

Original Article

# Comparison of visual and ultrasound based techniques to measure head repositioning in healthy and neck-pain subjects

Alexandra Roren\*, Marie-Anne Mayoux-Benhamou, Fouad Fayad,  
Serge Poiraudeau, Didier Lantz, Michel Revel

*Department of Rehabilitation, Cochin Hospital, 27 Rue du Faubourg Saint Jacques, 75679 Paris Cedex 14, France*

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## Abstract

Three-dimensional (3D) ultrasound based (US) and usual Revel visual techniques were compared to measure head repositioning ability in 41 healthy subjects and 41 subjects with neck pain. Head repositioning absolute value of the global error (AE) was calculated by both techniques after active head rotations. The AE was 3.6° and 3.7° for healthy subjects and 6.3° and 6.1° for neck-pain subjects for the visual and US techniques, respectively. The AE was higher in neck-pain subjects ( $p < 0.001$ ), and a value of 4.5° was identified as a threshold of abnormal repositioning for both techniques. The test–retest reliability, calculated in the neck-pain subjects, was moderate (intraclass correlation coefficient [ICC] = 0.68) for both techniques. The correlation between the two techniques for AE was poor for both groups with successive measurement of visual and US techniques ( $r = 0.32$  and 0.46, respectively) but excellent with simultaneous measurement ( $r = 0.95$  for both groups). Moreover, we showed substantial agreement between the techniques in discriminating healthy and neck-pain subjects ( $\kappa = 0.65$ ). The Revel visual technique is more appropriate for clinical practice, but with improved software, the 3D US method could provide additional quantitative and qualitative data invaluable for research.

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## 1. Introduction

The neural control of the head–neck system depends on the convergence of the cues provided by the proprioceptive, vestibular and visual paths (Lakie and Loram, 2006). The vestibular and proprioceptive systems interact (Karnath et al., 1994), and oculo-cervical coupling has been identified (Andre-Deshays et al., 1988). The cervical proprioception contributes importantly to head position and to head orientation in space, as suggested by the wealth of muscular and articular receptors

(McLain, 1994; Proske, 2005). The role of kinesthetic sensitivity disturbance in dizziness following cervical trauma has been emphasized (Treleaven et al., 2005). Even with nonspecific cervical pathologic conditions, alterations of proprioception should disrupt head–neck postural and dynamic control (Revel et al., 1991). A reliable measurement of sense of head and neck position is necessary.

Revel et al. (1991) devised a simple test to assess cervical proprioception using head repositioning ability. This test consists of a visual measurement of the error of relocating the head to the initial neutral position after an active cervical rotation. The ability to relocate the head was altered in patients with neck pain, and the authors identified a threshold of repositioning error expressed

\* Corresponding author. Tel. +33 1 58 41 25 41; fax: +33 1 58 41 25 45.

*E-mail address:* [alexandraroren@yahoo.fr](mailto:alexandraroren@yahoo.fr) (A. Roren).

in degrees that discriminates abnormal from normal repositioning. The mean error was  $>4.5^\circ$  for 89% of the neck-pain subjects and  $<4.5^\circ$  for 89% of the healthy subjects. The head repositioning test was also described as an exercise and used to measure the effect of a neck-pain rehabilitation program (Revel et al., 1994). This test has been widely used (Heikkila and Astrom, 1996; De Hertogh et al., 2000; Rix and Bagust, 2001; Kristjansson et al., 2001; Humphreys et al., 2002) and the test–retest reliability has been evaluated in a group of healthy subjects (Pinsault et al., 2006).

Recently, an ultrasound based (US) technique was used with various experimental procedures to measure sense of head and neck position in asymptomatic populations (Strimpakos et al., 2006; Lee et al., 2006).

We aimed to compare the original Revel visual method with a three-dimensional (3D) US technique in healthy subjects and those with neck pain to evaluate the clinical utility of the techniques and intra-rater reliability in head repositioning assessment.

## 2. Patients and methods

### 2.1. Population

To be included in the study, healthy subjects and those with neck pain had to be older than 18 years and not have any vestibular, neurological or inflammatory rheumatic disorders. All subjects were patients from a rehabilitation department and were therefore screened by the medical team.

We collected data on age, sex, height, weight and sports activity, as well as duration of pain (for neck-pain subjects) in months and intensity of the cervical pain at rest and during the tests by a visual analog scale (VAS, 0–100-mm length). French bioethics legislation does not require consent from the Hospital Ethics Committee for this type of study. The study was conducted in compliance with the protocol Good Clinical Practices and Declaration of Helsinki principles. In accordance with the French national law patients gave their written agreement to participate after being informed of the experimental protocol.

### 2.2. Instrumentation

The subject, who wore a helmet (different helmet for Revel visual and US technique), was seated in a supported position on a chair with a backrest in front of a target (similar for both techniques) (Fig. 1A and B).

#### 2.2.1. Revel visual technique

For the Revel visual technique, the helmet weighed 250 g and had a light beam on top (Fig. 1C). A circular graduated target (40-cm diameter with concentric circles

every centimetre) was divided into four quadrants separated by two axes intersecting at 0 (the horizontal axis in abscissa and vertical axis in ordinate). The target was placed on the wall in front of the subject and adjusted to align with the subject's reference head position. Opaque goggles (weight 30 g) were used to occlude the subject's vision during the test.

Manufacturers' details for Revel visual technique have previously been described (Savignat and Roren, 2007).

#### 2.2.2. US technique

For the US technique, we used a US motion analysis system to measure the head repositioning error in three cardinal planes (Zebris; Zebris medizintechnik GMBH, D88316, Isny, Germany). The US helmet, weighing 194 g, was fitted with a US tripod transmitter to detect real-time cervical spine motion (Fig. 1D), and data were stored on a computer.

A laser pen was fixed on the US helmet to visually determine the initial reference position with the light beam projecting on the target. Moreover, the laser pen allowed for, at each trial, a visual reading of the head repositioning error in addition to the results given by the US technique. The visual reading during the US experiment was defined as the US-visual technique.

Because of the design of the helmet, the subject could not wear goggles, so the vision was occluded by taping a square piece of fabric in front of each eye with adhesive tape (Fig. 1D).

### 2.3. Experimental procedure

The experimental procedure was similar with both Revel visual and US techniques. The US technique differed only in use of the US motion analysis system. As previously described (Revel et al., 1991), the subject, vision occluded, was instructed to adopt the self-determined neutral head–neck position, defined as the reference position. Then, the target was placed so that the light beam on top of the helmet pointed to the target's center (zero [0] on the target). The reference position was thus reliable for each trial with the visual or US technique.

For each trial, the subject was instructed to memorize the initial reference position, then to perform a maximal cervical rotation (horizontal plane) for about 2 s and to accurately return to the reference position without any speed constraint.

Subjects performed 10 trials for each technique. Before each trial, the examiner manually repositioned the subject's head to the reference position, and for the US technique, the motion analysis system was calibrated. The repositioning absolute value of the global error (AE) was recorded after each trial of head



Fig. 1. (A) Revel visual technique: subject on a chair in relaxed posture in front of the target. (B) US technique: subject on a chair in relaxed posture in front of the target, the transducer sensor stand is placed at 80 cm from the source to detect the US waves for all ranges of motion. By use of triangulation, the measurement was derived from the time delay between the US pulses measured at a sampling rate of 25 Hz. (C) Revel visual technique: helmet with a light beam, opaque goggles. (D) US technique: specially designed headgear with ultrasound tripod transmitter. A laser pen was added on top.

repositioning. No information on head repositioning ability was given to the subject.

We assessed unilateral repositioning ability so as to avoid subject fatigue, since the results do not differ after right or left head rotation (Revel et al., 1991; Kristjansson et al., 2001). The direction of cervical rotation and the order of the techniques were selected at random. The experiment lasted about 30 min.

We calculated test–retest reliability of the visual and US techniques in the neck-pain population by the same examiner repeating the entire procedure after a 1-h rest.

With the Revel visual and the US-visual techniques, for each trial, the head repositioning error was visually and directly measured on the target by the distance between the final position of the spot of light and the initial reference position (projection of the light beam on the center of the target). Because the purpose of the experiment was the evaluation of an error in head repositioning after angular head displacement, the centimetric measurements on the target were converted to degrees from the center of

rotation (taken as the source of the light beam at the top of the helmet, 90 cm from the target).

For the US technique, 3D data on cervical motion were processed by use of the Winspine V 1.78 software and expressed in degrees. The head repositioning AE corresponded to the final repositioned position registered by the US motion analysis system.

We considered the Pythagoras theorem as an appropriate way to convert the 3D data (US technique) into 2D data (Revel visual technique) (Fig. 2A).

#### 2.4. Statistical analysis

Data analysis involved use of Systat 9 software. Head repositioning error was expressed by the AE as mean  $\pm$  standard deviation (SD) of 10 trials of head repositioning. The AE means were compared in healthy and neck-pain subjects and by the Student's *t*-test. For both visual and US techniques, the relation between the AE means and quantitative anthropometric

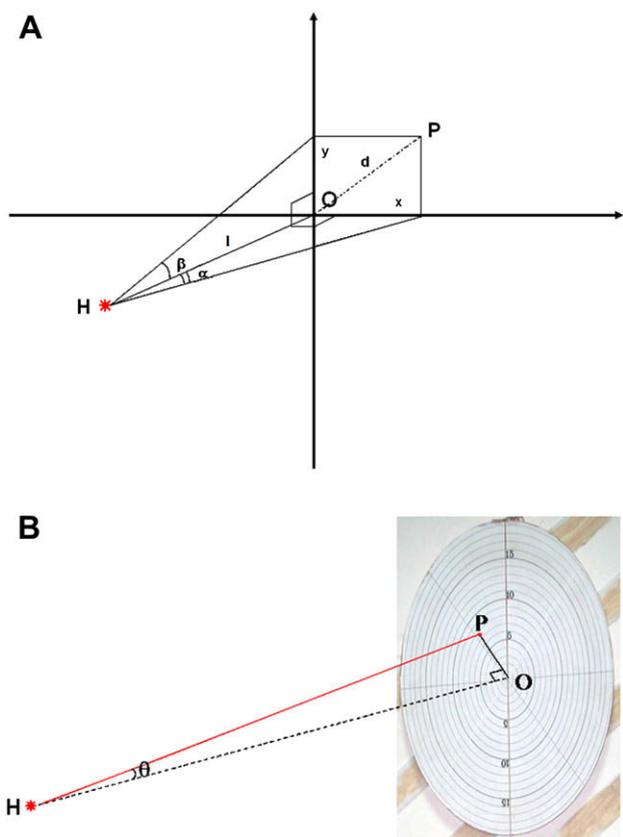


Fig. 2. (A) Conversion of the 2D data into 3D. Pythagoras equation,  $d = l\sqrt{(\sin \alpha^2 + \sin \beta^2)}$ . H, light beam on the subject’s head; d, distance between the initial reference position O and the final position P; x, abscissa of P; y, ordinate of P; l, distance between the cutaneous projection of the subject’s head center of rotation (localization of the light beam) and the target;  $\alpha$ , angle in the sagittal plane; and  $\beta$ , angle in the horizontal plane. (B) Conversion of the measurements in centimetres to degrees. H, light beam on the subject’s head; O, center of the target representing the initial reference position of the head; P, final position of the head; OH, distance between the light beam and the target in the initial reference position; HP, distance between the light beam and the target in the final position. The distance between “O” and “P” represents the head repositioning error in centimetres. The triangle HOP is rectangular, thus the trigonometric formula: tangent  $\theta = OP/OH$ ,  $\theta = \text{tang}^{-1} (OP/OH)$ , was used to convert head repositioning error measured in centimetres (OP) to degrees ( $\theta$ ).

parameters was assessed by the Spearman correlation coefficient (*r*) and that between the AE means and qualitative parameters (sex, sports activity) by Student’s *t*-test. A *p* < 0.05 was considered statistically significant.

To determine the threshold of abnormal repositioning, we used specificity and sensitivity analysis with receiver operating characteristic (ROC) curve analysis.

Test–retest reliability for the head repositioning AE in neck-pain group was assessed with the intraclass correlation coefficient (ICC) for Revel visual and US techniques (Shrout and Fleiss, 1979). In addition, the Bland and Altman (1986) method was used for testing agreement between the AE means of the two experiment sets.

The correlation between AE means for successive measurement with Revel visual and US techniques and for simultaneous measurement with US and US-visual techniques were calculated for healthy and neck-pain groups by the Spearman *r*.

The Kappa statistic was used to calculate the percentage agreement between the Revel visual and the US techniques in terms of threshold of abnormal repositioning. Although no standard for interpreting a reliability coefficient exists, Landis and Koch (1977) suggested the following for the Cohen *k* statistic in terms of agreement: <0.0, poor; 0.0–0.2, slight; 0.21–0.40, fair; 0.41–0.60, moderate; 0.61–0.80, substantial; and 0.81–1.0, excellent.

### 3. Results

All repositioning errors were expressed by AE as mean ± standard deviation (SD) of 10 trials of head repositioning.

#### 3.1. Population data

Basic data for the healthy and neck-pain subjects are in Table 1.

#### 3.2. Head repositioning with Revel visual and US techniques

The AE was significantly greater in the neck-pain group than in the healthy group with either the Revel

Table 1  
Basic data of the healthy and neck-pain subjects.

	Healthy (n = 41)	Neck pain (n = 41)	<i>p</i>
<b>Anthropometric data</b>			
Male, <i>n</i> (%)	18 (44)	11 (27)	0.159
Age (mean ± SD), years	30.5 ± 11.4	54.7 ± 14.2	<0.0001
Body mass index (mean ± SD), kg/m <sup>2</sup>	22.5 ± 3.8	25.1 ± 6.5	0.017
Sport activities, <i>n</i> (%)	13 (32)	0 (0)	NA
<b>Neck pain intensity</b>			
At rest (mean ± SD), mm	NA	15.9 ± 19.7	NA
During test (mean ± SD), mm	NA	26.8 ± 21.8	NA
Neck-pain duration (mean ± SD), months	NA	88.2 ± 68.3	NA
<b>AE</b>			
Visual technique (mean ± SD), degrees	3.6 ± 0.8	6.3 ± 2.4	<0.001
US technique (mean ± SD), degrees	3.7 ± 0.9	6.1 ± 2.9	<0.001

Sports activities refer to the percentage of subjects playing sports for at least 3 h a week.

Body mass index = weight (kg)/height<sup>2</sup> (m<sup>2</sup>).

Neck pain intensity was measured on a 100-mm visual analogue scale. NA, non applicable.

*p* < 0.05 was considered statistically significant.

visual or US technique ( $6.3^\circ \pm 2.4$  vs  $3.6^\circ \pm 0.8$  [ $p < 0.001$ ] and  $6.1^\circ \pm 2.9$  vs  $3.7^\circ \pm 0.9$  [ $p < 0.001$ ], respectively).

For the healthy group, the AE was not related to age ( $r = 0.1$ ,  $p = 0.5$  and  $r = 0.004$ ,  $p = 0.98$  for Revel visual and US techniques, respectively), sex ( $p = 0.26$  and  $p = 0.51$  for Revel visual and US techniques, respectively) or sports activity ( $p = 0.38$  and  $p = 0.86$  for Revel visual and US techniques, respectively) but was weakly related to body mass index for the Revel visual technique only ( $r = 0.37$ ,  $p = 0.02$ ). For the neck-pain group, the AE was not related to body mass index ( $r = 0.1$ ,  $p = 0.54$  and  $r = 0.05$ ,  $p = 0.75$  for Revel visual and US techniques, respectively), sex ( $p = 0.97$  and  $p = 0.77$  for Revel visual and US techniques, respectively), or pain ( $r = 0.07$ ,  $p = 0.66$  and  $r = 0.04$ ,  $p = 0.79$  for Revel visual and US techniques, respectively) but was weakly related to age for the Revel visual technique only ( $r = 0.37$ ,  $p = 0.02$ ).

### 3.3. The threshold value of abnormal repositioning

Sensitivity and specificity analysis gave a threshold value of  $4.5^\circ$  for Revel visual and US techniques (Fig. 3A and B). Sensitivity was 78% with both techniques and specificity 85% and 78% for the Revel visual and US technique, respectively. Positive and negative

predictive values were 0.8 with both techniques. The Revel visual and US techniques showed an 80% and 82% chance, respectively, that neck-pain subjects would reposition the head outside the limit of  $4.5^\circ$  and that healthy subjects would reposition within this zone.

### 3.4. Comparison of techniques in AE values

The correlation between the two techniques in head repositioning AE was poor for both healthy and neck-pain subjects ( $r = 0.32$ ,  $p = 0.04$ ; and  $r = 0.46$ ,  $p = 0.004$ , respectively). When measurements were taken with the Revel visual and US techniques simultaneously the two techniques showed excellent correlation in AE for both healthy and neck-pain subjects ( $r = 0.946$  and  $r = 0.952$ , respectively). For the threshold value of  $4.5^\circ$  for head repositioning AE, the kappa statistic showed substantial agreement (kappa = 0.65) between Revel visual and US techniques to discriminate between healthy and neck-pain subjects in repositioning.

### 3.5. Test-retest reliability of the Revel visual and US techniques for neck-pain subjects

ICC values were similar for both Revel visual and US techniques for the neck-pain subjects (ICC = 0.68). For the US-visual technique, the ICC was 0.62.

According to the Bland and Altman plot (Fig. 4A and B), most of the differences were within the confidence interval ( $-3.6$  and  $4.2$  for the Revel visual technique and  $-3.8$  and  $5.6$  for the US technique) and mean differences between test and retest were small. We considered that  $X$  (means of the two tests) and  $Y$  (differences between the two tests) were independent for both Revel visual and US techniques ( $r = 0.35$  and  $p = 0.04$  and  $r = 0.3$  and  $p = 0.05$  for Revel visual and US techniques respectively). There was no systematic trend in the plot.

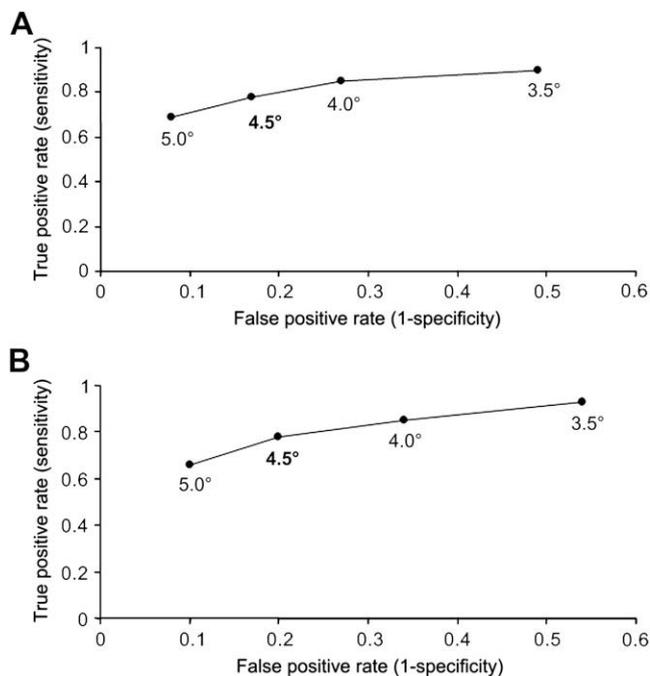


Fig. 3. The receiver operating characteristic (ROC) curve was constructed for four cutpoints:  $3.5^\circ$ ,  $4^\circ$ ,  $4.5^\circ$  and  $5^\circ$ . The best tradeoff between sensitivity and sensibility (largest ordinate for the smallest abscissa) was observed for a cutpoint of  $4.5^\circ$ , defined as the threshold of abnormal repositioning. (A) ROC curve with Revel visual technique. (B) ROC curve with US technique.

## 4. Discussion

This study was the first to assess AE in the head repositioning test and the clinical relevance of the test with use of two techniques, the usual Revel visual technique and a 3D US technique, in two populations: healthy subjects and those with neck pain. It was also the first to evaluate the test–retest reliability in a neck-pain group. We demonstrated that head repositioning ability could be quantitatively assessed by either technique, but the Revel visual technique might be more adapted to daily clinical practice.

The head repositioning AE we observed in the healthy and neck-pain groups was in agreement with those from previous studies of the Revel visual technique, which ranged from  $2.74^\circ$  to  $5.25^\circ$  for healthy

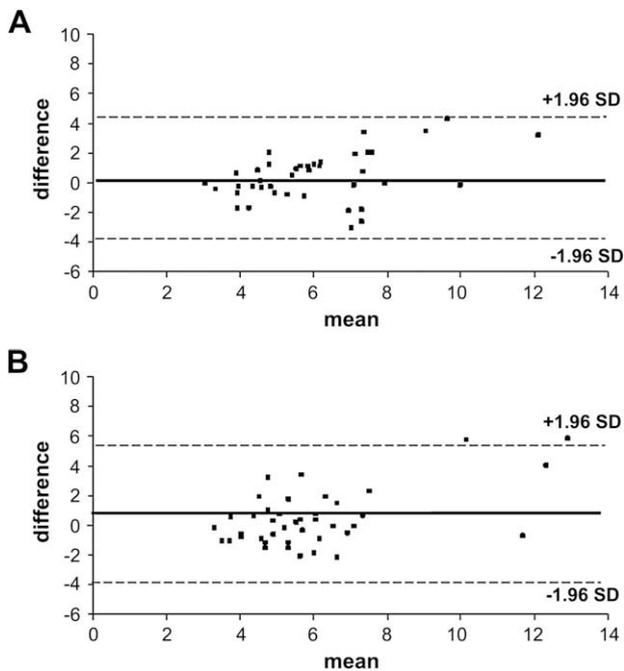


Fig. 4. Bland and Altman plot for neck-pain population: test–retest study for the AE plotting agreement of the means of the two tests against the difference between the tests for Revel visual (A) and US (B) technique. The mean of the differences between the two scores (0.3 and 0.9 for Revel visual and US techniques, respectively) was used to calculate the 95% limits of agreement (expressed by dashed lines) for the two scores:  $-3.6$  and  $4.2$  for Revel visual technique and  $-3.8$  and  $5.6$  for US technique. Means and differences were expressed in degrees.

subjects (Heikkilä and Åström, 1996; De Hertogh et al., 2000; Rix and Bagust, 2001) and from  $4.2^\circ$  to  $6.11^\circ$  for neck-pain populations (Revel et al., 1991; De Hertogh et al., 2000; Rix and Bagust, 2001). Previous studies of the US technique evaluated only healthy subjects, and the method of calculating the head repositioning error differed from ours in that it was assessed only in the horizontal plane and did not take into account associated motions in other planes (Strimpakos et al., 2006; Lee et al., 2006; Demaille-Wlodyka et al., 2007). In the present study, we transformed the 3D independent data into a 2D global result to compare the AEs obtained by both techniques.

In agreement with the previous results, our results showed a significant difference in head repositioning AE between healthy subjects and those with neck pain (Revel et al., 1991; Heikkilä and Åström, 1996). One study found no difference in head repositioning AE between similar groups but included only 11 subjects in each group and gave no instruction about the speed of the movement (Rix and Bagust, 2001).

Head positioning ability did not differ significantly by sex, age, pain intensity or sports activity in the healthy group. In agreement with our results, recent results showed in a large sample of healthy volunteers that

neck proprioception was unaffected by age (Demaille-Wlodyka et al., 2007). In the present study, AE was weakly related to age in the neck-pain group for the Revel visual technique. Because cervical osteoarthritis is more frequent with age, distinguishing between the effects of age and neck pain is difficult. Further research into the relation between age and head repositioning ability in a neck-pain population is required. In agreement with previous results, our finding of no correlation between repositioning AE and pain intensity did not reflect the possible influence of nociceptive inputs on the repositioning disability; however, in our sample, the mean intensity of pain at rest and during the tests was low (Revel et al., 1991). A difference in participation in sports between the control group and the patient group could account for the difference in repositioning ability. No one in the neck-pain group played sports, and in the healthy group, the AE measured by either technique was not related to sports activity. However, the sample was small and the range of sports was wide. Therefore, the effect of sports on neck proprioception remains unknown.

We could have used the same helmet (the US motion analysis system) for the Revel visual and US techniques and thus obtain only simultaneous measurements. We chose to use different headgears for each technique because we wanted to reproduce exactly the initial test (including the specific helmet) described by Revel et al. (1991).

Previous studies assessed test–retest reliability of the head repositioning test in healthy people. Excellent reliability was reported in a small sample of young healthy students with the Revel visual technique, and Bland and Altman plotting revealed satisfactory agreement between two successive measurements of head repositioning AE (Pinsault et al., 2006). With a US technique, test–retest reliability ranged from moderate to high (Lee et al., 2006). A different experimental procedure showed the intra- and inter-examiner studies with poor reliability (Strimpakos et al., 2006). In the present study, the test–retest reliability was assessed in the neck-pain group only because it had not yet been studied in a symptomatic group. Moreover, study of the evolution of neck pain and of the effects of treatments requires a reliability assessment of the head repositioning test in the symptomatic population. In neck-pain subjects, the ICC values were moderate with visual, US and US-visual techniques. However, the differences in AE for head repositioning between techniques and between the two sets of experiments still showed a narrow margin considering that we were studying human head repositioning performance. That raises the question of the relevance of the ICC test to assess the reliability of these kinds of measurements.

Bland and Altman plotting related to Revel visual and US techniques revealed satisfactory agreement between

the two successive measurements. The variability of the head repositioning ability was larger for subjects with higher repositioning AE. However, this trend was close to the significance threshold so it could be neglected.

When head repositioning was assessed with Revel visual and US techniques in random order in succession, the correlation of AE was poor for healthy and neck-pain groups but excellent with simultaneous measurement from US-visual and US techniques. Visual reading and US assessment could thus be considered as two different ways to measure the same head repositioning error. The results of correlation of Revel visual, US-visual and US techniques and reliability of Revel visual and US techniques in head repositioning error raise the question of the durability of head repositioning ability in a neck-pain population, which had been little studied until now (Revel et al., 1994). The difference in correlation between successive and simultaneous measurements and the moderate reliability also suggest that some of the items of the experimental procedure could increase the intra-individual variability. The weight and the shape of the two helmets were slightly different. The vision-occluding devices were not identical as well. The ultrasound source emitted a buzz, whereas the Revel visual technique was silent. With simultaneous measurements only (US-visual and US techniques), one could be sure that the experimental conditions remained strictly unchanged. Moreover, the duration of the experiment (one set of 10 trials with one technique immediately followed by one set of 10 trials with the other technique) and the numerous handlings (change of helmets and vision-occluding devices) could interfere with subjects' head repositioning ability and thus alter correlation and reliability. The human factors of variations and the experimental conditions of carrying out the tests tended also to reduce the reliability between trials in the same experiment set and supported the need for several trials.

We considered a comparison of Revel visual and US successive measurements according to a pathological threshold identified by both techniques to be clinically more relevant. In our study, the threshold value of inaccurate repositioning was  $4.5^\circ$  with both techniques and the intra-rater agreement between the two techniques measured separately was substantial. This same threshold was identified previously (Revel et al., 1991).

The visual measurements of the head repositioning ability confirmed results of previous studies. Among different tests evaluating sense of head and neck position, only the visual head repositioning test was successful in differentiating healthy subjects from those with neck pain (Kristjansson et al., 2003). The Revel visual technique is easy to handle, rapid and economical, so it fits well with clinical practice. However, data are not recorded and cannot be checked later. A detailed analysis of the repositioning procedure is thus impossible;

however, an alternate repositioning strategy, such as overshooting (i.e., overestimation of the distance for repositioning), has been described (Revel et al., 1991). Because our study aimed to compare the Revel visual and US measurement techniques and because the information provided by the Revel visual technique was incomplete, we did not detail how the head was repositioned. However, we noticed differences in repositioning strategy between the two groups that deserve further study. The error visually measured on the target is in two dimensions and results from the projection of 3D coordinates of the head posture on a vertical plane (the target), so a hypothetical projection error cannot be ruled out. On the whole, the Revel visual technique is useful in daily clinical practice for rehabilitation and to evaluate changes.

The 3D US technique is more accurate than the Revel visual technique (Dvir and Prushansky, 2000) and excludes any projection error (Bullitt et al., 1997). It also provides complementary data such as 3D measurement of the range of motion and speed of head movements and allows for a delayed analysis of recording. However, the US technique is expensive, time-consuming and not easily adapted to the assessment of head repositioning ability. The head position is expressed in each of the three dimensions separately, and calculations are needed to assess the global head repositioning error. A systematic calibration of the position was necessary before each trial and took several seconds, during which the examiner maintained the head in the reference position with one hand while managing the data-processing tasks with the other one. Thus, the examiner could provoke some perturbations in the subject's proprioceptive sensitivity. With modification of the software dedicated to the head repositioning test, this disadvantage could be avoided. The 3D US technique is probably more adapted to research in providing information about the individual procedure in repositioning the head.

## 5. Conclusion

This study confirmed the clinical relevance of the head repositioning test, whatever the technique used, Revel visual or US. Head repositioning global error was similar, whatever be the measurement technique. The head repositioning accuracy was significantly higher in the healthy group than in the neck-pain group, and the same pathological threshold was identified with both techniques. The two techniques are complementary: the Revel visual technique provides an efficient quantitative assessment of head repositioning ability but gives only little information on repositioning strategy, whereas the US technique does not improve the quantitative assessment of head repositioning ability but might well be used to study pathological repositioning strategy.

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