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Active range of motion of the head and cervical spine: a three-dimensional investigation in healthy young adults

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Abstract

Purpose. To define reference values for head–cervical range of motion (ROM) in healthy young adults, to assess the effect of sex, and to quantify the separate contribution of other body districts.

Methods. Thirty women and 30 men performed maximal head and cervical spine flexion–extension, lateral bending, and axial rotation. Movements were detected using a digital optoelectronic instrument. Maximum head–cervical spine and thoracic motions were separated.

Results. Flexion and extension were performed mainly in the sagittal plane. The movement was larger in women (136°) than in men (130°). During flexion, both sexes moved the head–neck and the thorax in the same direction. During extension, men moved only the head–cervical spine, while women moved the two analyzed districts in the opposite directions. Lateral bending was nearly symmetric, associated with head–cervical rotation and extension, and larger in women (91°) than in men (77°). Adjunctive thoracic motion was limited in the sagittal and frontal planes, but larger in the horizontal plane (opposite motions of about 20°). Head–neck rotation was symmetric, and associated with concomitant movements in both the sagittal and frontal planes. It was larger in women (162°) than in men (155°), and performed with limited adjunctive thoracic motions.

Conclusions. The present values can be used as a first group of normative data for head–cervical ROM in young men and women.

Introduction

The assessment of head and cervical range of motion (ROM) is an important part of the clinical evaluation of patients reporting several disturbances: traumas, head and neck problems, shoulder muscle tenderness, temporomandibular joint and dental dysfunctions [3,5–7,9–13,16,21,22,28,29]. Indeed, head and neck motion often accompanies the movements of other body districts, such as mouth opening and closing [11,30]. Alterations in head and neck movements have been reported not only in subjects with spine pathologies, but also in patients with temporomandibular disorders [9–11], and headache [22].

Clinical assessments are often limited to qualitative examinations [10], but this approach might not be adequate for a correct evaluation of active and passive head and neck movements. Indeed, a quantitative approach could be valuable both in the diagnosis of the alterations of the locomotor apparatus, and in the assessment of the effects of therapy [6,7,12,20,21,29]. Moreover, forensic medicine currently necessitates objective and quantitative measurements [3,4,20], because clinical examinations could be discordant, and only partly related to subjective pain and disability [13].

The quantitative study of head and cervical spine movements is more complex than the examination of limb joint mobility because of concomitant movements of other body districts, first of all the upper dorsal spine and shoulder girdle. Therefore, these 'external' movements should be reduced to a minimum or, at best, eliminated [1,4,5,20,23]. Indeed, different individuals may perform the same movements with peculiar modalities and diverse contributions from dorsal spine and

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thoracic girdle. To compare different individuals is therefore necessary to eliminate all external sources of motion, and to limit the analysis to a single district. Obviously, this kind of data cannot be directly applied to everyday life, but they only can be usefully employed for a numerical definition of normal ranges, and for clinical applications. Indeed, the quantitative definition of normal reference values is the first step to be taken [1,4,29].

The elimination of external movements can be correctly performed only using landmark-based systems which use a reference system internal to the subject, such as optoelectronic and electromagnetic motion analyzers. In contrast, the gravity-based systems necessitate of more strictly standardized measurement protocols [20,23]. Among the various instruments that have been used for the quantitative analysis of head and cervical movements, optoelectronic systems using passive markers appear the best suitable for the collection of normative data in healthy non-patient individuals [1,3,4,11, 16,24].

The aim of the present investigation was a quantitative three-dimensional analysis of the normal ROM of the head and cervical spine in a group of healthy young adults. Active movements were analyzed by a non-invasive optoelectronic instrument. The effect of sex, and the separate contribution of thoracic spine and scapular girdle, were quantified.

Methods

Sample

Thirty women and 30 men aged 19–25 volunteered for the study after a detailed explanation of the procedures and possible risks involved. They all were white Caucasians, students at Milan University. They were examined by a clinician, and found to be in good general health, free from present or past problems to the cervical spine and shoulder girdle, without neurological problems or vestibular disturbances. Standing height and body weight were measured in each subject (Table 1).

The study protocol was approved by the local ethics committee.

Experimental procedure

The subjects sat in an upright chair with a lumbar support and adjustable armrests. They had their feet on the ground, with the keens and elbows flexed at 90°. To reduce lower thoracic motion, a stick was positioned between their elbows, behind their back. They were asked to assume a natural head and neck position by looking at the reflected image of their eyes in a mirror positioned 2 m in front of them at eye level (Fig. 1), then to close their eyes and mouth keeping a light dental

Table 1
Descriptive statistics (mean and S.D.) of the anthropometric characteristics of the sample

	Age (years)	Standing height (cm)	Body weight (kg)
Women	23.2 (3.3)	163.2 (5.1)[a]	54.5 (8.6)[a]
Men	22.8 (4.9)	177.6 (6.3)[a]	73.3 (8.8)[a]

[a] Statistically significant difference between men and women, Student's t-test for independent samples, 58 degrees of freedom, $P < 0.001$.

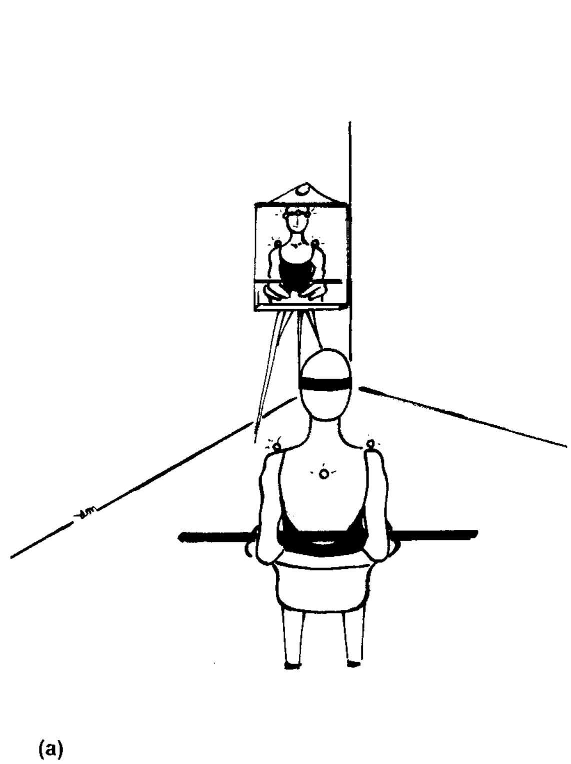

Fig. 1. Position of the subject during testing, mirror and location of the markers, frontal (a) and lateral (b) views.

contact (no clench). They performed maximal head and cervical spine movements of flexion–extension, lateral bending (left and right side), and axial rotation (left and right side). For each movement, three repetitions were performed at natural speed. The movements of other body districts were limited by the lumbar support and back stick.

The subjects were allowed to familiarize with the experimental apparatus and procedures, and performed some test movements before the actual data collection. They were asked to perform at their best, always keeping inside their 'maximum normal' range; no instructions about movement speed were given.

Head movement was detected using a digital image analyzer (Elite, BTS, Milan, Italy). The system uses wireless, stroboscopically illuminated retro-reflective markers, and high resolution infrared sensitive charge coupled device cameras with electronic shutters [3,4,16,24,26]. The different cameras, interfaced with the image analyzer, see the same markers under different points of view. The marker positions are detected by a real-time video processor, and a software calculates the three-dimensional coordinates of their centers of gravity. The system is calibrated before data acquisition, thus providing metric data free from optical and electronic distortions. Details on the instrumentation can be found elsewhere [4,16,24,26].

In the present investigation, six cameras were positioned around the subject, with a sampling rate of 100 Hz (Fig. 2). On each subject, six spherical markers (diameter 0.5 cm) were positioned on the front (glabella), left and right superciliary ridge, spinous process of the third dorsal vertebra, left and right acromion (Fig. 1).

Data analysis

An original computer program took the digital x, y, z coordinates of the six markers provided by the image analyzer, and for each frame of each movement separated head–cervical spine and thoracic motions as follows.

The three head markers identified a 'head' plane, while the three thoracic markers identified a 'trunk' plane. The inclination of the axis perpendicular to the head plane relative to ground provided the 'absolute' three-dimensional ROM (head and cervical spine plus trunk and shoulders), while the inclination of the same axis relative to the trunk plane provided the 'relative' ROM (head and cervical spine only).

A graphic subroutine allowed the qualitative control of the performance of each movement, separately for the absolute and relative components.

For each subject and movement (flexion, extension, right- and left-side rotation, right- and left-side lateral bending), the maximum value within each trial was found, and the mean of the three trials calculated. For an easier comparison to previous investigations, all movements were projected into the three spatial planes (sagittal, frontal, horizontal), and the separate angular motions assessed.

Statistical calculations

Mean and S.D. were computed separately for men and women. Bivariate variables were analyzed by using the rectangular components of the angles (sine and cosine) [2]. The effect of sex on the analyzed variables was assessed by Student's t-test for independent samples (univariate data, e.g., age) and by Watson–Williams' test (bivariate data, i.e., angles), with a level of significance set at 5%.

Error of method

To assess the reliability of the measurements, five men and five women, randomly selected from the whole group of 60 subjects, repeated the experiment with a two-week interval. Calculations were performed independently for each data acquisition, the differences between paired angular measurements were calculated, and Dahlberg's error [8], was computed.

For head flexion and extension, the error of the method was less than 1.5°. For head rotation, the method error was 1.5° (left side) and 1.2° (right side). For head lateral bending it was 2.9° (left side), and 0.8° (right side).

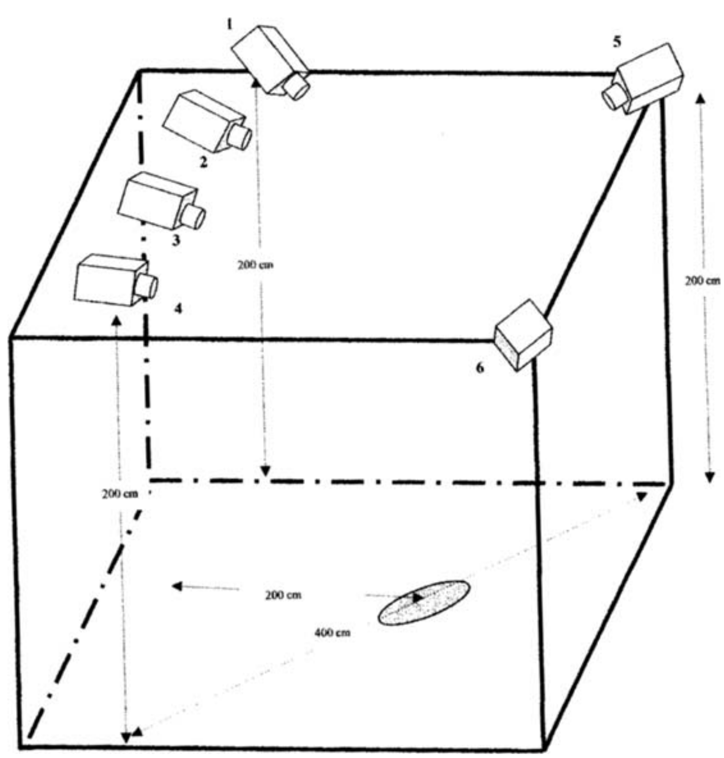

Fig. 2. Experimental setting. The six TV cameras are positioned around the subject (grey ellipse).

Results

On average, men were significantly taller and heavier than women, but they had a similar age (Table 1). For each subject and repetition, a preliminary qualitative control verified the path of motion of each movement, separately for the absolute and relative components. In all cases, the performance was considered correct. Moreover, in no cases the subjects reported discomfort during the execution of the movements, or immediately after. Mean values of the maximum angular displacements for each individual (over three repetitions) were then obtained, and averaged within sex.

Flexion and extension

Both in men and women, active head–neck flexion and extension were performed mainly in the sagittal plane, with minimal (on average, up to 6°) left–right lateral displacements (frontal plane) and rotations (horizontal plane) (Table 2). On average, the lateral displacements were significantly larger on the left than on the right side (about twice larger), a difference significant at the 0.001 level in both sexes (Watson–Williams' test). In women, also the absolute left-side rotation was significantly larger than the right-side one ($P < 0.05$).

Some sex-related differences in the performed movements were found, both for the mean values and for the different involvement of the dorsal spine and shoulder girdle. The total relative (head–neck only) movement (anterior plus posterior) was somewhat larger in women than in men (136° vs. 130°). The relative movement in the sagittal plane, posterior direction (extension) was, on average, 7.6° larger in women than in men ($P < 0.05$).

During flexion, both sexes moved the head–neck and the dorsal spine–shoulder girdle in the same direction. During extension, men on average moved only the head and cervical spine (similar absolute and relative ROM). On the contrary, women moved the two analyzed districts in the opposite directions, with an average difference of 4°.

Right- and left-side lateral bendings

In both men and women, during active head–neck lateral bendings concomitant posterior movements in the sagittal plane and axial rotations in the horizontal plane were found (Table 3). In men, both the absolute and relative right-side lateral bendings were significantly larger than the left-side ones ($P < 0.05$).

The two sexes performed the movements with the same modalities, but with different angular displacements. Overall, the total movement was about 12° larger in women than in men. Significant sex-related differences were found for the left-side bendings (about 10° larger in women than in men) and for the relative head–neck posterior motion (about 1.5 times larger in women than in men).

Head lateral bending was performed with limited dorsal spine–shoulder girdle motion in the sagittal plane (opposite movement in the posterior direction, about 4° in men, 8° in women), and in the frontal plane (concomitant movement, about 3.5° in men, 2.5–3° in women). Larger concomitant movements were found in the horizontal plane, with opposite motions of 15–18° in men, 20–22° in women.

Right- and left-side axial rotations

During active axial head–neck rotations, concomitant movements in both the sagittal and frontal planes were found (Table 4). In the frontal plane, both sexes had a larger motion on the left than on the right side. In

Table 2
Active head and neck flexion and extension in 30 men and 30 women

Plane	Movement	ROM	Women		Men		P
			Mean	S.D.	Mean	S.D.	
Sagittal	Anterior	A	65.0	9.4	70.1	15.0	NS
		R	58.5	9.7	60.4	12.1	NS
	Posterior	A	73.3	8.9	69.0	8.8	NS
		R	77.5	13.2	69.9	12.7	0.05
Frontal	Right	A	2.3	1.9	2.3	1.9	NS
		R	2.0	1.6	2.3	2.0	NS
	Left	A	5.2	2.7	5.0	2.9	NS
		R	5.7	2.9	5.0	3.0	NS
Horizontal	Right	A	3.0	2.4	4.5	3.1	NS
		R	3.2	2.8	4.2	2.9	NS
	Left	A	5.2	2.7	5.0	2.9	NS
		R	4.6	2.9	4.0	2.3	NS

Mean, S.D. and statistical comparison of maximum angular values over three repetitions for each subject. All values are degrees; ROM: A (absolute), head and cervical spine plus trunk and shoulders; R (relative), head and cervical spine only; *P*: probability value, men versus women (Watson–Williams' test); NS: not significant ($P > 0.05$).

Table 3
Active head and neck right and left lateral bending in 30 men and 30 women

Plane	Movement	ROM	Women		Men		
			Mean	S.D.	Mean	S.D.	P
Sagittal	Anterior	A	1.8	2.0	2.0	3.1	NS
		R	1.6	2.2	1.9	2.5	NS
	Posterior	A	13.0	5.4	10.8	4.3	NS
		R	21.0	7.5	14.9	6.2	0.001
Frontal	Right	A	47.9	9.6	44.4	9.4	NS
		R	45.3	9.5	40.9	8.3	NS
	Left	A	48.4	7.6	39.6	8.7	0.001
		R	45.5	7.6	36.3	8.0	0.001
Horizontal	Right	A	19.8	13.2	23.6	14.4	NS
		R	41.5	13.9	41.6	11.8	NS
	Left	A	18.0	10.0	21.5	13.0	NS
		R	38.6	12.8	36.9	11.4	NS

Mean, S.D. and statistical comparison of maximum angular values over three repetitions for each subject. All values are degrees; ROM: A (absolute), head and cervical spine plus trunk and shoulders; R (relative), head and cervical spine only; P: probability value, men versus women (Watson–Williams' test); NS: not significant ($P > 0.05$).

women, this difference in the relative bending was statistically significant ($P < 0.05$). In men, a significant asymmetry ($P < 0.05$) was found for the relative axial rotation, right side larger.

For the concomitant movements in the sagittal plane, a sexual dimorphism was found: on average, men performed predominant anterior movements (about twice larger than women), while women mainly performed posterior movements (about twice larger than men). The difference was statistically significant both for the absolute and relative motions.

Overall, axial rotation was larger in women than in men, a difference significant only on the left-side, relative movement. Conversely, frontal plane movements were larger in men than in women, a difference significant only for the right-side movements.

Axial rotation was performed with limited adjunctive dorsal spine–shoulder girdle motions. The largest angular movement was detected in the horizontal plane (about 2–3° in the same side).

Discussion

In the present investigation, the active head and cervical spine ROM was measured in a group of healthy young men and women by using a non-invasive optoelectronic instrument.

Optoelectronic instruments together with three-dimensional electromagnetic digitizers are the most recent products of technology, and can overcome several limits of less recent devices. Among the other characteristics, they are non-invasive (no use of X-rays), allow a complete investigation of head and neck movements in all their degrees of freedom free from projection errors,

Table 4
Active head and neck right and left axial rotation in 30 men and 30 women

Plane	Movement	ROM	Women		Men		
			Mean	S.D.	Mean	S.D.	P
Sagittal	Anterior	A	4.3	3.9	9.0	6.2	0.001
		R	3.4	3.3	7.6	5.9	0.001
	Posterior	A	9.4	4.7	4.6	3.3	0.001
		R	10.4	5.1	5.3	3.8	0.001
Frontal	Right	A	9.8	5.1	13.6	6.0	0.05
		R	9.3	4.9	12.9	5.7	0.05
	Left	A	12.3	5.1	15.4	6.4	NS
		R	11.9	4.9	14.7	6.5	NS
Horizontal	Right	A	83.9	7.9	82.6	8.3	NS
		R	81.8	7.2	79.8	7.6	NS
	Left	A	82.3	7.8	78.1	8.9	NS
		R	80.1	7.7	75.3	8.2	0.05

Mean, S.D. and statistical comparison of maximum angular values over three repetitions for each subject. All values are degrees; ROM: A (absolute), head and cervical spine plus trunk and shoulders; R (relative), head and cervical spine only; P: probability value, men versus women (Watson–Williams' test); NS: not significant ($P > 0.05$).

produce landmark-based digital data that can be easily used in biomechanical models and computerized simulations of movement, and are relatively low-cost [1,3,4, 11,16,24,29].

While three-dimensional electromagnetic digitizers are still limited to the analysis of a single landmark [23], optoelectronic systems can detect and record the three-dimensional movements of several landmarks. Optoelectronic instruments can use two kinds of markers: active light-emitting diodes (LED), and passive retro-reflective markers [24]. Passive markers are wireless, stroboscopically illuminated and are detected by infra-red sensitive cameras [3,4,11,16,18,24,26,29,30]. Retro-reflective markers are small and light-weight, and can be worn by the analyzed individuals without interfering with the investigated movements, a limitation found particularly disturbing with the electromagnetic digitizers [23]. In the present study, passive markers were used to individuate two planes (head–neck and shoulders). Their actual anatomical position was not critical for the analysis, even if position was standardized using well-defined anthropometric landmarks [26]. The choice of landmarks was a compromise between biomechanical modeling (the two reference planes) and anatomical considerations (marker movement relative to skin and to underlying bone structures [18,30]. Indeed, for all six markers movements relative to skin were negligible [4,16,26]: not only bony prominences with a negligible subcutaneous fat layer were chosen, but also the relevant landmarks were not directly involved in head–neck motion. Similar findings have already been reported for head and mandibular motion [18,30].

The major limitation of optoelectronic instruments currently seems that they provide a dynamic assessment of the total motion, considering the atlanto-occipital and cervical spine joints as a whole [3,4,11,16]. Indeed, only radiographic systems allow to separate the contribution of single joints to the global movement [3,17,19, 23,27]. Nevertheless, the error in landmark identification has been reported to be larger for radiographic analyses than for optoelectronic instruments [4].

It has to be mentioned that all the previous investigation used optoelectronic systems with a 50 Hz sampling rate [4,11,16,30], and two or four TV-cameras only [1,3,4,16,29]. In the present study, a 100 Hz sampling rate and a six TV-camera configuration allowed the detection of the head and thoracic markers (corresponding to the anatomical landmarks chosen for the description of the movements) in all the range of movement, without introducing other 'technical' markers or calibration recordings [4,16]. Moreover, to reduce the measurement variability [5], the mathematical procedure allowed the separation of head–cervical and thoracic motions.

The instrumentation and measurement protocol had a limited method error, with Dahlberg's errors up to 3°, a value well comparable to those reported in the other investigations performed with optoelectronic instruments [4]. In contrast, larger errors were found in electrogoniometric studies, with variations of 20° for head flexion–extension, 12° for lateral bending, and 14° for rotation [7].

In both the method error assessment and the actual data collection procedure, all subjects performed three repetitions of each movement, and the mean of the three trials was considered for further statistical analyses. Similar procedures (mean of three-to-six repetitions) were followed in several other investigations [3,4,6,7,13, 20–22].

Previous investigations found a significant effect of the initial head position on active ROM [13,27,28], and it has been recently recommended to standardize the initial head and body posture in order to minimize protocol errors [5]. Therefore, head position before each test was accurately standardized by asking the subjects to look at the reflected image of their eyes in a mirror. This natural head position has already been found to be very reproducible [14,15,25], even if also the reverse has been reported [5].

In the present study, some sex-related differences were found for both the mean angular values and the different involvement of the dorsal spine and shoulder girdle. Overall, in all the three investigated movements women had a larger angular ROM than men. The sex differences could be explained by a larger joint mobility in women. Indeed, while no sex-related differences in the mean values were reported in other investigations [13,23,28], a recent meta-analysis of normative cervical ROM literature found greater angular values in women than in men [5]. On the contrary, no previous literature information on the actual movement performance in the two sexes was found.

In the flexion–extension movement, the total head–neck movement was 6° larger in women than in men. This sex-related result replicated previous findings [20]. In both sexes the present maximum angles recorded for head–cervical extension were similar to those listed by Mayer et al. [20], while the current values obtained during head flexion were about 10° larger than the previous findings. The present values for head flexion were about 20° (women) to 25° (men) larger than those obtained using a three-dimensional electromagnetic digitizer, while the corresponding values for head extension were similar in men, and about 8° larger in women [23]. Overall, in both sexes the complete movement in the sagittal plane was well comparable to the data reported by Bonelli et al. [3]. On the contrary, the total movement was approximately 10° larger, and had a smaller S.D., than that previously measured [13] using electrogoniometry; moreover, in that study cervical flexion was larger than extension, a result in contrast with the present values, and with other investigations

[3,5,20,23]. It has to be mentioned that in the study by Feipel et al. [13] the shoulders of the subjects were not immobilized.

In the two sexes, the movement was performed with limited out-of-plane components [13,16]: in the horizontal plane, the angular motion was about 6.3% (men) and 5.7% (women) of the total motion recorded in the sagittal plane; in the frontal plane, it was 5.6% regardless of sex. Men and women performed the test with different modalities (difference between the absolute and relative mean values): during head–neck extension women moved the thoracic spine and shoulder girdle forward (in a flexion direction), while men moved both body districts in the same direction.

In the lateral bending movement, the total movement (left plus right) was about 12° larger in women than in men, but the difference was significant only for the left-side bending. In men, the present values were similar to the data obtained by some electrogoniometric literature reports [20], larger than other ones [13], and smaller than those reported by a recent optoelectronic investigation [3]. In women, the current data were about 5° larger, especially on the left side, than some reports [20], or well comparable to other ones [3,13]. In both sexes, the bending was associated with head–cervical rotation [27] and extension. Head–neck rotation in the horizontal plane was approximately 101.7% (men) and 88.2% (women) of the total angular displacement obtained in the frontal plane; in the sagittal plane, it was 25% in women, and 35% in men. On the contrary, Feipel et al. [13] found that associated rotation was approximately 40% of lateral bending.

Also axial rotation was larger in women than in men (approximately 7°), a difference significant on the left-side. Larger motion in women was also found by Bonelli et al. [3]. In both sexes, the comparison of the present values to previous electrogoniometric investigations yielded contradictory results, values being either 5–10° smaller [20] or 10–20° larger [13]. Conversely, a good correspondence was found for optoelectronic data [3]. A further sex-related difference was found for the actual performance of the movement. During axial rotation, women had a concomitant head–neck extension, men a concomitant flexion. This sagittal plane movement was about 8.5% of the horizontal plane displacement in both women and men. Head rotation was associated also with a frontal plane movement (13% in women, 18% in men) [27].

The paired movements recorded in the present study were on average symmetric, as already reported by other investigators [3,13]. Indeed, some statistically significant differences between the right- and left-side motions within sex were found (see Results), but they were all of limited practical and clinical significance, being 5° in the worse case (lateral bending in men, right-side movement wider).

Several factors can be called to explain (at least in part) the contradictions between the current results and literature findings: the age range of the analyzed individuals, the different statistical methods (both descriptive and inferential), the different methods for the measurement of head–cervical motion, the position of the subjects during motion. For instance, the effect of age on cervical ROM is still discussed, and both no-age related variations [20], and age-related decrements [5,13,28] have been reported. As far as the statistical methods are concerned, apparently in no previous study the angular values were analyzed by using bivariate statistics [2], and only linear statistics were employed. In this case, usually a larger S.D. is obtained, and the inferential tests of the linear statistics (Student's t-test, for instance) are less powerful than the most appropriate tests.

Axial rotation by inclinometric techniques is recorded in a supine position [5,20], which imposes different constraints to the subjects than the upright position. Indeed, the differences within a single method have been reported to be as large, or even larger, than that found between different methods [5]. The measurement protocol used in the present study allowed each subject to perform natural movements (apart the limitations given to lumbar and lower thoracic spine motions). Obviously, data cannot be directly compared to real life values, but each kind of testing requires a simplification of the analyzed model, and a standardization of the procedures.

The use of methods recording the entire three-dimensional ROM seems mandatory [12,13], especially when significant out-of-plane components are present (e.g., during lateral bending). In particular, instruments that supply digital data for a mathematical description of the movement are necessary for the quantitative analysis of the global characteristics of motion [12,29]: motion patterns, velocity, fluidity of movement may all be analyzed for a deeper insight into the normal head–cervical complex as well as for the characterization of patients [3,29].

The same protocol could be applied both to normal individuals of different ages, and to patients with several alterations of the head and neck locomotor apparatus. Quantitative diagnostic tools could then be developed [1,4,29]. Currently, we are testing patients with a mild whiplash injury during their rehabilitation therapy. This longitudinal analysis might be used to assess the effects of treatment on the global head and neck function.

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