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Neck motion patterns in whiplash-associated disorders: Quantifying variability and spontaneity of movement

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ABSTRACT

Background: Whiplash-associated disorders have usually been explored by analyzing changes in the cervical motor system function by means of static variables such as the range of motion, whereas other behavioural features such as speed, variability or smoothness of movement have aroused less interest.
Methods: Whiplash patients (n = 30), control subjects (n = 29) and a group of people faking the symptoms of whiplash-associated-disorders (*Simulators*, n = 30) performed a cyclical flexion–extension movement. This movement was recorded by means of video-photogrammetry. The computed variables were: range of motion, maxima angular velocity and acceleration, and two additional variables that quantify the repeatability of a motion and its spontaneity. Two comparisons were made: *Control* vs. *Patients* and *Patients* vs. *Simulators*. At each comparison we used ANOVA to detect differences between groups and discriminant analysis to evaluate the ability of these variables to classify individuals.
Findings: Comparison between *Controls* and *Patients* showed significant reductions in the range of motion, and both the maximum of angular velocity and acceleration in the *Patients*. The most efficient discriminant model only included the range of motion and maximum angular velocity. Comparison between *Patients* and *Simulators* showed a significant reduction in all measured variables in the *Simulators*. The best classification model was obtained with maximum angular velocity, spontaneity and repeatability of motion.
Interpretation: Our results suggest that the pathological patterns differ from those of *Controls* in amplitude and speed of motion, but not in repeatability or spontaneity of movement. These variables are especially useful for detecting abnormal movement patterns.

1. Introduction

Whiplash-associated disorders (WAD) include a broad spectrum of illnesses related to cervical soft-tissue injury typically resulting from motor vehicle accidents. Due to the difficulties of identifying damage to bone and soft tissue causing chronic neck pain, WAD is usually described by its symptoms. The Quebec Task Force describes a wide range of associated symptoms (Spitzer et al., 1995) that are the basis for defining clinical exploration procedures to evaluate the severity of WAD. The most common techniques are based on changes in the cervical motor system function. These changes include reduced neck movement, proprioception alterations and modification of motion patterns.

Some studies show the existence of a decreased range of motion in both active and passive tests (Feipel et al., 1999; Dall'Alba et al., 2001). Thus, an impaired range of motion (RoM) can be useful for distinguishing between asymptomatic persons and those with persistent whiplash-associated disorders by using multivariate discriminant techniques (Dall'Alba et al., 2001; Sterling et al., 2003).

Most of these studies analyze static position variables such as angular ranges of motion in different movements or variability in angular data. Nevertheless, kinematic variables associated with movement could provide more information to describe motor control disturbances. This approach has been explored by Feipel et al. (1999), who suggested an increase in reaction time and a decrease in speed in pathological people. These results are confirmed in later studies in which the maximum speed of neck movement is an important variable for distinguishing between healthy and pathological groups (Öhberg et al., 2003; Grip et al., 2008).

Although all these objective measurements are useful for clinical applications, their reliability depends on patient cooperation in performing the tests, otherwise it becomes very difficult to determine the severity of the disorder (Dvir et al., 2004). On the other hand, the legal and economic consequences of such decisions increase the need

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for well-founded criteria to evaluate sincerity in performing the tests (Dvir et al., 2001). Surprisingly, analysis of the effect of patient cooperation has received little attention in biomechanical literature. The identification of abnormal patterns has been associated with intra-subject variability in RoM measurements (Dvir et al., 2001, 2004; Prushansky et al., 2006). Another approach is that suggested by Feipel et al. (1999) who used the presence of hesitation or changes of velocity in movement performance to detect abnormal patterns of movement.

The objective of this paper is to quantify some of the features of neck motion patterns, such as variability and spontaneity of movement, in order to objectively evaluate behavioural aspects related to whiplash-associated disorders (WAD), including the possibility of a lack of cooperation by patients. We assume that the selection of a particular strategy affects the spontaneity and repeatability of the movement in cyclical motions. Therefore, these characteristics could be good indicators of behavioural aspects such as the exaggeration of symptoms. In order to confirm or reject this hypothesis we have developed an experiment that included healthy people and chronic WAD patients, as well as an additional group of people faking acute WAD symptoms. In this way we can analyze the differences between healthy and pathological patterns as well as the characteristics of anomalous motion patterns associated with non-spontaneous movements.

2. Methods

2.1. Dynamic model: harmonic oscillator

For repetitive movements such as those reproduced in our study, driven harmonic motion can be a simple and suitable reference for comparing motion patterns. From a kinematic point of view, the harmonic oscillator is described by the position variable and its derivatives. Assuming that the position variable is an angle (flexion–extension angle θ, for example), these variables can be expressed as:

$$\theta = A\sin(2\pi f t) \tag{1}$$

$$\dot{\theta} = 2\pi f A\cos(2\pi f t) \tag{2}$$

$$\ddot{\theta} = -(2\pi f)^2 A\sin(2\pi f t) = -(2\pi f)^2\theta \tag{3}$$

where A is the amplitude of cyclical motion and f is its frequency. $\dot{\theta}$ *and* $\ddot{\theta}$ are the angular velocity and acceleration respectively.

Given that the harmonic model does not require any specific control, spontaneous repetitive movements may be similar to a harmonic oscillator, whereas a deliberate controlled motion should differ from this model. Fig. 1 shows the similarities between the harmonic oscillator and the spontaneous neck flexion–extension movement of a healthy person. In Fig. 1a we have represented $\dot{\theta}$ *vs* θ. The ideal harmonic model must fit an ellipse (see Eqs. (1)–(2)). The actual movement of the control is similar to an ellipse but there is some dispersion due to natural intra-subject variability. In Fig. 1b we have represented $\ddot{\theta}$ *vs* θ. The ideal oscillator must fit a straight line with a negative slope (see Eq. (3)); for the actual motion, this linear behaviour remains within almost all the range of movement. These characteristics will be used to describe intra-subject movement variability as well as spontaneity measured as the fit between the motion performed and the harmonic model, or harmonicity (Fernandez and Bootsma, 2004).

2.2. Sample of study

Eighty-nine volunteers participated in the study. The size of the sample met the criteria of Lachenbruch and Goldstein (1979) for a discriminant analysis with five independent variables and two groups

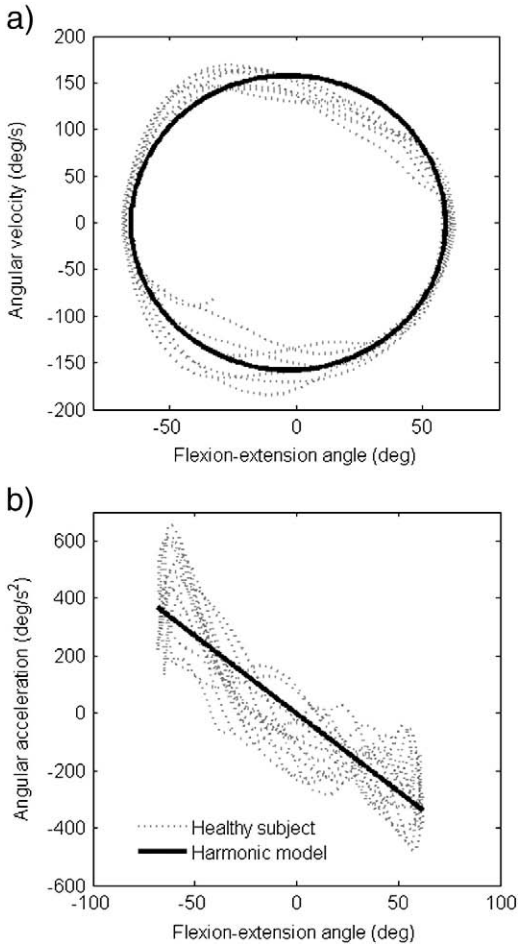

Fig. 1. Similarities between the harmonic oscillator and spontaneous neck flexion–extension movement in a healthy person. a) Angular velocity vs. flexion–extension angle. b) Angular acceleration vs. flexion–extension angle.

(a minimum of 26 subjects per group). The subjects were classified into three different groups defined by the following selection criteria:

- Control group (*Controls*): this group consisted of 29 volunteers meeting the following criteria: absence of whiplash-associated disorders, absence of neurological antecedents and absence of osteo-articular disease.
- Chronic whiplash group (*Patients*): this sample (n = 30) was recruited by the medical team of the Rehabilitation Unit of the ASEPEYO Hospital (San Cugat del Vallés, Spain). The criteria for inclusion were: patients affected by WAD with altered mobility of the neck, corresponding to degrees II and III of the Quebec Task Force Scale (Spitzer et al., 1995), for more than 6 months and less than 1 year.
- Recovered WAD group (*Simulators*): this group (n = 30) included people who had recovered from a WAD and who had not presented any symptoms during the previous 2 years. They were requested to reproduce voluntarily the same pattern of movement that they had had during the period with cervical pain. It has been assumed that people with a satisfactory recovery from a WAD were more likely to feign the painful pattern well. The subjects were recruited from the IBV database.

In order to control the potential effects of age and gender, all groups were balanced by these variables (see Table 1). All the subjects signed an informed consent form for participation in the study, which was approved by the Ethics Committee of the Universidad Politécnica de Valencia.

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Table 1
Sample of participants in the study.

Group	Age-group	Male	Female	Total
Controls	(20–30)	4	6	**10**
	(31–40)	5	4	**9**
	(41–50)	5	5	**10**
	Total	**15**	**15**	**29**
Patients	(20–30)	3	6	**9**
	(31–40)	5	6	**11**
	(41–50)	7	3	**10**
	Total	**15**	**15**	**30**
Simulators	(20–30)	5	6	**11**
	(31–40)	4	5	**9**
	(41–50)	5	5	**10**
	Total	**14**	**16**	**30**

2.3. Experimental setup

People sat down on an adjustable chair designed to immobilize the trunk. Trunk mobility was limited by means of a set of straps on the shoulder and around the thorax and pelvis as described in Baydal-Bertomeu et al. (2007). In this way we characterized neck motion by measuring head movement. Head position and movements were recorded by means of a video-photogrammetry system (Kinescan-IBV; Page et al., 2006a) from the coordinates of a set of reflective markers located on a helmet.

At the beginning of the tests, the subjects were instructed on the kind of motion to be performed. Then they performed some non-controlled movements in order to familiarize themselves with the equipment and to practise the motion.

In order to have a reference position to measure angles, a calibration phase was performed prior to each measurement session. In this session people sat on the chair and looked at a 3×8 cm mirror placed 2.5 m in front of the chair at eye height (measured by means of a Martin anthropometer). Two additional markers were placed in the ears in order to define an anatomical medio-lateral axis. After the calibration phase, the additional markers were removed.

In the measurement phase, the subject was requested to perform repetitive flexion–extension cycles at a self-selected speed for 30 s. Measurement sessions started and finished with the subject in the reference position.

2.4. Data processing and statistical analysis

We computed the finite displacement from point coordinate data by using the algorithms described in Page et al. (2009). The results were the angular displacements expressed as the attitude vector (Woltring, 1994). The projection of the attitude vector on the medio-lateral axis provided a measurement of the flexion–extension angle.

Angular velocity and angular acceleration were estimated by numerical differentiation of the flexion–extension angle using a local smoothing technique (Page et al., 2006b). From the smoothed angles, angular velocity and acceleration, we computed the following variables:

- *Range of motion* (RoM): angular excursion of the motion.
- *Maximum angular velocity* (MAV), measured as percentile 95 of angular velocity during the test.
- *Maximum angular acceleration* (MAA), measured as percentile 95 of angular acceleration during the test.
- *Phase area ratio* (PAR): defined by

$$\mathrm{PAR} = 100 \times \frac{S_P}{S_M} \tag{5}$$

where S_M is the area delimited by the mean cycle of the $\dot{\theta}$ *vs* θ diagram; S_P is the area delimited by the mean cycle ± 1 standard deviation (Fig. 2). In the ideal case with no variability, S_P is null and then *PAR* = 0. In real movements some variability is present and then $S_P > 0$. Therefore, PAR quantifies the intra-subject variability across cycles; its meaning is similar to a coefficient of variation, but includes information on angles and speed performance.

- *Harmonicity* (HARM): is the absolute value of the correlation coefficient between $\dot{\theta}$ *and* θ. Thus HARM quantifies the fit between the actual movement and the simple harmonic motion.

The statistical analysis was done using the software SPSS 16.0 (SPSS Inc., Chicago, IL). We performed a descriptive analysis of the selected variables, as well as a comparison between groups (*Controls* vs. *Patients* and *Patients* vs. *Simulators*, respectively) by means of an ANOVA. The ANOVA provides a good description of the mean differences between groups but it does not allow us to quantify the similarities or differences between each individual pattern and its group. This kind of description was done by means of a discriminant analysis in order to analyze the capability of the whole set of kinematic variables to classify individuals. Two classifications were considered: *Controls* vs. *Patients* and *Patients* vs. *Simulators*. The most significant variables in each model were selected by forward stepwise analyses. These models were compared with the simplest one obtained by using only the RoM that is the most widely used variable in the literature.

For each model analysis we calculated sensitivity and specificity as:

$$\mathrm{Sensitivity} = 100 \times \frac{\mathrm{TN}}{\mathrm{TN} + \mathrm{FP}}$$

$$\mathrm{Specificity} = 100 \times \frac{\mathrm{TP}}{\mathrm{TP} + \mathrm{FN}}$$

where TN = true negatives; FP = false positives; TP = true positives and FN = false negatives. In both models we used a leave-one-out classification method. Note that in the *Controls* vs. *Patients* classification the positive cases are the patients because the aim of the model is to identify people with WAD symptoms. In the *Patients* vs. *Simulators* classification the aim is to identify non-spontaneous patterns, therefore the cases here are simulators.

3. Results

Fig. 3 depicts a comparison of the diagrams $\dot{\theta}$ *vs* θ and $\ddot{\theta}$ *vs* θ corresponding to a typical control subject, a patient and a simulator. These diagrams show the main features of each pattern of motion that are summarized in Table 2.

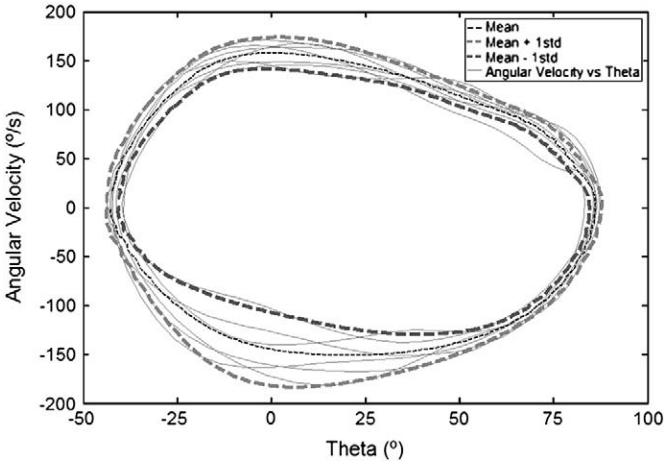

Fig. 2. Computation of variable PAR from the diagram $\dot{\theta}$ vs θ.

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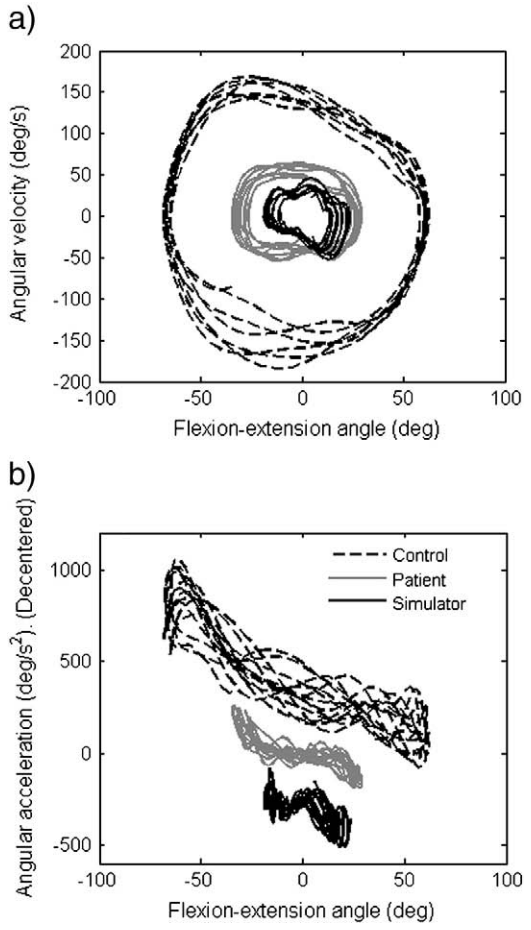

Fig. 3. Comparison of motion patterns of a typical control subject, a patient and a simulator. a) Diagram angular velocity-angle. b) Diagram angular acceleration vs. angle. The plots of accelerations have been decentred on the Y-axis to avoid overlap and improve comparisons.

Significant differences have been found between *Patients* and *Simulators* for all variables. RoM, MAV and MAA also show significant differences between *Controls* and *Patients*.

The mean of the range of motion (RoM) was significantly higher in *Controls* than in *Patients* and even more than in *Simulators*. Moreover, within-group variability was also different for each group, being highest in *Simulators* and lowest in *Controls*. Variable MAV showed a similar trend. The *Controls* presented MAV values which were significantly higher than those of *Patients*, and this latter was also higher than those of *Simulators*. Differences in the mean values of MAA were also evident among the three groups analyzed. Regarding the variable PAR, *Controls* and *Patients* presented very similar values whereas the *Simulators* mean was significantly higher. Finally, the variable HARM presented similar high values in *Controls* and *Patients* (0.79 and 0.78 respectively), but the values for *Simulators* were significantly lower (0.54).

Finally, Tables 3 and 4 show the results of the two sets of discriminant analyses. With regard to the classification between *Controls* and *Patients* (Table 3), the simplest model with only the RoM provided a modest classification with a good sensitivity of 86%, but with a specificity of only 70%. The best model included only two variables: RoM and MAV. In this model, specificity in classifying individuals increased from 70% to 93%, whereas sensitivity decreased slightly to 83%. *Controls* presented larger and faster movements than *Patients* (positive values of RoM and MAV coefficients in the discriminant functions), the MAV variable having more influence on the classification than the RoM (standardized coefficients were 0.72 and 0.52, respectively). Despite the significant differences of MAA between *Controls* and *Patients*, the MAA variable was not included in the model.

Regarding the classification between *Patients* vs. *Simulators*, the results were quite different (Table 4). The first classification with only the variable RoM presented a modest classification with a specificity of 73% and a sensitivity of 80%. The best model included the variables MAV, HARM and PAR. This model increased sensitivity to 87% and specificity up to 97%. All three variables made similar contributions to the discriminant function. *Patients* were distinguished from *Simulators* by their higher speed of motion and harmonicity (positive coefficients in the standardized discriminant function) and their lower variability when repeating cycles of the movement (negative coefficient of PAR).

In both cases we obtained a classification equation from the Fisher discriminant functions (MacLachlan, 1992). The differences between coefficients of standard discriminant functions and the classification coefficients are due to a change in the measurement scale (standardized and raw values, respectively).

4. Discussion

The aim of this paper was to quantify some features of neck motion patterns in order to objectively assess functional alterations associated to WAD, and evaluate behavioural aspects related to atypical motion performance. For this reason our study included three groups: *Controls*, *Patients* and another group of people who had recovered from a previous WAD with no current symptoms (*Simulators*).

The selection of a sample of appropriate "*Simulators*" is a critical question in the studies aimed to identify feigned or non-cooperative behaviour. In this study we have tried to reproduce this hypothetical situation by means of a sample of subjects who know the symptoms of WAD and who were requested to voluntarily reproduce the behaviour associated with pain. This strategy is similar to that used in previous papers in which patients or even healthy people are requested to exaggerate their symptoms or to feign the effect of an imagined pain, respectively (Dvir et al., 2001, 2004; Dvir and Penso-Zabludowski, 2003; Sartori et al., 2003; Endo et al., 2008).

Table 2
Descriptive analysis of the variables in the study. The listed p-values correspond to two separate comparisons by means of ANOVA: *Controls* vs. *Patients* and *Patients* vs. *Simulators*, respectively.

Variable	*Controls* mean (SD)	P-Value *Controls* vs. *Patients*	*Patients* mean (SD)	P-Value *Patients* vs. *Simulators*	*Simulators* mean (SD)
RoM (°)	119 (17)	<0.001	90 (22)	<0.001	55 (24)
MAV (°/s)	149 (50)	<0.001	71 (22)	<0.001	29 (16)
MAA (°/s²)	410 (200)	<0.001	168 (93)	<0.001	59 (36)
PAR (%)	8.5 (2.6)	0.764	9.3 (2.5)	<0.001	17.0 (5.8)
HARM	0.79 (0.09)	0.978	0.78 (0.1)	<0.001	0.54 (0.14)

Table 3
Results of discriminant analysis for classifying *Controls* vs. *Patients*. The first model included only the RoM as independent variable. The second one is the best model obtained by means of a stepwise procedure. We included the standardized coefficients of the discriminant function in order to describe the relative contribution of each independent variable to the discriminant function. The last row shows the classification equation obtained from the Fisher discriminant functions (for equal probability to belonging to each group, P = 0.5).

Variables in the model	Standardized discriminant function coefficients	Canonical correlation	Specificity (%)	Sensitivity (%)
RoM	1.00	0.61	86	70
RoM	0.52	0.73	83	93
MAV	0.72			

Classification equation
0.55 RoM + 0.035 MAV < 9.6 → Prob(Patient) > 0.5

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Table 4
Results of discriminant analysis for classifying *Patients* vs. *Simulators* individuals. The first model included only the RoM as independent variable. The second one is the best model obtained by means of a stepwise procedure. We included the standardized coefficients of the discriminant function in order to describe the relative contribution of each independent variable to the discriminant function. The last row shows the classification equation obtained from the Fisher discriminant functions (for equal probability to belonging to each group, P = 0.5).

Variables in the model	Standardized discriminant function coefficients	Canonical correlation	Specificity (%)	Sensitivity (%)
RoM	1.00	0.57	73	80
MAV	0.47	0.82	97	87
PAR	−0.43			
HARM	0.46			

Classification equation
0.67 MAV − 28 PAR + 10.5 HARM < 4.0 → Prob(Simulator) > 0.5

The motion analyzed was a cyclical flexion–extension movement recorded by means of video-photogrammetry. However, the data analysis does not depend on this specific measurement technique and this study could be reproduced using any other instrument able to provide continuous measurement of the neck flexion–extension angles, such as electrogoniometers, electromagnetic or ultrasonic motion tracking systems.

We selected a continuous cyclical motion in order to analyze the dynamics of the movement i.e. the relationships between the angle variable and its derivatives. This strategy is common in motor coordination studies (Stergiou, 2004), but not in the studies published on WAD which analyzed repetitions of single executions of neck motions (Dall'Alba et al., 2001; Sterling et al., 2003; Öhberg et al., 2003 and Grip et al., 2007, to mention some examples). The use of relationships between angular displacement and velocity provides a simple way to quantify the variability of movement in a kinematic sense i.e. including the variability associated to position and speed. Moreover, the correlation between angle and angular acceleration provides a measure of the spontaneity of movement.

Controls and *Patients* differ by a clear reduction of the average RoM (from 119° to 90° respectively), the MAV (from 149°/s to 71°/s) and the MAA (from 410°/s^2 to 168°/s^2), but no significant differences have been found in PAR (8.5% vs. 9.3%) or in HARM (0.79 vs. 0.78). These results suggest that in cyclical movements WAD alterations affect mobility in the range of motion and speed but do not change the movement strategy substantially, as measured by PAR and HARM.

The decrease in the RoM of WAD patients has been reported in several previous studies (Dall'Alba et al., 2001; Sterling et al., 2003; Öhberg et al., 2003; Prushansky et al., 2006; Grip et al., 2007), although we have found higher values of the RoM in the *Patients* than those measured in previous studies. This difference could be due to the type of motion analyzed, a continuous and cyclical movement, which can induce larger amplitudes of motion than single trials of movements reported by other authors.

There are fewer studies analyzing the role of speed. Öhberg et al. (2003) identified velocity as the most discriminant variable between controls and WAD patients. Grip et al. (2008) analyzed the mean velocities and found significant differences between *Controls* and *Patients*. On the other hand, Sjölander et al. (2008) found small non-significant differences, probably due to the reduced size of the sample analyzed. Our results agree with Öhberg's paper, although we have found smaller MAV values. These differences are probably due to the way in which the movement was performed: in the Öhberg study the subjects were asked to perform the movement as quickly as possible, while in our experiment each subject chose his or her preferred speed.

No studies have been found analyzing the acceleration of movement. Our results show a significant reduction in the acceleration of *Patients* vs. *Controls*. This reduction is consistent with a harmonic motion, in which slower movements with lower amplitude involve a reduction in acceleration (see Eq. (3)). Therefore, the information provided in MAA is redundant when RoM and MAV are taken into account and consequently MAA does not appear in the classification models. The interest in acceleration appears in the HARM variable, as a way of quantifying spontaneity of movement.

RoM variability has been studied in previous papers. Sjölander et al. (2008) studied neck rotation and found a small but significant increase in the RoM variation coefficient in *Patients*. Prushansky et al. (2006) defined a variation coefficient averaged across some movements and found a significant increase in the coefficient in *Patients*. In our study we did not find any significant increase of variability in *Patients*. These differences among results can be explained by the different methods for the measurement of variability. In our study, variability has been measured from the $\dot{\theta}(\theta)$ diagram in some cycles of a continuous movement; the results suggest that this strategy produces more repeatable movements than simple repetitions of discontinuous movements.

Feipel et al. (1999) found differences in movement spontaneity between *Patients* and *Controls*. For the analysis of spontaneity Feipel used a harmonic index obtained by a polynomial fitting. Sjölander et al. (2008) used an index based on the jerk for the analysis of neck rotation. However, estimating the jerk from position variables (such as angles) requires the evaluation of the third derivative, and is subsequently very dependent on noise and the smoothing technique applied (Ramsay and Silverman, 2005). This could be the reason why the Sjölander's results are not very conclusive. In our approach a simpler coefficient has been used quantifying the similarity between the movement and a harmonic oscillator. According to this coefficient, *Controls* and *Patients* show very similar behaviour in relation to movement harmonicity (HARM). However, there are wide differences between *Patients* and *Simulators*.

Few papers have been found analyzing the motion patterns of simulators. Dvir et al. (2001) used the coefficient of variation in differentiating maximal from submaximal (feigned) cervical motion in healthy patients. Prushansky et al. (2006) used variability to identify abnormal pathological motion patterns. According to our results, with respect to *Patients*, *Simulators* show a clear reduction in RoM, MVA and MAA, a clear increase in movement variability and a reduction in harmonicity. The reduction in RoM, MVA and MAA could be similar to a severely-injured patient. However, the increase in variability is much higher and the loss of harmonicity does not occur in all patients.

Most of the above-mentioned results are based on a comparison between groups by means of average values. This approach is useful for defining mean patterns of motion; however, its clinical usefulness is limited because it is unable to classify individual patterns of movement or to detect abnormal behaviour. Some classification models have been used for these purposes. Dall'Alba et al. (2001) used a discriminant analysis model based on RoM variables for classifying healthy and WAD individuals. Dvir et al. (2004) used a logistic model to distinguish maximal from submaximal efforts in patient performances. Prushansky et al. (2006) proposed a logistic regression model based on a combined RoM and a mean coefficient of variation in order to classify WAD patients and controls; from this analysis they proposed a criterion to detect atypical WAD patterns based on specific cutoff values. Our discriminant classification models included both static variables (RoM) as well other kinematic variables in order to provide a description of neck movement patterns.

The model that best discriminates between *Controls* vs. *Patients* uses RoM and MAV, providing a sensitivity of 93% and a specificity of 83%. These results are similar to those obtained by Dall'Alba et al. (2001) (95% sensitivity and 86% specificity), although there are some methodological differences in the model as well as in the classification process. Dall'Alba used a classification model with 20 variables, while in our study only two kinematic variables are used (RoM + MAV). The

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use of a higher number of variables in the classification could affect the reliability of the results. In addition, our study uses a cross-validated process to improve robustness.

With regard to the classification between *Patients* and *Simulators*, the model with MAV, PAR and HARM variables presents a specificity of 97% and a sensitivity of 87%. When *Simulators* try to feign a pathological pattern of movement they tend to exaggerate the loss of mobility and the reduction of angular velocity excessively. In addition, there is a significant increase in variability and a loss of harmonicity which is much higher than that found in *Patients*. These results suggest the possibility of objectively identifying non-spontaneous patterns of movement.

Classification models have previously been used for providing quantitative criteria or cutoff values to identify abnormal behaviour (Dvir et al., 2004; Prushansky et al., 2006). The discrimination model used in this paper leads to the classification equations shown in Tables 3 and 4. In spite of their potential interest these equations must be used with caution, because they are based on simple biomechanical tests. There is evidence of the role of psychological factors in chronic pain (Linton, 2000). These factors, as well as others related to functional scores and pain perception, should be considered in order to develop more comprehensive models able to provide a valid basis for clinical decisions.

5. Conclusions

Continuous cyclical movement trials provide relevant information on alteration in neck mobility and movement strategies associated with WAD. Mobility has been characterized by the angular position (RoM) and its derivatives (MAV and MAA). Furthermore, movement strategy has been characterized through intra-subject variability (PAR) and harmonicity (HARM). With these two sets of variables it is possible to characterize pathological patterns (reduction of mobility in *Patients* vs. *Controls*), but it is also possible to find differences between pathological patterns and the patterns of healthy subjects faking pathological symptoms. This possibility could be useful in developing clinical applications where the reliability of biomechanical tests requires patient cooperation.

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