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Stabilization of the Head Position in Pitch Plane: Study of Imbalance During a Multisegment Posturography Examination

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Abstract: Our purpose was to evaluate head stabilization in pitch plane in patients with different kinds of imbalance when standing over firm and movable surfaces. We used the STATITEST (Société Mumedia, Belgium), a multisegment platform for recording and computing postural adjustments at different body levels. We detected these data by two sensors placed on the head and hip of each subject in four situations: eyes open on a firm surface (EOFS); eyes closed on a firm surface (ECFS); eyes open on a movable surface (EOMS); and eyes closed on a movable surface (ECMS). For each recording, a magnetic field was broadcast by an antenna placed in front of the patients. First, as the manufacturer did not provide the normal range limits for shoulder sway, we conducted a statistical analysis on a population and selected a sample of 31 normal individuals. Second, we performed the experiment with 91 patients in two steps: standard examination and an assessment with sensors on the head and shoulder. The following values of increased head-shoulder relationship were found: on EOFS, 6; on ECFS, 5; on EOMS, 6; and on ECMS, 11. We noted the predominance of smaller head adjustments, reflecting accurate head stability. However, a small percentage of patients showed increased head movement, a pigeonlike sway. A correlation of these individuals with postural strategies revealed that almost all adopted ankle strategies.

Key Words: head stabilization; imbalance; multisegment platform; postural adjustments

In stance, body stabilization is ensured by the synergic action of muscular groups that act on the various segments of the body, as if they were independent modules controlled through a complex, interlinked neuronal network. To put it simply, we can regard body sway in stance as if it were an inverted pendulum with a vertex situated at the tibiotarsal joint. However, especially when patients are standing on a movable surface, we can observe swaying of various segments of the body (knees, hip, shoulder, head) that are different in extent, phase, and frequency from what might be expected according to the model of the inverted pendulum. It was on the basis of this evidence that Horak [1] described the different posture strategies: ankle, hip, and stepping strategies.

According to Shupert and Horak [1], in normal subjects the passive viscoelastic properties of the neck may be sufficient to stabilize head position during platform perturbations without a contribution from vestibular or neck reflexes. However, patients with profound bilateral vestibular loss show both excessive neck muscle activity and abnormally high head accelerations in response to perturbations of the support surface. This implies that vestibular patients had difficulty in controlling head acceleration during the execution of postural response itself, rather than immediately in response to the support surface movement. In these patients, the vestibulocollic reflex seems to play a major role in the neck muscles' responses.

Considering that in our posturography examinations

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many patients with normal hip sway presented with apparently exaggerated head adjustments, we wished to observe whether this increased head sway was isolated or was also accompanied by increased adjustments at the shoulder level. Thus, the purpose of this study was the evaluation of head stabilization in the anteroposterior plane in patients with different kinds of imbalance when standing over firm and movable surfaces. What are the percentages of patients in whom head motion overcomes shoulder sway? In what percentage of patients does the head remain stable in space or stiffened to the trunk?

MATERIALS AND METHODS

The posturographic system used was a STATITEST, a multisegment platform for recording and computing the postural adjustments detected by two sensors placed on the head and hip of each patient in four situations: eyes open on a firm surface (EOFS); eyes closed on a firm surface (ECFS); eyes open on a movable surface (EOMS); and eyes closed on a movable surface (ECMS). For each recording, a magnetic field was broadcast by an antenna placed in front of a patient. The patient was positioned on the platform, and each of the four situations was repeated three times. The duration of each trial was 10 seconds. This equipment renders it possible to study the sway at different body levels and to obtain the sway in centimeters and as a percentage of normal range values.

The movable surface (Bessou platform) is shaped like a square with a lower side resting on the horizontal ground-level surface between two disc segments. The patient is placed only in the anteroposterior direction, although the lateral adjustments are also recorded. In all test situations, the frequencies of body sway showed values of less than 0.5 Hz, with a predominant maximum frequency of 0.1–0.2 Hz.

Statistical Analysis

In our experiment, as the manufacturer did not provide the normal limits for shoulders, we began by conducting a statistical analysis on a population and selected a sample of 31 individuals of both genders, none of whom had complaints or a clinical history of imbalance or vertigo. The average age of this sample was 31.7 years (SD, 11.26 years), and the average height was 169 cm (SD, 1.09 cm). The raw data introduced for these calculations were the arithmetic mean obtained from three consecutive trials for each of the four conditions.

Our first target was to try to understand the measured data (i.e., being able to process the raw data statistically and validate the given normal values for a certain population). We began by obtaining a graphic representation of the samples (Fig. 1). The histogram was used for displaying data that have been summarized into intervals. We began by defining the 90% and 95% confidence intervals ($1-\alpha$). We calculated the average and the standard deviation. For a normal distribution $Z\alpha/2$ ($n \geq 30$), the confidence interval is given by the formula $\{\mu - Z\alpha/2 * \delta/\sqrt{n}\,;\, \mu + Z\alpha/2 * \delta/\sqrt{n}\}$ (Fig. 2).

The population followed a normal distribution, and the 90% confidence interval for the sample corresponding to the shoulder sway was estimated (Table 1): EOFS, 12.6–15.7; ECFS, 13.9–16.8; EOMS, 20.7–25.9; and ECMS, 67.8–84.9. Similar estimates were obtained from the head sway, and the 90% confidence intervals calculated were as follows: EOFS, 20.7–25.6; ECFS, 23.2–28.3; EOMS, 33.8–42.0; and ECMS, 112.0–144.2.

Normal Limits

To evaluate head-neck stabilization, we considered the normal sway limits for the shoulder to be 16, 17, 26, and 85 mm, and for the head, 26, 28, 42, and 144 mm. However, the normal limits for head sway provided by

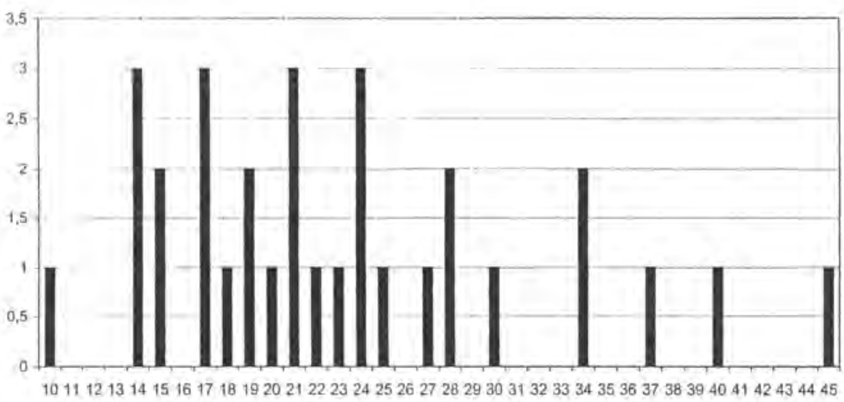

Figure 1. Frequency distribution of sway magnitude in the sample of 31 healthy individuals. The raw data were the arithmetic mean obtained from three consecutive trials for each of the four conditions.

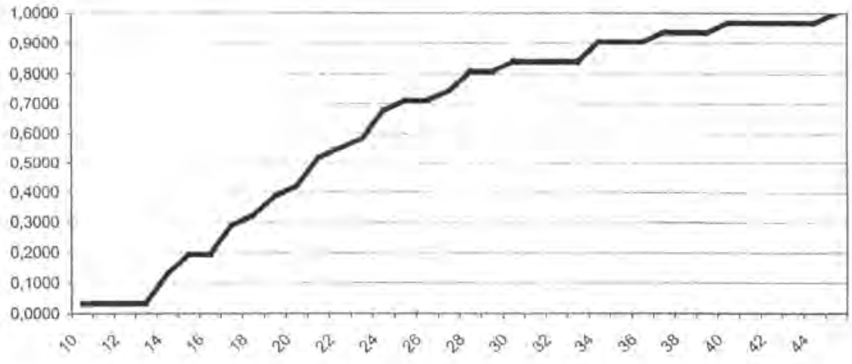

Figure 2. Distribution of the cumulative relative frequencies of the amplitude sway movements. The interval between 18 and 26 contains 50% of the sample.

the manufacturer (27, 31, 50, and 95 mm) were slightly smaller than the superior limit of the confidence levels found in our sample.

Evaluation of Head Stabilization

We then performed studies on 91 patients of both genders who had imbalance complaints and were referred for posturography examination, regardless of association with vertigo; included were cases of benign paroxysmal positional vertigo, presbyastasia, Ménière's disease, whiplash injury, psychogenic imbalance, transient ischemic attack, unknown causes, and so on. The average age of patients in this group was 58 years (SD, 15.2 years), and average height was 162 cm (SD, 8.46 cm). The breakdown by age group was as follows: ≤ 50 years, 29 patients; 51–65 years, 30 patients; 66–75 years, 18 patients; ≥ 76 years, 14 patients (Fig. 3). We performed the examination in two steps: standard examination with the sensors on the head and hip and a second assessment with sensors on the head and shoulder.

Table 1. Estimates of Shoulder and Head Sway Movements During Four Conditions of Evaluation (N = 31)

	EOFS	ECFS	EOMS	ECMS
Head				
Average	23.1	25.8	37.9	128.1
SD	8.3	8.7	13.9	54.4
CL_{90}	20.7	23.2	33.8	112.0
	25.6	28.3	42.0	144.2
CL_{99}	19.3	21.8	31.5	103.0
Shoulder				
Average	14.2	15.4	23.3	76.3
SD	5.2	4.9	8.9	28.9
CL_{90}	12.6	13.9	20.7	67.8
	15.7	16.8	25.9	84.9
CL_{99}	14.2	15.4	23.3	76.3

CL_{90} = 90% confidence level; CL_{99} = 99% confidence level; EOFS = eyes open on firm surface; ECFS = eyes closed on firm surface; EOMS = eyes open on movable surface; ECMS = eyes closed on movable surface; SD = standard deviation.

Note: Statistical analysis conducted on a selected a sample of 31 individuals of both genders, none of whom had complaints or a clinical history of imbalance or vertigo.

RESULTS

Taking into account the magnitude of head adjustments above normal-range values and simultaneous shoulder and hip sway equal to or below normal limits, the following values of increased head-shoulder relationship were found (N = 91): EOFS, 6; ECFS, 5; EOMS, 6; and ECMS, 11 (Table 2; Fig. 4). Considering eyes open and eyes closed on each support surface, we recorded two and three cases of increased head sway, respectively, on the firm surface and the movable surface.

The predominance of head adjustments smaller than the normal-range values, reflecting accurate head stability, is noteworthy. However, on pitch plane, a small percentage of patients showed increased head motion with respect to the trunk. On a firm surface, the motions were larger when patients' eyes were open than when they were closed and, on a movable surface support, larger movements were found mainly when patients' eyes were closed (Fig. 5).

Correlation of these individuals with postural strategies that they adopted in the four conditions revealed that almost all adopted ankle strategies. We observed

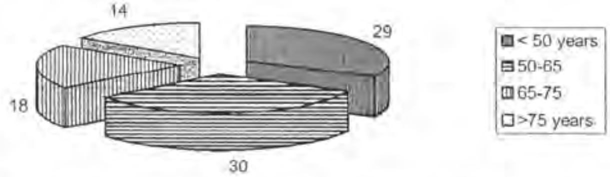

Figure 3. Age distribution of the studied population with imbalance complaints (N = 91). There were cases of benign paroxysmal positional vertigo, presbyastasia, Ménière's disease, whiplash injury, psychogenic imbalance, transient ischemic attack, and unknown causes.

Table 2. Increased Head-Shoulder Relationships (N = 91)

	EOFS	ECFS	EOMS	ECMS	FS (EO + EC)	MS (EO + EC)
No. of patients	6	5	6	11	2	3
Percentage	6.6	5.5	6.6	12	2.2	3.3

EOFS = eyes open on firm surface; ECFS = eyes closed on firm surface; EOMS = eyes open on movable surface; ECMS = eyes closed on movable surface; FS = firm surface; MS = movable surface; EO = eyes open; EC = eyes closed.

Note: Data obtained from 91 patients of both genders referred for posturography examination and having imbalance complaints.

only one case of ankle and hip strategies in ECFS and two cases in EOMS and ECMS conditions (Fig. 6).

DISCUSSION

During gait or stance on a movable support surface, the various body segments provide compensation movements of differing magnitude to maintain the center of gravity within the boundaries of foot support. As regards trials performed on a Bessou platform (eyes open and closed), body movements are triggered only in the pitch plane, and head sway is normally attenuated regardless of the inverted-pendulum hypothesis; however, sometimes scores are larger than expected, considering hip and shoulder sway. Could this attenuation disturbance be provoked by deficient head-trunk coordination? Cromwell et al. [2] gave one possible answer in addressing the gait of elderly people. Those individuals present deficient head-trunk coordination with eyes closed when they are dependent on vestibular and proprioceptive inputs. However, the frequency range of head movements during gait (0.7–10.0 Hz) is greater in the elderly than in persons standing on a Bessou platform (< 0.5 Hz), and our patients were younger.

We wondered also why individuals with apparently exaggerated head motion (with respect to shoulder and hip sway) do not adopt hip strategies. Could it be because the main purpose of balance is to keep the trunk stable—hence the greater head movements in subjects standing on a firm surface?

To Horak et al. [3], in subjects adopting ankle strategies, a compensated unilateral vestibular loss provokes an irrelevant contribution to head postural control; nevertheless, in conditions demanding hip strategies, the center of gravity and head control are abnormal. These patients are not able to activate neck muscles in anticipation of hip movements and, consequently, display inaccurate control of the head position in relation to the axis of gravity. Accordingly, a small percentage of our patients seem to have a disturbance of head-neck postural control.

In conditions of surface-support perturbations, normal patients adopt two strategies concerning head-trunk coordination: one with stabilization of the head in space (gravity-fixed) and another with the head-trunk fixed.

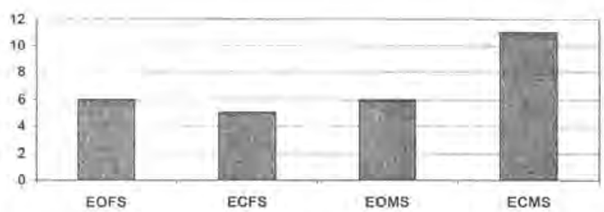

Figure 4. Number of cases during the four conditions (EOFS, ECFS, EOMS, and ECMS) in which amplitude of head adjustments exceeded normal-range values while shoulder and hip sway movements were equal to or lower than normal range. (*EOFS* = eyes open on firm surface; *ECFS* = eyes closed on firm surface; *EOMS* = eyes open on movable surface; *ECMS* = eyes closed on movable surface.)

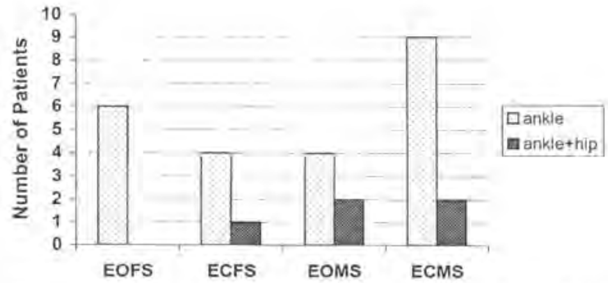

Figure 5. Postural strategies (ankle and ankle plus hip) adopted by patients with increased head-shoulder relationship during the four situations of posturography examination. (*EOFS* = eyes open on firm surface; *ECFS* = eyes closed on firm surface; *EOMS* = eyes open on movable surface; *ECMS* = eyes closed on movable surface.)

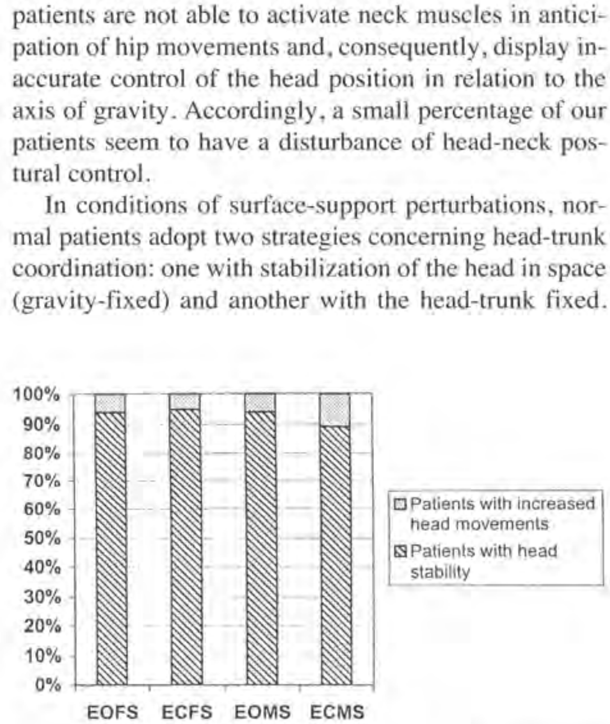

Figure 6. Percentage of increased head motion versus head stability during the examination in four conditions. (*EOFS* = eyes open on firm surface; *ECFS* = eyes closed on firm surface; *EOMS* = eyes open on movable surface; *ECMS* = eyes closed on movable surface.)

Data collected in our study show that a small patient sample, in at least one of the four conditions (EOFS, ECFS, EOMS, ECMS), adopts in stance a third, pigeonlike posture, with increased head sway with respect to the shoulder and the center of gravity. In our sample, no correlation with the causes of imbalance was possible, and we doubt that these cases accurately reflect bilateral vestibular loss.

In our experiment, the range of postural adjustment frequencies during standing was below 0.5 Hz (0.1–0.2 Hz). Tokita et al. [4] considered the postural responses triggered by horizontal sinusoidal sway of the platform with higher frequencies than ours. They pointed out that the roles of the visual, vestibular, and proprioceptive reflexes in forming the basic pattern of postural adjustment differ according to the frequency of body sway.

Whereas, in normal subjects, the passive viscoelastic properties of the neck may be sufficient to stabilize head position during platform perturbations, patients with profound bilateral vestibular loss display both excessive neck muscle activity and abnormally high head acceleration in response to perturbations of the support surface. Patten et al. [5] presented evidence that, during free-speed gait on the ground, vestibulopathy impairs coordination of the head toward the body's center of gravity. However, in our experiment, patients experienced different etiological causes of imbalance and were assessed standing on both firm and movable surfaces. Thus, these facts do not enable us to make any causality correlation between head motion patterns and imbalance etiology.

Another limitation results from the fact that sway raw data obtained feature sway amplitudes but do not point out the direction of the movement (forward or backward). Head and shoulder sway amplitudes may be within the confidence intervals (and, as such, are considered normal), yet the difference between them (representing the magnitude of head movement regardless of the shoulder) may be greater than that found in persons with increased head sway and simultaneous shoulder motion within the confidence intervals. Thus, establishing whether the head-shoulder sway relation increases is difficult.

The software does not take into account changes in postural sway caused by different patients' heights. The use of hip reference values provided by the manufacturer can also be an error factor although, considering the fact that sway movements are smaller at this level, the differences should also be less evident. Nonetheless, we intend to carry on with this line of investigation using new software that will enable us simultaneously to record sway at the three levels now considered—head, shoulder, and hip.

CONCLUSIONS

In most cases, head adjustments seem to express head stabilization even during perturbation of the support surface. However, some patients showed anteroposterior pigeonlike head sway that apparently was exaggerated with respect to shoulder sway. In patients with increased head motion, visual input did not reduce the amplitude of body sway within a frequency range of 0.1–0.6 Hz in the standing position over a firm surface. On the contrary, over a movable surface, visual input seems to play a role in patients' use of the same strategy.

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