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Trunk Position Sense in the Frontal Plane

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Twenty healthy volunteers (ages 18 to 25 years) were tested for their ability to sense the lateral position of the top of their thoracic spine. When moved slowly from side-to-side in the frontal plane with vision occluded and pelvis immobilized, they could sense the position of a midline point on the skin at the T1 level to within 3 mm of a mean center position in relaxed standing tests, and to within 9 mm in supine tests. When subjects centered themselves actively, or additionally, contracted trunk flexor or extensor muscles to predetermined levels of activity, no increase in trunk positioning accuracy was found. The effect of a lateral pelvic tilt or lateral trunk moment had little effect on trunk positioning accuracy, but always induced a characteristic trunk offset. No differences were found in any of these results between males or females, or gymnasts or nongymnasts. © 1985 Academic Press, Inc.

INTRODUCTION

The motivation for this study is the well-known clinical observation that patients with lateral spine deformities (idiopathic scoliosis) are typically unaware that they may also have a lateral trunk list of several centimeters (19). As we could find no published studies describing the accuracy with which the trunk or spine can normally be centered over the pelvis, we determined how well a healthy adult population can do that.

The spine essentially serves to support the head and upper extremities. It is a complex, flexible structure, whose postural control system probably receives afferent information from visual, vestibular, and musculocutaneous sources. For example, the thoracic and lumbar spine alone is a structure with 102 mechanical degrees-of-freedom controlled by roughly 200 para-

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vertebral muscle slips. Afferent information is available from receptors in these muscles (1), the capsules of the 34 capsular zygoapophyseal joints, and the many spinal ligaments (11), and the periphery of the 17 intervertebral discs (10). Additional useful information may be available from the costovertebral joints (7), intercostal (6) and other trunk musculature, fascia, and cutaneous receptors.

The object of this study was to determine how accurately the top of the thoracic spine (T1) can be repositioned over the pelvis after lateral displacement. Tests were performed in the upright standing and supine positions, with active and passive movements. The effects of static postural disturbances on positioning accuracy were also studied.

MATERIALS AND METHODS

Ten males and ten females aged 18 to 25 years served as subjects. Five of the males and five of the females were members of the University gymnastics team. The remainder were students not in active training. None reported current back complaints or a history of spine disorders.

Small ink crosses were placed on the skin, posteriorly over the T1 spinous process, and anteriorly on the midline at the level of the T1 rib. The lateral position of the T1 mark was read to the nearest millimeter from a transparent rule mounted transversely to the trunk. The posterior mark was used in the standing experiments, and the anterior mark was used in the supine experiments. Parallax error was minimized by a cursor which projected a thin beam of light onto the T1 mark.

The pelvis and lower extremities were immobilized by adjustable lateral pads and straps attached to an external frame. The knees were maintained in an extended position by additional straps. In the supine tests, a foot support and upper body supports were provided (Fig. 1). Because it was used as a datum, we needed to minimize any motion of the pelvis. As motion of the pelvis in the frontal plane results in heel motion if the knees remain in extension, we included heel switches and circuitry in the foot support so that any pelvic movement exceeding 1 mm turned on a warning light. Results were voided when this occurred. The upper body rested on two padded low-friction supports, riding on multiple glass spheres. One supported the head and shoulders, the other supported the lower back such that the subject could completely relax his trunk musculature (Fig. 1). The horizontal force required to move one support carrying a typical load of 200 N was less than 0.3 N (25 g). Subjects' arms were folded over their chests.

Five tasks were carried out in the standing and five in the supine position, all with eyes closed. Depending on the task, the subject was initially moved

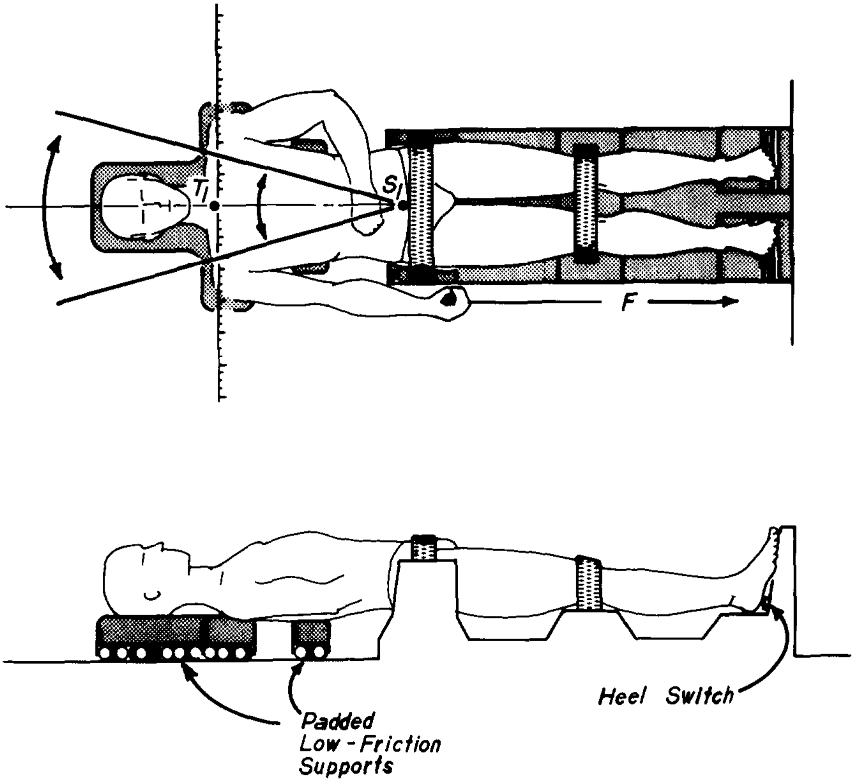

FIG. 1. Two views showing subject in supine test apparatus. In this particular task the subject attempted to center T1 over S1 as accurately as possible while resisting a 6-N·m lateral trunk moment caused by force *F*.

passively or moved himself actively from side to side for 20 s, so that T1 moved 10 cm in either direction at about 5 cm/s. This was to prevent his remembering any specific trunk position. Then, with T1 moving at about 1/10th this velocity he was asked to report when his head and shoulders were exactly centered over his sacrum/pelvis. When he reported achievement of this, a reading of the lateral position of T1 was taken. Five repetitions were performed in each task, with the center position approached from alternate sides in a L, R, L, R, L sequence (a pilot study in five subjects had shown no differences in accuracy when approaching from each side). The five tasks consisted of:

(i) Passive Positioning. After the initial 20 s of random movement and without interruption, the subject was moved so that T1 lay about 10 cm from a center position and T1 was then moved at about 0.5 cm/s toward

the center by the experimenter. The subject was asked to indicate when he felt his head and shoulders were exactly centered over his pelvis, whereupon a reading of the lateral position of T1 was taken. The final direction of travel was alternated from each side.

(ii) Active Positioning with 20% Rectus Abdominis Contractions. This was similar to (i) except that subjects were required to move and position themselves while contracting the rectus abdominis muscles bilaterally, at approximately 20% of their maximum voluntary contraction. To indicate this contraction effort, myoelectric activity was recorded using pairs of bipolar surface electrodes placed at the L3 level over the rectus abdominus and erector spinae muscles on the right side. The signals at the L3 level were amplified, rectified, and integrated. The levels of the integrated signals were indicated by visual display to the experimenter, and by audible tone to the subject. Both feedback sources were calibrated by asking the subject to tense his trunk muscles maximally. Control settings were then adjusted so that a 20% contraction produced a high-frequency tone. Stronger or weaker contractions produced different tone frequencies, both lower than the 20% level tone frequency. After a few minutes of practice, subjects could achieve a 20 ± 10% contraction level in the rectus abdominus muscles, while maintaining the erector spinae muscles relaxed.

(iii) Active Positioning with 20% Erector Spinae Contractions. The test situation was the same as in (ii), except that the rectus abdominus muscles were relaxed and the erector spinae muscles were contracted.

(iv) Active Positioning with 5° Pelvic Tilt. A 5° lateral pelvic tilt was achieved by inserting a suitable spacer under the right foot. The procedure was otherwise similar to (i) except that the subject moved himself from side to side and positioned himself as centrally as he could.

(v) Active Positioning while Resisting a 6 N·m Lateral Moment. The subject continually resisted a 25-N inferiorly directed force applied to his right hand, which was placed at his side. This resulted in approximately a 6 N·m lateral moment about S1, the base of the spine and top-center of the sacrum/pelvis. In the supine position this was achieved with pulleys, a cable, and a weight (*F*, Fig. 1); in the standing position with a weight. Otherwise the procedure was similar to (iv).

For each subject the average of the five measured T1 positions was calculated for each of the tasks. At this position, the trunk and spine was defined to be centered in the midsagittal plane. The mean and standard deviation of the absolute value of the five differences from this center position were also calculated. This mean difference in the lateral displacement (d) of T1 from the centered position was used as the measure of positioning accuracy. It was also expressed in nondimensional terms as the angular displacement (θ) from the midsagittal plane at the S1 level. If the T1–S1 distance is l, then $\theta = \sin^{-1}(d/l)$.

Statistical significance of differences between group means (20 subjects) was tested using the two-tailed Student's t test. Differences between subgroups (10 subjects) were tested using the Mann–Whitney U test.

RESULTS

No significant differences in positioning abilities were found between males or females or gymnasts and nongymnasts. All results reported here are therefore from data pooled for all 20 subjects.

In the relaxed standing position, subjects in the mean were able to sense the position of the T1 mark to within 3.1 mm of the centered position, corresponding to an angle of 0.3° subtended at the sacrum (Table 1). This was the condition under which the best trunk positioning accuracy was found. In the relaxed supine position this deviation increased significantly ($P < 0.001$) to 8.8 mm, corresponding to an angle increase to 0.9°. This is nearly a threefold decrease in accuracy. In fact in every test, trunk positioning accuracy was significantly poorer in the supine position than in the standing position (Table 1).

The experimental design allowed comparison of trunk position accuracy in active versus passive positioning tests conducted in both standing and supine positions. A pilot study of five subjects showed no significant differences between positioning accuracy when subjects were moved passively, or actively moved themselves in either position. In no case in the present

TABLE 1

Mean Error in Repositioning the T1 Skin Mark from the Mean Center Position[a]

	Standing		Supine	
	mm	Degrees	mm	Degrees
After passive movements				
Relaxed	3.1 (1.7)	0.3 (0.3)	8.8 (3.3)**	0.9 (.7)**
After active movements				
5° Lt pelvic tilt	6.3 (4.0)	0.7 (0.7)	9.9 (4.7)$^{\times}$	1.0 (.8)^{NS}
6 N·m Rt lateral moment	6.4 (3.0)	0.9 (0.5)	9.2 (1.4)**	1.0 (.9)^{NS}
20% Abdominal activity	4.7 (2.2)	0.5 (0.4)	8.0 (4.2)*	0.8 (.7)^{NS}
20% Erector spinae activity	5.0 (3.6)	0.5 (0.5)	8.9 (4.8)*	0.9 (.7)$^{\times}$

[a] The angle is that subtended at the S1 level. Means are over five trials. Standard deviations in parentheses.

$^{\times,*,**}$ Denote $P < 0.05, 0.01, 0.001$, respectively, comparing supine results with standing results.

experiments did voluntarily increased trunk muscle activity lead to an improvement in the mean accuracy with which the T1 mark could be repositioned. In fact, in the presence of the 20% maximum isometric voluntary contractions of the trunk muscles, repositioning error was found to be significantly ($P < 0.05$) increased when standing. When standing with either the 5° lateral pelvic tilt or the 6 N·m lateral moment, a significant ($P < 0.001$) twofold increase in repositioning error was found compared with relaxed standing values; the corresponding differences were not significant when supine.

The perceived central position of the T1 mark in the frontal plane was altered by the pelvic tilt and the lateral moment (Table 2). In response to the left pelvic tilt, the perceived central position was shifted in the same direction: by a mean 5 mm when standing and by 31 mm when supine. In response to the right lateral moment, the perceived central position was shifted in the mean 7 mm to the left when standing, but 35 mm to the right when supine. The effects of the voluntary trunk muscle contractions here were similar in nature to those of the lateral moment, but were of smaller magnitudes.

DISCUSSION

Sensory input to the postural control system responsible for positioning the trunk with respect to the pelvis is probably derived from three sources: visual, vestibular, and musculocutaneous. In our investigation visual information was not available to the subjects. Useful otolith information was available only in the standing tests, due to the direction of the gravity

TABLE 2

Mean Changes in the Perceived Central Position of T1 in the Lateral Direction in Response to Postural Disturbances[a]

	Standing		Supine	
	mm	Degrees	mm	Degrees
5° Lt lateral pelvic tilt	−5 (7)	−0.6 (0.9)	−31 (17)**	−3.9 (2.8)**
6 N·m Rt lateral moment	−7 (11)	−1.1 (1.2)	35 (21)**	4.4 (2.6)**
20% Rectus abdominus activity	−5 (10)	−0.6 (1.3)	12 (22)**	1.4 (3.3)**
20% Erector spinae activity	−3 (7)	−2.7 (0.9)	17 (23)**	2.1 (2.8)**

[a] The angle is that subtended at the S1 level. Changes were measured from the mean center position and were positive to the subjects' right. Standard deviations in parentheses.

** Denotes $P < 0.001$ comparing supine results with standing results.

vector in the supine tests. Afferent information from the muscle, joint, and cutaneous receptors in the trunk and lower extremities was always available, but probably depended on body orientation.

In the standing position afferent information from the lower extremities can reflect the percentage body weight placed on each leg and hence how the trunk is placed over the pelvis in the frontal plane. When the supine position is compared with the upright position, the supine position is characterized by less trunk muscle activity (2), 50% less axial compression of the spine (16), and essentially no otolith or lower extremity information pertinent to positioning of the spine relative to the pelvis.

Our results demonstrate that in the standing position T1 could be repositioned to within 3 mm or 0.3°. For a structure that is some 450 mm long and has more than 100 degrees of freedom, this represents remarkable precision. In the supine position this accuracy was significantly reduced to ±9 mm or ±0.9°. It seems unlikely that this reduction in positioning accuracy was caused by friction in the supine trunk supports; the 25-g friction force was essentially negligible. Rather, the difference could be due to the reduction in pertinent afferent information to the spine postural control system (decreased vestibular and possibly lower limb kinesthetic input discussed above), or possibly a decrease in corollary discharge (23) due to the lack of trunk muscle activity in the relaxed supine position.

Comparison with Other Positioning Abilities. The accuracy of trunk positioning in the supine passive tests (±0.9°) may be compared with the results of similar tests of joint position sense in other parts of the body. For example, Horch *et al.* (9) found subjects could match knee joint angle to within 2 to 3° when one limb was moved passively at a speed of 1°/min. In the shoulder joint, repositioning accuracy in an active pointing task has been shown to be 2.7° (5) and significantly worse in a passive positioning task (18). So even in the supine position, with its reduced afferent input, spine lateral positioning abilities are still remarkable.

Active versus Passive Positioning. These results show that positioning accuracy was independent of whether the subject was moved passively, or moved himself; indeed the pilot study in five subjects showed no significant differences between passive and active positioning in either the supine or the standing position. Furthermore no improvement in accuracy was found in the tests in which subjects actively positioned themselves, while additionally resisting a lateral moment whose magnitude was less than 3% of that which can maximally be resisted (15): rather the converse was true. This is in contrast to limb positioning tests (12, 18) in which active positioning has been found to be superior to passive positioning accuracy in tests that required limb angles to be matched.

Vestibular Input. When moved passively, subjects reported difficulty in perceiving any motion at all, so angular accelerations may have been less than threshold values for the semicircular canals. The accuracy of positioning T1 in the standing position (±0.3°) is equivalent to the ±0.28° threshold of the internal otolith organs in sensing head rotations (17). This vestibular capability could have been used by stiffening the muscular support of the cervical spine so that the head moves with the trunk. The agreement of positioning accuracy and otolith threshold values suggests that these organs could have played a role in lateral positioning of the upright spine. However, the threefold decrease in positioning accuracy in the supine position indicates how much the standing subject relied on vestibular information together with kinesthetic information on body weight shifts for accurate positioning.

Effect of 5° Pelvic Tilt. In response to the 5° lateral pelvic tilt in the supine position, subjects shifted the top of their thoracic spines laterally by about 30 mm. So, the spine was essentially kept at right angles to a line joining the iliac crests, and rotated with the pelvis as a rigid body. This suggests that the central nervous system may have compared muscle, ligamentous, and/or cutaneous stretch on either side of the spine, using the pelvis as a reference. In the standing position, however, T1 was moved only 15% as far in the direction of the pelvic tilt, but was positioned with greater variability. One might speculate that this variability could reflect a conflict between choosing two strategies: on the one hand wanting to remain as upright as possible and, on the other, aligning their spine at right angles to the tilted pelvis, as was done in the supine tests. Increased erector or abdominal muscle activity did not appear to affect these results.

Effect of 6 N·m Lateral Moment. The lateral moment was presented to the subjects in the form of a familiar task; holding a 2.5-kg weight in one hand when standing, or its supine equivalent. It was not in the least stressful. Table 1 shows that no increase in positioning accuracy was seen in either the standing or supine positions: so any increased corollary discharge or kinesthetic feedback arising from muscle or joint receptors due to the active resisting of this lateral load had a negligible effect on positioning accuracy.

The response in terms of T1 positioning was different in the supine and standing positions. Supine subjects moved T1 in the direction of the applied load, while standing subjects moved T1 away from the load (Table 2). This latter result suggests that in the upright position emphasis was placed on minimizing spine loading by using trunk weight to balance the applied moment: this was accomplished by leaning in the opposite direction. Of course, there would be no advantage to this strategy in the gravity-free plane, as the data indeed show.

As noted in the Introduction, we could find no studies of trunk positioning accuracy or of the mechanisms subserving it. More is known about the role of the various afferent inputs in subserving joint position sense in the limbs, though this area is still somewhat controversial (13). There is evidence that muscular receptors play an important role (14), possibly in conjunction with a sense of muscle effort ascribed to the tendon organs (20, 22). Neither joint capsule receptors (3, 8) nor cutaneous receptors (4, 21) seem to play an important role. Lastly, corollary discharges can complement afferent information (13).

There is much to learn of the mechanisms by which trunk position in space is sensed and controlled. However it is accomplished, these healthy adult subjects achieved an impressive degree of precision in their trunk position sense and in laterally centering their shoulders over their pelvices in widely varying postural situations.

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