J Rehabil Med 2006; 38: 44–49

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# PREDICTIVE AND DISCRIMINATIVE VALUE OF SHOULDER PROPRIOCEPTION TESTS FOR PATIENTS WITH WHIPLASH-ASSOCIATED DISORDERS

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***Objective:*** **To evaluate whether patients suffering from whiplash-associated disorders have impaired shoulder proprioception and whether the acuity of shoulder proprioception is reflected in the patients' symptoms and self-rated function.**
***Design:*** **A comparative group design, including a correlation design for the patient group.**
***Subjects:*** **Patients with chronic whiplash-associated disorders (*n* = 37) and healthy subjects (*n* = 41). The groups were matched for age and gender.**
***Methods:*** **All subjects underwent a shoulder proprioception test involving active ipsilateral arm position-matching. Group difference was evaluated by multiple analysis of variance and analysis of variance. The patient group completed questionnaires addressing functioning and health and performed pain ratings. Associations between proprioceptive acuity and self-rated functioning and symptoms were studied by correlation and regression analyses.**
***Results:*** **The patient group showed significantly lower acuity of shoulder proprioception. Moderate correlations were found between proprioceptive acuity and questionnaire scores representing physical functioning, so that low proprioceptive acuity was associated with low self-rated physical functioning. Scores representing pain-intensity did not correlate with proprioceptive acuity.**
***Conclusion:*** **The results show that, at the group level, patients with whiplash-associated disorders have impaired shoulder proprioception. The clinical relevance of this finding is strongly supported by the association between shoulder proprioceptive acuity and self-rated functioning in the patient group.**

*Key words:* neck pain, whiplash injury, shoulder, proprioception, motor control, position sense, functional self-efficacy.

J Rehabil Med 2006; 38: 44–49

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Submitted October 30, 2004; accepted May 16, 2005

## INTRODUCTION

Whiplash injuries of the cervical spine are a major health problem and present a risk for permanent disability and suffering. Although the majority of those subjected to whiplash trauma recover relatively rapidly, persistent disorders following whiplash incidents are frequent (1).

The clinical signs of whiplash-associated disorders (WAD) present a complex picture of neck and shoulder pain, headache, numbness and radiating pain in the upper extremities as well as difficulties with concentration and memory (1). Symptoms such as increased fatigability, fumbling (2), vertigo and dizziness (3, 4), have also been reported.

The reported objective findings at physical examination are usually considered weak (5) and evidence of structural damage beyond normal healing time can rarely be confirmed on X-ray (6). Thus, diagnosis of WAD is primarily based on medical history and symptoms (6). The discrepancy between the weak objective findings and the severity of the symptoms has been puzzling and sometimes led to mistrust of the patients' impairment. However, various objective findings of soft-tissue lesions have been reported (7, 8).

Lately, disturbances of sensory-motor control has received attention, both as a possible source of symptoms and signs, as well as a component in the pathogenesis in cervical pain conditions (9–13). Co-ordination of movements, including balance, is dependent on information from the visual, vestibular and proprioceptive systems. The high concentration of muscle spindles in the neck and cephalic muscles (14) and disturbances in motor control after anaesthesia of neck muscles (15) supports the importance of neck muscle receptors for motor control.

As a result of whiplash trauma, lesioning of receptor-bearing structures or functional impairment of muscular and articular receptors may occur. This would obviously have an impact on proprioception and motor control and provides an explanation for the disturbances in sensory-motor control of the neck found in patients with WAD (9, 12, 13). However, injuries or inflammation of structures in the neck may also have an impact on proprioception of adjacent joints, by effects mediated via spinal reflexes. Hence, it was demonstrated that activation of chemoreceptors by inflammatory agents in neck muscles and cervical facet joint in the cat can have a direct impact on muscle spindle sensitivity, not only in the injected muscle, but also in adjacent muscles (16). This "spreading-effect" was attributed to reflex effects from chemoreceptor afferents onto heteronymous gamma-motoneurones. Thus, injured structures or inflammation in the neck region might also have an impact on proprioception of the upper limbs (e.g. the shoulder) and

 *ISSN 1650-1977*
DOI: 10.1080/16501970510042847

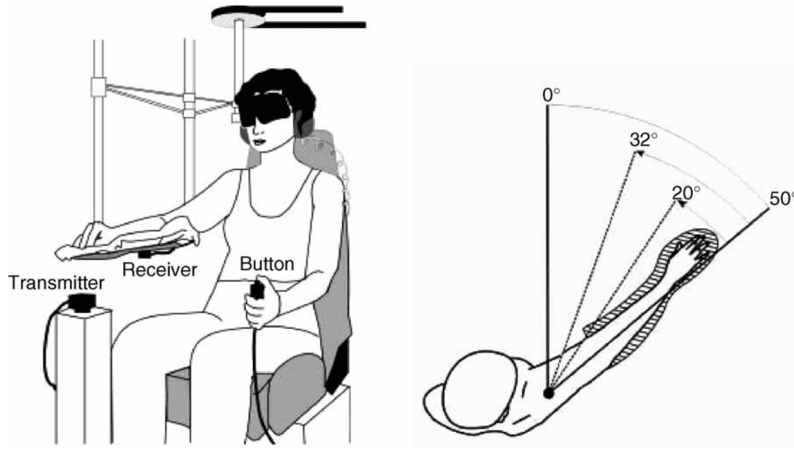


*Fig. 1.* (a) Position sense testing apparatus and (b) starting and target positions.

provide an explanation for complaints involving the upper extremities. However, to our knowledge proprioception of the upper extremities has not been studied in WAD.

The aim of this study was to test the hypothesis that (1) patients with WAD have impaired shoulder proprioception and (2) that the degree of proprioceptive impairment is reflected by the patients' symptoms and self-rated function.

These hypotheses were tested by measuring shoulder position sense acuity in patients with WAD and a group of age- and gender-matched controls, and by studying associations between position sense acuity and the scores of questionnaires related to health status and functioning as well as pain ratings in the WAD group.

## METHODS

*Subjects*

Thirty-seven consecutive patients (17 men and 20 women, mean age 39.9 (SD 9.7) years), suffering from WAD participated in the study along with a control group comprising 41 age- and gender-matched healthy subjects (15 men and 26 women, mean age 39.0 (SD 9.6) years). The tests took place at Alfta Rehab Center, Alfta, Sweden where all patients had been referred for rehabilitation. Car accidents (rear-end collision) were the most frequent cause of injury in the WAD group. The time since trauma varied between 6 months and 13 years (median 2.5 years) and pain in the neck-shoulder area was their major complaint.

Patients were included if they were right-handed, had been subjected to a whiplash trauma more than 6 months ago and met the classification of the Quebec Task Force of grade II (neck complaint and musculoskeletal signs) and III (neck complaint and neurological signs) (6). A strict separation between grade II and III was not possible since the medical records regarding the acute status of the patients were often brief or non-existent, making a detailed retrospective classification arbitrary. Notes stating fractures or diagnosed rhizopathia disqualified the patient from participation. Twenty-five patients had present neurological signs including: weakness in the arm/hand, paresthesia/pin-prick sensations or brachialgia. It should be noted that these were signs present at arrival at the rehabilitation centre and, thus, to various degrees may have represented symptoms due to disuse or sensitization effects rather than neurological injuries from the trauma. Control subjects were recruited from the rehabilitation centre staff and through advertising in the local community. They were included if they were right-handed, had no history of head, neck or shoulder trauma, no current shoulder or arm problems or longer periods of constant or intermittent neck-shoulder pain as reported when enrolled. Patients and controls were excluded if they reported recent injuries to their right arm or shoulder (fractures, joint sprains or luxations less than 2 years ago), conditions of neurological disease, diabetes or fibromyalgia.

The study was approved by the ethical committee at the Faculty of Medicine at the University of Umeå and was performed after obtaining informed consent from each subject.

*Position sense test*

Subjects were seated in the testing apparatus while wearing a blindfold and headphones in order to minimize visual and auditory cues. The headphones also provided pre-recorded verbal instructions. The apparatus consisted of a steady chair and a rig for the arm (Fig. 1(a)) (17). The rig and the chair were adjusted for each subject so that the axis of rotation of the rig was congruent with the centre of the glenohumeral joint. An electromagnetic tracker system was used to monitor the rig angle.

From a starting position of 50° to the sagittal plane, horizontal shoulder adductions to target positions at 20° (short target) and 32° (long target) relative to the starting position were conducted (Fig. 1b). The starting and target positions were chosen in a relatively narrow range within the normal range of motion in order not to provoke any pain in the patient group. From the starting position, the subject actively moved the arm until a command "Stop" was given. The rig was then locked. Due to a slight time delay between the "Stop" command and the locking of the rig, the command was given 5° before the intended target position. This delay resulted in slight shifts from the intended target positions along with some variation ($20.5 \pm 3.6$ and $31.6 \pm 3.0$ degrees, mean $\pm$ SD). When the rig was locked an instruction to "memorize the position" was given and the arm remained at the target for 5 seconds. Then the subject actively returned to the starting position. Thereafter the subject was instructed to "try to find the position". After moving the arm to match the target position, the subject pressed a switch in their left hand to indicate target recognition. Six trials were performed for each target, making a total of 12 trials. The order of the target positions was randomized. A training session was given to each subject prior to the test. During this session subjects were also advised to perform the movements smoothly and consistently by presenting passive movements at a speed of 10° per second.

Due to logistical limitations, the test leader was not blinded to the grouping of the subjects (i.e. WAD or control). However, the test leader was blinded with respect to all patient data.

*Questionnaires*

One week before arriving at the rehabilitation centre the patients were asked to rate their pain intensity "right now", every morning and evening for 1 week, on a 100-mm non-numerical visual analogue scale (VAS) anchored at no pain at all = 0 and worst pain imaginable = 100. The individual mean values were calculated and used in the analysis. They also answered 3 health questionnaires:

- The Pain Disability Index (PDI) (18) was used to assess the degree to which chronic pain interferes with daily functioning. The PDI estimates the disabilities in the areas of; responsibility of family and home, leisure, job and social activities, sexuality, personal independence and daily living. Internal consistencies of 0.85–0.87 for mixed groups of chronic pain patients have been presented (18, 19).

- A 20-item Functional Self-Efficacy Scale (20) was used to measure the patients' expectations of their own capability to accomplish certain tasks and activities of daily living. The version of the self-efficacy instrument used was originally based on the activities most difficult to carry out for chronic back pain patients (20). High internal consistency (0.93–0.97) for chronic pain patients, including patients with neck pain, has been shown for the total score (19). The scale has also been found to correlate to pain intensity ratings, PDI as well as measurements of catastrophizing and kinesiophobia (19).
- The Short Form Health Survey, SF 36 (21) is a generic quality-of-life evaluation comprising 8 scales: limitations in physical activities (PF), limitations in social activities (SF), limitations in usual physical role activities (RP), limitations in usual role activities because of emotional problems (RE), bodily pain (BP), general mental health (psychological distress and well-being; MH), vitality (energy and fatigue; VT) and general health perception (GH). Higher scores reflect better health status.

*Data handling and analysis*

As the outcome measure for the position sense test we calculated the variable error (VE). To this end, the difference between the reproduced position and the target position were calculated for each trial (algebraic errors). Then the population standard deviation of the algebraic errors was calculated for each subject and target position. The VE was determined after detrending the data in each subject's test series (i.e. least square means was computed for the algebraic errors for each target position. This was done in order to remove possible drift in bias, which is unrelated to the response variability but will affect VE (22).

In all analyses the VE for the 2 different target positions were included as separate variables since the position-matching acuity for different movement extents may depend on partly different mechanisms (23, 24).

Multivariate analysis of variance (MANOVA) and 2-way analysis of variance (ANOVA) were used to determine differences and interactions between the factors "group" (patients and controls) and "gender" for the short and long target positions. For evaluation of statistic significance of the MANOVA model, Wilk's lambda was used.

The time between target presentation and reproduction was considered a potential covariate since retention time may affect VE. However, the retention time was not correlated with VE and thus not used in the analyses.

Pearson's correlation analysis was used to study associations between VE and the scores of the questionnaires. Spearman's rank correlations were used for pain ratings and for data that was not normally distributed.

Linear multiple regression was used to analyse how much of the position sense test outcome (VE) that could be explained by the questionnaire scores (i.e. questionnaire scores as predictors of VE). In order to get an estimate of the inverse relation, that is; how well can the questionnaire scores be explained by the position sense test (i.e. VE as predictor of the questionnaire scores), a 2-step analyses was made.

First, in order to reduce the dimensionality of the data while retaining as much as possible of the variation present in the data set, a principal component analysis (PCA) was made (25). The PCA creates a set of new orthogonal (uncorrelated) variables denoted principal components (PCs) by a linear transformation of a dataset. The eigenvalue of each resulting PC is proportional to the amount of the total variance of the data that is explained by the PC. The relationships between a PC and the original variables are represented by the variable loadings, which are correlation coefficients between the original variables and the PC. Hence, if the degree of correlation among the original variables is high, PCA can "extract" the information and represent it in much fewer PCs than the number of original variables. Parallel analysis (26) was used to evaluate how many PCs were needed to represent the questionnaire data. The idea behind parallel analysis is to compare the eigenvalues of the PCs of the real data with eigenvalues of PCs obtained in a large number of iterative runs of PCA on random data matrices of the same dimension as the real data matrix. If a real data PC-eigenvalue is larger than the random data PC-eigenvalues, this component is considered significant (i.e. it probably reflects real relationships among the variables). Loading values above 0.4 were considered significant.

As the second step a linear regression analysis was performed to estimate the amount of variance in the questionnaire data (as modelled by the PCs) that could be explained by the position-matching VE.

The statistical software used was Minitab for Windows statistical program (Minitab Inc. 1998). In all analyses, a $p$-value $<0.05$ was considered significant.

## RESULTS

Due to a calibration error in the position sense test, 1 subject in the patient group was excluded from the analyses. Of the 36 remaining patients, 3 did not fill in the questionnaires properly and were excluded from the correlation analyses. Only 21 out of the 36 patients performed the pain ratings according to the instructions.

*Position sense acuity*

Descriptive statistics for the VE of the position sense test are shown in Fig. 2. The distribution of VE for the patients and controls and target positions are shown in separate box plots. While the VEs for the groups show a clear overlap, a trend for higher VEs for the WAD-group is evident for both target positions.

The MANOVA for VE revealed a significant effect of group ($F[1, 62] = 6.50$; $p = 0.003$) with a higher VE for the WAD-group (2.03°) than for the controls (1.51°). The ANOVAs for VE for the 2 target positions separately showed significant effect of group for both VE-short and VE-long (Table I). Gender was not significant in any of the analyses, and no interactions between the factors were found.

*Associations between position sense acuity and questionnaire scores and pain ratings*

Table II shows the correlation coefficients between the patients' position-matching VE and the questionnaire scores and VAS pain-ratings for the short and long target positions separately.

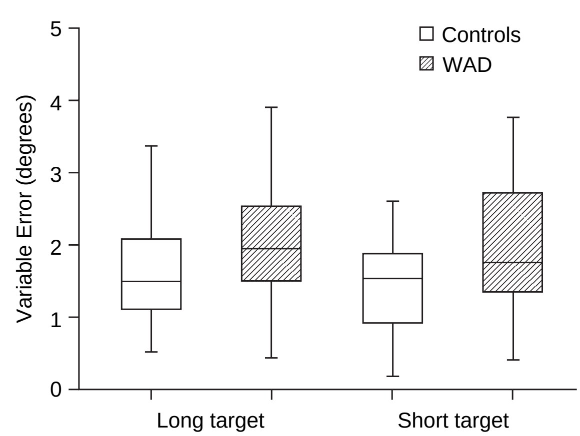


*Fig. 2.* Box plots (25th quartile, mean and 75th quartile, whiskers are 95% confidence intervals) for the position-matching variable error (degrees), separate for patients with whiplash-associated disorders (WAD), controls and target positions.

Table I. *Analysis of variance of the position-matching variable error for the 2 target positions separately*

| | | | Variable error | |
|---|---|---|---|---|
| Target | Variable | df | F | *p* |
| Short | Group (A) | 1,66 | 9.69 | 0.003 |
| | Gender (B) | 1,66 | 0.71 | 0.401 |
| | AB | 1,66 | 0.00 | 0.983 |
| Long | Group (A) | 1,70 | 6.74 | 0.011 |
| | Gender (B) | 1,70 | 3.20 | 0.078 |
| | AB | 1,70 | 0.10 | 0.748 |

A = WAD and control; B = men and women.

Scores from all questionnaires correlated significantly to VE for the short target position (VE-short), while no significant correlations were found for the long target (VE-long). For SF-36, VE-short correlated with the subscales representing limitations in physical activities, limitations in social activities and vitality. The subscale reflecting bodily pain approached significance ($p = 0.087$). The consistent pattern was that a low level of functioning corresponded to a high VE for the short target position. The VAS pain-ratings (range 26–83 mm, median 55) correlated neither with VE-short nor VE-long.

### *Variance of position sense acuity explained by questionnaire scores*

Only VE-short was included in the analyses, since VE-long did not show any association with questionnaire scores. To investigate how much of the variance of VE-short that could be explained by the 3 questionnaires together, all scores with significant correlation coefficients (Table II) were included as predictors in a multiple regression model. As outlined in Table III, the questionnaire scores explained 51% of the variance for the VE of the short target position of the position sense test. Variance inflation factors were small, ranging from 1.2 to 1.6 indicating that collinearity was not a problem in the model.

### *Variance of questionnaire scores explained by position sense acuity*

In order to investigate how much of the patients' self-reported symptoms and functioning, as represented by the questionnaire scores, could be explained by the proprioception test, we analysed how much of the total variance of the questionnaire scores that could be explained by VE. As above, only VE-short was analysed. First a principal component analysis (PCA) of the questionnaires correlating with VE-short was performed. Thus, PCA was done on a data matrix with 33 rows (subjects) and 5 columns (questionnaires scores).

Figure 3 shows the result of the parallel analysis. It is evident that the first PC-eigenvalue was substantially larger that the mean eigenvalues of random data. The following PCs of the real data had eigenvalues smaller than the mean eigenvalue of random data. Thus, the parallel analysis indicated only 1 significant PC, which accounted for 44% of the total variance. The implication is that PC 1 alone could model the major part of the non-random variance of the 5 different questionnaire scores entered in the PCA. This was also reflected by the fact that 4 out of the 5 indices had significant loadings for PC 1. The variable loadings (i.e. correlation coefficients) were: SF-36 (PF) $r = -0.506$, PDI $r = 0.493$, SF-36 (SF) $r = -0.449$, Self-Efficacy Scale $r = -0.408$, SF-36 (VT) $r = -0.363$. Finally, a regression analysis with VE-short as predictor and the WAD-patients' scores for PC 1 as dependent variable showed that VE-short explained 43% of the variance of PC 1 ($r^2 = 0.429$, $r^2(\text{adj}) = 0.407$).

## DISCUSSION

This study demonstrates that patients with WAD have a reduced shoulder position sense compared with age- and gender-matched controls. To our knowledge this has not been reported previously. In the patient group, we also found that the acuity in shoulder position sense could explain a substantial amount of the patients' self-rated physical functioning, particularly the ratings of functional self-efficacy.

### *Shoulder position sense*

For estimation of hand location, errors in proximal joint angles are amplified to a greater extent than distal joint angle errors. In line with this basic geometric fact, the shoulder joint was shown to have superior proprioceptive acuity in comparison to more distal joints (27, 28). This highlights the functional importance of shoulder joint proprioception for determining the location of the hand. Thus, the reduced acuity of shoulder proprioception for the patients in the present study could give objective support for the reported symptoms of fumbling in patients with WAD (2).

Table II. *Correlation table (r-values) for variable error (VE), questionnaire scores (Functional Self-Efficacy Scale, Pain Disability Index (PDI) and the 8 SF-36 indices; limitations in physical activities (PF), limitations in social activities (SF), limitations in usual physical role activities (RP), limitations in usual role activities because of emotional problems (RE), bodily pain (BP), general mental health (MH), vitality (VT) and general health perception (GH)) and VAS pain-ratings for the WAD group. Role limitations (SF-36 RP and RE) and VAS were calculated with Spearman's rank correlation due to non-normal distributions*

| | VE-long | Self-Efficacy | PDI | SF-36 (PF) | SF-36 (RP) | SF-36 (RE) | SF-36 (SF) | SF-36 (BP) | SF-36 (MH) | SF-36 (VT) | SF-36 (GH) | VAS ($n = 21$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VE-short | 0.28 | −0.51* | 0.38* | −0.46* | −0.01 | −0.00 | −0.46* | −0.32 | −0.18 | −0.48* | −0.12 | 0.07 |
| VE-long | | −0.26 | −0.05 | −0.05 | 0.17 | 0.08 | −0.26 | −0.01 | −0.06 | −0.09 | −0.15 | −0.33 |

* $p < 0.05$.

Table III. *Multiple regression analysis predicting variable error-short from self-efficacy, Pain disability and correlating SF-36 indices, where $\beta$ is the regression coefficient and t the test statistic*

| Model $p$-value | $r^2$ | $r^2$ (adj) | Variable | β | t | $p$ |
|---|---|---|---|---|---|---|
| 0.003 | 0.51 | 0.41 | Self-efficacy scale | −0.232 | −2.15 | 0.042 |
| | | | Pain Disability Index | 0.025 | 0.23 | 0.819 |
| | | | SF-36 (PF) | −0.004 | −0.37 | 0.716 |
| | | | SF-36 (SF) | −0.008 | −1.46 | 0.159 |
| | | | SF-36 (VT) | −0.017 | −2.09 | 0.048 |

The mechanism responsible for the decreased shoulder positions sense acuity can only be speculated on. One possibility emerges from the fact that activation of nocioceptive afferents in cervical facet joint in an animal model was shown to alter muscle spindle sensitivity in the trapezius muscles (16). Such mechanisms may possibly also affect shoulder muscles engaged in the matching task of the present study. Impaired information flow (e.g. from nerve injuries) anywhere along the sensory pathways would also have a negative effect on proprioception. Also, since the test in the present study requires memorization of the target position, central memory mechanisms can affect the test outcome. Since memory deficits are often reported in WAD this is an issue to consider in the design of future studies.

One intriguing result of the position sense test was the lack of significant correlation between the long and the short target position VE ($r = 0.28$ in the WAD group). This dissociation was corroborated by the fact that none of the questionnaire scores correlated significantly with VE-long, while several significant correlations were present for VE-short. These results indicate that the matching of the short vs the long target position depended on, at least partly, different mechanisms in the patient group. Several mechanisms may account for this dissociation. Thus, location estimation during short movement distances was proposed to rely more on movement-related sensory information and longer extents more on position-related (24). Another possibility lies in the proposition that location estimation during short movement distances rely more on predictions based on the motor commands, while longer movement distances rely more on feedback of sensory information (29). Still, no firm conclusion can be drawn on the mechanisms behind the matching acuity for the 2 target positions in the present study, which motivate further research on this issue.

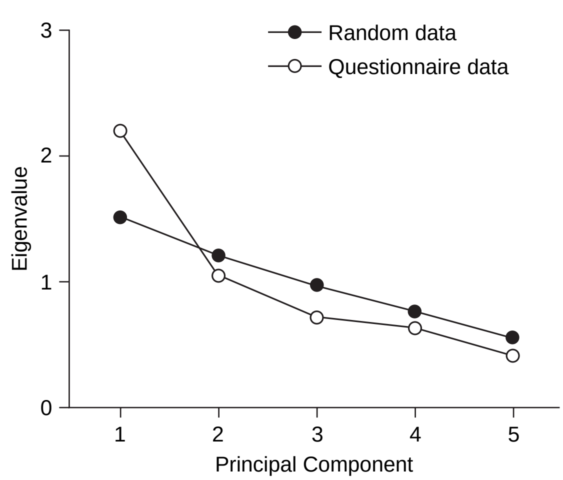


*Fig. 3.* Eigenvalues of the principal components of questionnaire data and mean eigenvalues of random data.

In contrast to the vast majority of clinical studies involving measurement of proprioception in chronic pain conditions, we used the VE as the outcome measure instead of the absolute error or the systematic error (constant error). Since absolute error is a composite of constant error and VE, it is hard to interpret (30). Constant error is labile: it drifts over time (31), depends on aftereffects (32) and is easily modified by feedback (33). VE does not change easily; to a large extent it reflects the signal-to-noise ratio in a system, and thus the limitation for information transfer. Accordingly, a variability measure seems best suited for measuring proprioceptive acuity (22, 34). This fact supports that indeed shoulder proprioception deficits in the WAD-group accounted for the results of the present study, which supports hypothesis 1.

One limitation of the present study was that, due to logistical limitations, the test leader was not blinded for the grouping of the subjects. However, since all instructions during the position sense test was pre-recorded and delivered by the computer controlling the test, we judge the risk of the lack of blinding influencing the outcome as minimal. Moreover, the test leader was blinded with respect to all patient data. Thus, the data used for analysing associations between position sense acuity and the questionnaire data were obtained by blinded sampling.

*Associations between position sense acuity and self-rated functioning and pain*

The correlation analysis revealed that VE for the short target was associated with the questionnaire scores of the Pain Disability Index, the Functional Self-Efficacy Scale and 3 of the scales of the SF-36 (limitations in physical activities, limitations in social activities and vitality) so that high VE corresponded to poor functioning. The same questionnaire indices could together explain 51% of the variance for VE-short among the patients. No associations were found for VE-long.

The PCA of the questionnaire scores correlating with VE-short, and the subsequent parallel analysis, revealed that the questionnaire data could be modelled by just one principal component. This indicates that one common factor, possibly reflecting general functional impairment, could account for the variance of the questionnaire scores correlating with VE-short. The regression analyses showed that a substantial amount (43%) of this factor could be explained by VE-short.

We found no evidence of associations between shoulder position sense acuity and pain intensity (VAS and SF-36 scale bodily pain). Given the facts that pain intensity is not a reliable predictor of functioning (for references see (35)) and the close association between VE-short and self-reported physical functioning, this is not surprising. The high dropout rate in the VAS assessments should, however, be noted. The procedure (i.e. multiple ratings on VAS during 1 week) was most likely too demanding to obtain good compliance. Thus, hypothesis 2, that the degree of proprioceptive impairment is reflected by the patients' symptoms and self-rated functioning, was partly supported.

In conclusion, this study shows that patients suffering from chronic neck pain resulting from trauma, at the group level, have deficits in shoulder position sense. The fact that position sense testing to a high degree also predicted the patients' ratings of physical functioning lend support for the validity of such tests for estimation of functional capacity. If the findings can be confirmed in future research, shoulder proprioception testing may be a valuable tool for identification of functional impairments as well as for evaluation of rehabilitation of patients suffering from chronic neck pain. The results also provide indirect support for treatments focusing body awareness (e.g. tai-chi, Mensendieck system, body awareness and Feldenkrais therapy). Finally, attending to self-efficacy beliefs regarding function in everyday activities might be important in rehabilitation.

## ACKNOWLEDGEMENTS

We thank Nisse Larsson for excellent engineering assistance. The study was supported by grants from VINNOVA (project number 510240) and funding from the Alfta Research Foundation. We also thank 2 anonymous reviewers for their valuable comments and suggestions.

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