NS, not significant; RL, regional level.
Values are mean (SD).

subject's postural performance: the smaller the area, the better the performance.[10] The COP velocity (sum of the cumulated COP displacements divided by the total time) evaluates the subjects' postural control.[10] COP excursions were also investigated in the frequency domain to assess the preferential involvement of short or long neuronal loops in balance regulation.[11] Fast Fourier transforms were applied to COP displacements from 0 to 20 Hz. Hence, the total spectral energy was calculated and distributed in three frequency bands: low frequencies (LF), 0–0.5 Hz; medium frequencies, 0.5–2 Hz; and high frequencies, >2 Hz.[12] Low frequencies mostly account for visuovestibular regulation, medium frequencies for cerebellar regulation and high frequencies for proprioceptive regulation.[12]

Sensorial manipulation

Before the postural tests (EO and EC) in the MAN condition, subjects' feet were placed in a metal bucket filled with ice-cold water (5℃) to mid-calf for 20 min. The aim was to anaesthetise the sensitivity of the cutaneous receptors.[1] Immediately after cooling, the postural tests were performed in the MAN condition. During each test, the gastrocnemius medialis and lateralis, and vastus medialis and lateralis of both legs were electrically stimulated (Cefar Rehab 4 Pro, Malmo, Sweden). One electrode (Cefar Stimtrode, 50×89 mm, Axelgard, Sweden) was placed over the motor point on each of the four muscles with a biphasic symmetric square wave (continuous pulse 350 µs, 25 mA, 80 Hz). The aim was to disturb the myotatic proprioceptive information.[4] The subjects wore a cervical collar to jointly render the head with the trunk in order to limit information from the cervical articulations (fig 1).

Statistical analysis

The effects of condition (REF and MAN), group (HL and RL) and vision (EO and EC) were tested using three-factor ANOVA with repeated measures on three factors. When significant treatment effect occurred, Newman–Keuls post hoc analyses were used to test the difference among means. The level of significance was set at $p<0.05$.

RESULTS

For the REF and MAN conditions, the COP velocity was significantly greater in the RL group than in the HL group with EO and EC (table 2). For both groups (HL and RL), in the two conditions (REF and MAN), the COP velocity was significantly greater in the EC situation than in the EO situation (table 2). Furthermore, the condition–vision interaction was significant for the COP velocity (table 2). The COP surface area was not different between the two groups in all the conditions (table 2).

The MAN condition significantly altered the COP surface area and the COP velocity for both groups with EO and EC (table 2). In addition, a significant group–condition interaction was observed for the COP velocity (table 2).

The spectral analysis showed that the energies of the low-frequency band and the medium-frequency band were greater for the HL players than for the RL players irrespective of the postural condition (REF and MAN; table 3). Statistical analysis did not reveal any other significant effects or interactions.

Figure 1 Illustration of the postural test (eyes wrapped for eyes-closed situation) in the manipulated sensorial condition immediately after cooling of the subjects' feet in a metal bucket filled with ice-cold water. During this test, the gastrocnemius medialis and lateralis and vastus medialis and lateralis were electrically stimulated and the subject wore a cervical collar. Informed consent was obtained for publication of this figure.

DISCUSSION

Irrespective of the condition (REF or MAN), COP velocity was slower in the HL soccer players than in the RL players, which showed that the HL players demonstrated better postural control than the RL players. This confirms the results of Paillard *et al*,[9] which showed that national players' postural control was better than that of regional players in the REF condition. Moreover, Era *et al*[8] had already also observed that there is a close relationship between the level at which the sport is played and the effectiveness of postural regulation in rifle shooters.

Table 2 Comparison of postural parameters between regional-level and high-level soccer players with eyes open or closed in the two conditions

Group	Condition	Vision	Surface area	Velocity
RL	REF	EO	115.3 (54.2)	6.0 (1.2)*
		EC	114.8 (55.3)	6.4 (1.2)*†
	MAN	EO	387.7 (175.2)‡	9.8 (2.9)*‡§
		EC	496.7 (355.2)‡	13.3 (4.9)*†‡§¶
HL	REF	EO	171.1 (73.1)	5.0 (1.1)
		EC	187.0 (138.2)	6.0 (1.7)†
	MAN	EO	274.5 (132.2)‡	6.2 (1.9)‡
		EC	392.3 (306.1)‡	8.0 (2.5)†‡¶

EC, eyes closed; EO, eyes open; HL, high level; MAN, manipulated condition; REF, reference condition; RL, regional level.
*Significant group effect (RL or HL).
†Significant vision effect (EO or EC).
‡Significant condition effect (REF or MAN).
§Significant group–condition interaction ($p<0.05$).
¶Significant condition–vision interaction.
Mean (SD) values of the centre of foot pressure (COP) surface area (mm^2) and the COP velocity (mm/s).

Table 3 Spectral analysis of postural sways in the reference and manipulated conditions

Group	Condition	Vision	LF band	MF band	HF band
RL	REF	EO	2213.6 (1523.9)*	755.8 (513.1)*	8.7 (7.6)
		EC	2096.5 (1370.8)*	716.2 (453.1)*	3.8 (3.7)
	MAN	EO	5068.1 (4908.0)*	1721.0 (1618.3)*	4.5 (5.2)
		EC	3657.7 (1230.8)*	1282.0 (461.4)*	21.9 (19.7)
HL	REF	EO	12234.8 (9990.5)	4089.8 (3328.3)	4.8 (3.9)
		EC	18743.8 (8353.3)	6274.2 (2795.4)	12.9 (28.1)
	MAN	EO	9266.6 (10579.2)	3102.1 (3522.0)	2.2 (2.0)
		EC	16326.9 (10883.5)	5457.6 (3618.1)	12.5 (17.8)

EC, eyes closed; EO, eyes open; HF, high frequency; HL, high-level; LF, low frequency; MAN, manipulated condition; MF, medium frequency; REF, reference condition; RL, regional level.
*Significant group effect (RL or HL; $p<0.05$). No significant condition effects (REF or MAN) or vision effects (EO or EC) and no significant interactions were observed.
Distribution of normalised values of the total spectral energy (V^2/Hz) in three frequency bands is as follows: LF (0–0.5 Hz); MF (0.5–2 Hz); and HF (>2 Hz). Values are mean (SD)

Two phenomena could explain why the HL players demonstrated better postural control than the RL players. Firstly, the HL players presented probably a better neuromuscular activation responsiveness (they modulated better muscle activity) at the level of ankle extensors than the RL players as the COP velocity is inversely correlated to the ankle torque.[13] Secondly, according to Perrin *et al*,[14] high-level athletes develop a higher sensitivity of sensory receptors than lower level athletes.

For the two groups in the two conditions, the COP velocity being significantly greater in the EC situation than in the EO situation means the suppression of vision disturbed postural control in all circumstances. Moreover, the condition–vision interaction was significant for the COP velocity, which illustrated that the suppression of vision disturbed the postural control more in the MAN condition than in the REF condition for the two groups. Without sensorial manipulations (REF condition), the proprioception partially compensated the loss of visual information, whereas with sensorial manipulations (MAN condition), the proprioception compensated less the loss of visual information. Therefore, sensorial manipulations can disturb the proprioceptive information and thus the postural control. However, Vuillerme *et al*[15] showed that after a proprioceptive perturbation delivered by tendon vibration of ankle muscles, the contribution of visual information was not altered by the reintegration of proprioceptive information. These authors only disturbed proprioception at a very local level, whereas in the present study the manipulation concerned proprioceptive information at a more extended level (electrical stimulation of calf and thigh muscles, and reduced neck movements due to the cervical collar) and the plantar cutaneous information. Thus, the wider the manipulation of sensory information, the more visual information would compensate the deterioration of the efficiency of the disturbed sensory receptors to regulate balance.

Moreover, the COP velocity and the COP surface area were greater in the MAN condition than in the REF condition for the two groups. These results showed that the sensory manipulation deteriorated the postural abilities. In addition, the group–condition interaction showed that the COP velocity increase was weaker in the HL soccer players than in the RL players in the MAN condition. This means that the postural control was less disturbed in the HL than in the RL players when the sensory information was manipulated. With the vestibular system not stimulated, two reasons could explain why the HL soccer players compensated the effects of erroneous proprioceptive information better than the RL players. Either the otolithic inputs are more efficient and allow better detection and control of the body orientation or the interoceptive inputs are more precise and induce a better internal model of verticality. Bringoux *et al*[16] have already shown that the relevance of otolithic and/or interoceptive inputs increases with increasing sporting expertise. The results of the spectral analysis confirmed this as the visuovestibular (LF band) contribution was greater in the HL players than in the RL players. However, the LF band showed neither a significant condition effect nor a group–condition interaction. Hence, the vestibular system could not lead to a better compensation of otolithic information in the HL group than in the RL group in the MAN condition. Moreover, in the static postural condition, the frequencies of body oscillations are below the detection threshold of movement of the vestibular system.[17] Therefore, in the MAN condition the vestibular system probably did not bring any additional information in the HL soccer players than in the RL soccer players to regulate their balance. The results of Balter *et al*[18] confirm this hypothesis as they showed that professional gymnasts did not present a higher sensitivity of the vestibular system than control subjects. Therefore, the HL soccer players probably possessed a better internal model of verticality (a better knowledge of the body axis and verticality) than the RL players.

CONCLUSION

The postural regulation of subjects with a better sports performance level was less disturbed by sensorial manipulation than that of sportsmen with a lower level of performance.

What is already know on this topic

There is a close relationship between the level at which the sport is played and the effectiveness of postural regulation. However, no study has analysed (1) whether high-level sportsmen can preserve better postural control than sportsmen at a lower level when their proprioceptive and exteroceptive information are disturbed and (2) whether these two categories of sportsmen are differently affected by sensorial manipulation.

What this study adds

The present study shows that the high-level sportsmen conserve a better postural control than the sportsmen at a lower level when their proprioceptive and exteroceptive information is disturbed. Furthermore, it also shows that the postural control is less disturbed in the high-level sportsmen than in the sportsmen at a lower level when the sensory information was manipulated.

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Informed consent was obtained for publication of figure 1.

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Figure 1 Pekka Kannus.