Sensorimotor characteristics in chronic neck pain
Possible pathophysiological mechanisms and implications for rehabilitation

Peter Michaelson

Department of Surgical and Perioperative Science, Sports Medicine Unit, University of Umeå, Southern Lapland Research Department, Vilhelmina, Centre for Musculoskeletal Research, University of Gävle, Umeå
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"Du blir aldrig färdig, och det är som det skall"
Tomas Tranströmer 1989

"Livet är det som pågår medan vi sysslar med annat"
Lennart Hagerfors 1990

To Magdalena, Klara and Maja
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ABSTRACT

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Peter Michaelson, RTP
Department of Surgical and Perioperative Science, Sports Medicine Unit, University of Umeå,
Southern Lapland Research Department, Vilhelmina,
Centre for Musculoskeletal Research, University of Gävle, Umeå
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Pain from the musculoskeletal system is very common in the modern society. Chronic musculoskeletal pain syndromes causes not only individual suffering but also dysfunctions of movements and postural control, as well as large costs for the society due to e.g. sick-leave, rehabilitation and early retirement. In spite of significant efforts, there is a shortage of knowledge on effective prevention, diagnoses and rehabilitation of different chronic musculoskeletal pain syndromes.

The general aims of this thesis was to investigate the predictive value of physical, sociodemographic, and psychosocial-behavioural variables for pain reduction after multimodal rehabilitation in patients with chronic low back or neck pain, and to develop and evaluate tests for objective and quantitative evaluation of characteristic sensorimotor disturbances in chronic neck pain.

Logistic regression models revealed that pain reduction after treatment was poorly predicted by the baseline variables. However, unchanged pain intensity was predicted with good precision (specificity 86% for both back and neck pain). Treatment-related pain alteration in chronic low back pain was predicted by partly different variables than in chronic neck pain. Significant predictors for patients with neck pain were high endurance, low age, high pain intensity, low need of being social along with optimistic attitudes on how the pain will interfere with daily life, and few vegetative symptoms. Whiplash associated disorders as the cause of the neck pain had no predictive impact. One of the conclusions was that objective measures of specific sensorimotor disturbances should improve the precision by which treatment-induced effects can be assessed and predicted.

A study was designed to objectively and quantitatively evaluate a large numbers of different sensorimotor characteristics in a small group of patients with chronic neck pain of different aetiology (whiplash-related and insidious). Kinematic data was recorded during different motor tasks, involving cervical rotations, arm movements and standing. Data was collected from a force platform, an electromagnetic positioning system and from questionnaires. In comparison to a group of asymptomatic control subjects, chronic neck pain was characterised by slower movements, poor balance, reduced cervical stability during perturbations, larger movement ir-
regularities (jerk index), and reduced movement precision (variable error and variability in range of motion). A regression model based on peak velocity during arm movements and cervical stability during perturbation correctly classified nearly 90% of the subjects as having chronic neck pain or being asymptomatic (sensitivity and specificity, both 87%).

There were only minor differences in sensorimotor characteristics between patients with whiplash-related and insidiously developed chronic neck pain. This was confirmed in a regression model that failed to separate the two groups of patient (sensitivity for insidious neck pain, 44%; whiplash-related 67%). A multivariate factor analysis exposed a striking individuality in sensorimotor disturbances among the patients - some showed only disturbances in one or two variables while others demonstrated disturbances in most of the variables.

By investigating associations between the different sensorimotor variables, close relation was found between the repositioning acuity (variable error) and variability in range of motion, and between standing balance, standing balance during perturbation and cervical stability during perturbation. These two groups of variables were only weakly related to each other and to movement irregularities and velocity.

The results indicate that chronic neck pain is characterised by specific sensorimotor deficits, and that there are common pathophysiological mechanisms in chronic neck pain of different aetiology. However, the lack of close correlation between several sensorimotor disturbances indicates different mechanisms. The thesis indicates that objective sensorimotor tests should be used to improve the quality of functional assessments in chronic neck pain. Methods that objectively and quantitatively measure e.g. movement precision, balance and cervical stability are also needed in order to evaluate current treatment methods and to develop new rehabilitation programs for specific sensorimotor deficits.

Key words: Outcome prediction, Pain intensity, Neck Pain, WAD, Motor control, Proprioception, Balance, Cervical stability, Jerk, Neck kinematics.
This thesis is based on the following papers, which in the text are referred to by their numbers:


ABBREVIATIONS

AE = absolute error
CE = constant error
CMPS = chronic musculoskeletal pain syndrome
CNS = central nervous system
CoP = center of pressure
CoP_{pp} = anterio-posterior displacement of peak-to-peak centre of pressure
EMG = electromyography
Head_{pp} = anterio-posterior peak-to-peak cervical translation
LBP = low back pain
ROM = range of motion
ROM-V = end position variability of range of motion
VE = variable error
WAD = whiplash associated disorders
WRP = work-related chronic neck pain
INTRODUCTION

Pain from the musculoskeletal system is common in the modern society, affecting most people sometime during their life. The incidence of a pain episode from the neck and low back occurring the past year has been reported to range from 67% to 84% (Cassidy et al. 1998; Cote et al. 1998; Linton & Ryberg 2000). For most people the pain resolves naturally within a few weeks, but with possible functional disturbance still present (Hides et al. 1996; Sterling et al. 2003). Chronic pain from the musculoskeletal system has been reported to occur in about 40% of the population (Brattberg et al. 1989), chronic low back pain (LBP) in 20% (Andersson et al. 1993; Elliott et al. 1999), and chronic neck pain in 18-30% (Andersson et al. 1993; Guez et al. 2003). Among those with chronic LBP, 25% reported sick leave and substantial functional impairments due to the pain condition (Linton et al. 1998). Approximately 10 000 persons each year sustain a neck injury in Sweden, of which 10% have residual pain after 6-9 months (Bjornstig et al. 1990). The prevalence of whiplash associated disorders (WAD) is increasing as a consequence of increasing number of traffic accidents causing whiplash trauma (Galasko et al. 1993).

The pain and functional impairments associated with chronic musculoskeletal pain syndromes (CMPS) are not only causing suffering and handicap in every day life, but have also significant economic consequences. The total costs for the society of LBP and neck pain are enormous, being estimated to 1.7% of Swedish gross national product (Nordlund & Waddel 2000).

Terminology and motives for classification

The clinical condition labelled CMPS describes pain that arises from the muscles and joints. Research in recent years has emphasised the importance of the nervous system, in addition to muscles and joints in the initiation, progress and preservation of symptoms in CMPS (c.f. Johansson et al. 2003). To account for disturbances of the neuromuscular system it has been proposed that *chronic neuromuscular pain disorder* (CNMPD) would be a more appropriate term for these syndromes (Thunberg 2002).

With generous inclusion criteria, the diagnosis CMPS includes most people with pain arising from the musculoskeletal system. A number of attempts have been made to specify the syndromes by relating them to their causes or aetiology (e.g.; work-related musculoskeletal disorders, work-related myalgi, whiplash associated disorders), or alternatively to the anatomical region of occurrence (e.g.; temporomandibular pain and dysfunction syndromes, cervicobrachial syndrome, neck-shoulder myalgi, chronic low back pain and chronic neck pain). Diagnoses such as these are unspecific, lacks precision and simply refers to the affected area, and are therefore of
marginal value for the rehabilitation process since they tells us nothing about functional disturbances related to the condition and the underlying pathophysiology.

Clinical studies and experimental research indicate that the heterogeneity among those who suffer from back and neck pain is large regarding pathophysiological mechanism and dysfunctions. The aim of a conventional clinical examination has traditionally been to identify the affected structure as the cause of the pain syndrome, which has been criticized for being too rudimentary (Sterling 2004). Furthermore, the manual examination is difficult to standardize and often lacks reliability and validity (Strender et al. 1997; Fjellner et al. 1999; Smedmark et al. 2000).

It has been advocated that examination methods should be developed which are based on scientifically identified mechanism involved in the pain syndromes, rather than on the pathoanatomical origin of the pain (Woolf & Decosterd 1999; Sterling 2004). Methods that objectively identify disturbances closely related to involved pathophysiological mechanism would certainly result in new criteria for categorization of pain syndromes, criteria that include symptoms of neuromuscular dysfunctions possible to treat (cf. Hodges & Moseley 2003; Sterling 2004).

Objectives of rehabilitation

The prime goal of many rehabilitation programs for CMPS is work resumption (Kool et al. 2002). The success rate varies in different studies and the effect seems to deteriorate over time (Mayer et al. 1987; Oland & Tveiten 1991; Mitchell & Carmen 1994). Work resumption has been criticized for being an inappropriate and harsh measure of treatment effects, and for being more influenced by the local labour market and the social security system then by the rehabilitation process (Fishbain et al. 1993; Fishbain et al. 1999).

For patients with CMPS entering a rehabilitation program, a significant and permanent relief of pain is often the most desired outcome of the treatment (Colvin et al. 1980; Chapman et al. 1981; Merkesdal et al. 1999). Therefore, pain reduction is a standard goal in most rehabilitation programs. However, changes in pain sensation have only occasionally been used as the outcome variable when attempts were made to identify factors that predicted treatment results. Hildebrandt and colleagues showed that reduced pain intensity one year after treatment could be predicted by a short period of absence from work, if the patient had not applied for pension, had few medical consultations and improved physical performance in response to treatment (Hildebrandt et al. 1997). For a similar group of patients, slightly different results was presented by Bendix and co-workers who showed that high pain intensity on admission, good daily life functionality, participation in sports activities and high isometric back endurance, in addition to young age and few sick leave days, were correlated with reduced pain intensity one year after treatment (Bendix et al. 1998). A preadmission interview by a psychologist was the only predictor for pain
reduction reported by Fredrickson (Fredrickson et al. 1988). These findings indicate that pain reduction in response to treatment may be predicted with reasonably good accuracy by pre-treatment variables. However, there is a shortage of data on short- and long-term pain prediction, on pain prediction in CMPS conditions other than chronic LBP, and on the predictive value of different variables, in particularly psychosocial and functional variables (Turner et al. 1983; Fredrickson et al. 1988; Hildebrandt et al. 1997; Bendix et al. 1998).

Next to relief of pain, many patients rank improvement in functional capacity as a highly desired goal of the rehabilitation (Fishbain et al. 1993; Merkesdal et al. 1999). However, the rehabilitation regimes applied to reduce pain and dysfunctions in LBP and neck pain mostly have limited effects (Aker et al. 1996; Gross et al. 2000; van Tulder et al. 2000). To improve the efficiency of rehabilitation increased knowledge is needed on specific functional disturbances and their causes.

Sensorimotor functions in patients with chronic neck pain

In clinical practice, movement disturbances in CMPS have been recognised for a long time. Lately, methods for objective and quantitative assessments of some of the motor disturbances have started to emerge (e.g. Revel et al. 1991; Brumagne et al. 1995; Karlberg et al. 1995; Hodges & Richardson 1996; Luoto 1998; Taimela et al. 1999; Hodges 2001; Treleaven et al. 2003; Falla et al. 2004).

Interaction between sensory input and intrinsic motor control properties

Almost all active movements are performed as a result of interactions between sensory input and motor control properties (e.g. Prochazka 1996; Nichols et al. 1999). In feedback-based movements, the muscle activity can be modified by sensory input during the execution of the movement. In contrast, feedforward-controlled movements do not allow sensory input to influence the movement while it is executed, but the sensory activation caused by a feedforward movements can modify the next movement to be performed (Latash 1998).

The close interaction between sensory information and intrinsic motor control properties makes it virtually impossible to assess the relative effect of the different properties during the execution of voluntary movement in humans. Despite this, it is quite often claimed that movement dysfunctions assessed by, for instance, kinematic parameters are caused by deficits in proprioception. In most cases this is incorrect since deranged motor control properties and psychological factors never can be excluded as contributing factors in voluntary movements.

To account for the integrated feature of the sensory systems and intrinsic motor aspects, the term “sensorimotor” is used in the present thesis to denote processes
and variables that might be a result of both sensory input to the CNS and intrinsic motor control properties.

Proprioception

The term proprioception was first introduced by Sherrington ("The integrative action of the nervous system", 1906) who coined the term from the Latin prorius (one’s own) and receptus (the act of receiving) and described it as the perception of limb position and movements without the aid of vision, touch or the vestibular system. As indicated by the definition, proprioception implies both sensations of static position and movements (McCloskey 1973). Recent findings argue for a further subdivision of the movement sense into direction and velocity components (for references see Sjölander & Johansson 1997). Thus, sensory information on position, and velocity induces perception of different movement qualities, and may be separately used in the control of movements (Sittig et al. 1985; Clark et al. 1986). Even though the specific effects of different proprioceptive modalities largely remain to be elucidated, there is no doubt that proprioceptive information is crucial for optimal control of movements (Sainburg et al. 1993; Cordo et al. 1995; Sainburg et al. 1995).

After processed in CNS, sensory information arising from mechanoreceptors in the muscles, the joints and in the skin are thought to generate internal models of the body configuration (Wolpert et al. 1995), which might be envisaged as the proprioception at a conscious level. The most important of the mechanoreceptors contributing to the proprioceptive input is the muscle spindle. Activation of muscles spindles through vibration of muscles or tendons elicits illusions of movement in stationary limbs, indicating that muscles spindles contain vital information for perception of movement (Goodwin et al. 1972; McCloskey 1973; Sittig et al. 1985). Also, removal of other sources of proprioceptive information, such as from joint and skin mechanoreceptors, only slightly reduces the proprioceptive acuity (McCloskey et al. 1987). In this context it is interesting to note that the density of muscle spindles is considerably higher in cervical muscles, particularly in the deep cervical muscles, as compared to other muscles of the body (Bakker & Richmond 1982).

Balance

The control of the body’s position in space, with the purpose of maintaining stability and orientation, is often referred to as postural control (Horak & Macpherson 1996). Balance in quiet standing has been modelled as an inverted pendulum which requires a continuous correction of the body posture in order to maintain the balance (Latash 1998). Thus, in upright stance, the force of gravity must be counteracted by muscular forces in order to maintain the vertical projection of the centre of body mass within its base of support (Horak 1987; Massion 1994). This requires a precise and fine-tuned interaction between perception and action involving musculoskeletal
and neural systems, predominantly regulated through feedback controlled movement (Horak 1997). Accurate sensory information from the neck has been stressed as most important for the ability to maintain the vertical balance (de Jong & Bles 1986; Brown 1992).

Concerning patients with neck pain, several studies have investigated the standing balance by analysing postural sway, often derived from measures of the migration of centre of pressure (Alund 1993; Karlberg et al. 1995; Karlberg et al. 1996; Sjostrom et al. 2003). The postural sway was reported to be significantly increased among patients with chronic neck pain, including in chronic WAD (Alund 1993; Karlberg et al. 1995; Karlberg et al. 1996; Sjostrom et al. 2003; Madeleine et al. 2004). By studying the standing balance in patients with chronic neck pain during sensory perturbations it has been indicated that neck proprioception influences both the postural control and the eye movements, and might be involved in processes underlying dizziness and balance disturbances (Karlberg et al. 1995; Karlberg et al. 1996). To gain further understanding of the neuromuscular mechanisms behind such disturbances, associations between postural dysfunctions and other sensorimotor disturbances of the neck should be investigated.

**Cervical kinematics**

In the clinic, reduced range of cervical motion (ROM) is one of the most well recognised dysfunction in patients with neck pain. This has been verified in a number of studies using objective methods for measuring the ROM (e.g. Osterbauer et al. 1996; Feipel et al. 1999; Bonelli et al. 2000; Dall'Alba et al. 2001; Dumas et al. 2001; Öhberg et al. 2003; Madeleine et al. 2004). Although the subject-to-subject variability appears to be large, there is a significant reduction in ROM at group level in both traumatic and non-traumatic neck pain as compared to healthy control subjects.

It has been proposed that analyses of higher order of derivatives of position (e.g. velocity, acceleration) would enhance the discriminatory capacity of functional evaluations used on patients with chronic pain (Lehman 2004). Öhberg et al showed that cervical rotations were performed significantly slower by patients with WAD as compared to by asymptomatic subjects (Öhberg et al. 2003). However, since no correction for reduced ROM was applied when analysing the velocity, it remains to be confirmed whether the velocity of voluntary movements are decreased in neck pain.

Jerky and irregular head movements are often observed clinically among patients with chronic neck pain. Attempts to quantify disharmonic movement patterns have been applied with some success in evaluations of movement disturbances related to neck pain (Osterbauer et al. 1996; Feipel et al. 1999). Another way of quantifying irregular movement performance would be to address the jerkiness or smoothness of movement. Smoothness of movement has been suggested to represent a significant
optimization principle of human voluntary movements (Brown & Cooke 1990; Wolpert et al. 1995). One way of quantitatively evaluate smoothness is to measure movement jerk, i.e., changes of acceleration (Hogan 1984). Several studies have demonstrated that poor movement control, as for example in children, elderly people and patients with neurological diseases, is associated with a high jerk cost, i.e., a high rate of change of acceleration (Yan et al. 2000; Contreras-Vidal & Buch 2003). The jerkiness of movements in chronic neck pain conditions has so far not been investigated by objective and quantitative methods.

Proprioceptive acuity
In attempts to investigate proprioceptive disturbances of patients with chronic neck pain, a number of researchers have measured the repositioning errors following cervical rotations. In such repositioning tests the subjects are trying to relocate the starting position of the head as accurately as possible after a cervical movement (e.g. rotation, flexion, extension). Studies on patients with neck pain have shown partly contradictory results, some demonstrating increased repositioning errors in neck pain (Revel et al. 1991; Heikkilä & Åström 1996; Kristjansson et al. 2003; Treleaven et al. 2003), while others were unable to find any differences in repositioning acuity between such patients and asymptomatic control subject (Rix & Bagust 2001; Öhberg et al. 2003; Madeleine et al. 2004). Moreover, there is a lack of knowledge on whether the proprioceptive acuity is differentially affected in neck pain of different aetiology. The only study to my knowledge that has addressed this issue indicates that there might be differences in repositioning ability between patients with insidious neck pain and WAD (Kristjansson et al. 2003).

Major reasons for the somewhat inconstant findings regarding repositioning acuity in neck pain are that the results were derived from studies using different test conditions and methods for error estimation. In some of the studies the repositioning errors were determined by manual procedures, which are easily biased by the experimenter (Rix & Bagust 2001). Other results are based on very few trials which might cause large impact of the outcome in a single trial (cf. Allison & Fukushima 2003).

When studying aiming or repositioning tasks in motor control research, three outcome measures are often analysed – the absolute error (AE), the variable error (VE) and the constant error (CE) (Schmidt & Lee 1999). Mathematically, AE is a non-linear combination of VE and CE and describes the average absolute deviation of the matched position and the target (Schmidt & Lee 1999). Attempts to assess the CE have been made by counting numbers of under- and overestimations of the target position (Heikkilä & Åström 1996; Treleaven et al. 2003). Another, more objective ways of analysing CE is to calculate it from the AE. The CE, often called bias, is the average directed deviation from a target (Schmidt & Lee 1999) and would represent a systematic bias in the motor control system (Craske & Cranshaw 1974). The VE
represents the variability of the repositioning errors within a number of consecutive trials, and it is thought to reflects the acuity of the sensorimotor processes (Schmidt & Lee 1999).

It has been suggested that measures based on the error variance (i.e., VE) could provide good estimates of the proprioceptive acuity since the variance reflects the effect of noise in the sensorimotor system (Clark et al. 1995). As noise limits information transmission (Shannon & Weaver 1964), it would limit the proprioceptive acuity.

In most studies of repositioning acuity in patients with neck pain, only the AE has been analysed. However, the AE is a composite of CE and VE and is therefore hard to interpret in terms of underlying mechanisms (Schutz & Roy 1973). Thus, analyses of the CE and the VE among patients with chronic neck pain might provide additional insights in the sensorimotor processes related to chronic neck pain.

Muscle coordination
Reduced muscular strength and endurance of the cervical flexor muscles is common in patients with neck pain (Silverman et al. 1991; Watson & Trott 1993; Barton & Hayes 1996). For instance, recordings of EMG-activity in muscles around the neck have displayed increased fatigability of these muscles already at low contraction levels (Gogia & Sabbahi 1994; Falla et al. 2003; Falla et al. 2004).

In a cranio-cervical flexion test that measures the ability to maintain and control the force output of neck flexor muscles, it has been found that patients with neck pain show increased activity in the superficial muscles in combination with reduced activity in the deep muscles and an inability to successfully perform a controlled cervical flexion (Jull et al. 1999; Jull & Richardson 2000; Falla et al. 2004; Jull et al. 2004). Deranged control of cervical muscles in neck pain has also been reported in response to cervical perturbation imposed by fast arm movements (Falla et al. 2004). A delayed contraction of deep cervical flexors was observed prior to the perturbation, and the author concluded that disturbances of the feedforward control of these muscles were responsible for the altered preparatory activation. Since the deep cervical flexor muscles are suggested to provide support for the cervical lordosis and joints (Mayoux-Benhamou et al. 1994; Conley et al. 1995; Vasavada et al. 1998), it seems possible that a consequence of the altered preparatory activation would be an increased vulnerability of the cervical segments to mechanical stress.

Altered pattern of activity has also reported to occur in accessory neck muscles in response to neck pain. Patients with chronic neck pain and patients with trapezius myalgia have been reported to demonstrate increased EMG-activity in the trapezius muscle during task performance, and inability to relax the trapezius muscle in phases of movements when the muscle normally is inactive (Veiersted et al. 1990; Vassel-
Moreover, during a functional task of moving the arm, the trapezius muscle showed decreased activity while the contralateral trapezius and superficial neck muscles exhibited increased activity (Falla et al. 2004). Interestingly, there were significantly differences between patients with idiopathic neck pain and WAD regarding these disturbances of muscle coordination.
AIMS

The main aim of the thesis was to evaluate sensorimotor functions in patients with chronic neck pain in order to explore possible neuromuscular mechanisms responsible for disturbed sensorimotor performances. Another aim of the thesis was to study the effect of potential physical, sociodemographical and psychosocial-behavioural predictors on self-reported pain reduction following a multimodal rehabilitation program.

Specific aims of the thesis

The specific aims of the four papers were to investigate:

Paper 1
1. whether treatment related alterations of pain intensity in patients with chronic LBP are predicted by different baseline variables as compared to patients with chronic neck pain.
2. whether the predictors show different impact on pain alterations on the short- and long term.
3. whether decreased and increased self-reported pain intensity are predicted with similar precision by the predictors.

Paper 2
1. standing balance (postural sway) in patients with chronic neck pain.
2. effect on balance and cervical stability of expected and unexpected perturbations.
3. effect of the aetiology of the neck pain on postural performances and cervical stability.

Paper 3
1. sensorimotor functions during cervical rotation in patients with chronic neck pain by assessing peak velocity, variability of ROM (ROM-V), movement jerk, and repositioning acuity (VE) and bias (CE).
2. effect of the aetiology of the neck pain on cervical kinematics and repositioning acuity.

Paper 4
1. associations between different manifestations of sensorimotor disturbances in chronic neck pain.
2. whether patients with chronic neck pain and asymptomatic subjects can be separated based on sensorimotor characteristics.
3. whether patients with chronic neck pain of different aetiology can be separated based on sensorimotor characteristics.
4. whether the objectively assessed sensorimotor disturbances correspond to self-reported functional disturbances.
METHODS

Prediction of pain reduction (Paper 1)

Patients
To be eligible for the study, the primary pain region of the patients’ had to be either the neck or the lower back, together with a pain duration of at least six months. Out of 315 patients, 303 completed the 4-week rehabilitation program (Fig. 1). Sociodemographic and pain characteristics of the patients are shown in Table 1.

Table 1. Gender distribution and pain characteristics.

<table>
<thead>
<tr>
<th></th>
<th>Total N = 303</th>
<th>Low back pain N = 167</th>
<th>Neck pain N = 136</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>43</td>
<td>43</td>
<td>42</td>
</tr>
<tr>
<td>Gender distribution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>203</td>
<td>104</td>
<td>99</td>
</tr>
<tr>
<td>Male</td>
<td>100</td>
<td>63</td>
<td>37</td>
</tr>
<tr>
<td>Pain characteristics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intensity (mm)</td>
<td>58 (17*)</td>
<td>56 (17*)</td>
<td>60 (17*)</td>
</tr>
<tr>
<td>Duration (month)</td>
<td>106 (91*)</td>
<td>104 (96*)</td>
<td>108 (87*)</td>
</tr>
</tbody>
</table>

* = standard deviation

Rehabilitation
Saxnäsárgården’s Rehabilitation Center was a clinic for patients with chronic musculoskeletal pain, and provided a typical multimodal rehabilitation program including physical and cognitive-behavior modalities. The standard schedule included daily exercise and therapeutic activities over a 4-week period. After the rehabilitation period, and for the forthcoming 12-months, the patients were encouraged to follow individually designed rehabilitation programs.

Outcome measurement
In this study, altered pain intensity in the primary pain region was used as the outcome measure. The patients were included in the group with reduced pain (Fig. 1) if the reduction of the pain intensity were equal or larger then 25 mm on the visual analog pain scale (VAS-scale). The pain was assessed as the average perceived pain intensity over the last week on a blank 100 mm VAS-scale, where 0 mm correspond to “no pain at all” and 100 mm to “the worst imaginable pain”. This ‘safety margin’ of a 25 mm decrease on the VAS-scale was adopted in order to increase the probability that the perceived pain reduction was considered as meaningful by the patients (Keefe et al. 1986; ter Kuile et al. 1995; Rahme 1998). Based on the rating of pain intensity in the neck or lower back following the rehabilitation period and the 12-month follow-up, the patients were separated into four groups, i.e. reduced or unchanged/increased pain intensity in the neck or the lower back (see Fig. 1).
Predictors
At the beginning of the rehabilitation program the patients were evaluated on 17 different variables. Most of them were previously found to predict pain alteration in neck and low back pain.

Age and gender were documented together with information on current working/sick leave status and number of days on sick leave over the previous year. The patients’ general health status was evaluated through the OS-index (Gerdle et al. 1994), which is based on a number of somatic and psychosomatic complaints (e.g. dizziness, insomnia, tiredness, and stomach pain). Endurance indices for evaluation of the physical status of the neck and the lower back were calculated. For pain characteristics, the average pain intensity and the pain duration were included. Information on psychosocial and behavioral characteristics were obtained using Beck’s Depression Inventory (Beck et al. 1961), and five indexes from the Multidimensional Pain Inventory (MPI), i.e. pain severity, interference, support, life control and affective distress (Kerns et al. 1985). Motivational factors were assessed through the Optimism Index (Esbjörnsson 1984). The Sociability Index from Edwards Personal Preference Scale was applied to evaluate the patients’ need of being social, to do things with others rather than alone, and to be helped rather than to help one-self (Rubenowitz 1963).

Sensorimotor functions in chronic neck pain (Paper 2-4)

Subjects
Eighteen patients referred to a four-week rehabilitation period at the Saxnäsgårdens Rehabilitation Centre participated. Inclusion criteria were chronic neck pain with a duration of at least six months. Exclusion criteria were neurological disease, signs of brain damage, rheumatic disease and severe pain in other body parts than the neck. Patients with self-reported hip, knee or ankle injuries, with documented impairment

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**Fig. 1.** Study population and outcome categories.
of the vestibular system and those who used medication with side effects on the postural control system, were excluded.

Nine patients demonstrated idiopathic non-traumatic neck pain with insidious onset (in short, patients with insidious neck pain). Eight of these claimed that their neck pain was work-related, while the aetiology was uncertain for one patient. For the other nine patients the primary aetiology of the neck pain was a whiplash trauma, mostly as a result of car accidents (in short, patients with WAD), of which three were classified as grade II and six as grade III (Quebec Task Force-classification, Spitzer et al. 1995).

From the community a control group was recruited to match the patients by age and gender (Table 2). Absences of current and previous episodes of neck pain, dizziness and vertigo were inclusion criteria for the control group. They were also excluded if they complied with any of the exclusion criteria for the patients.

Anthropometric and pain characteristics of the three study groups are shown in Table 2. No significant differences were observed for anthropometric parameters, pain duration, pain intensity and prevalence of self-reported vertigo between the groups of patients, while the WAD-group reported a significantly higher prevalence of unsteadiness.

**Table 2. Anthropometric and pain characteristics of the two groups of patients with chronic neck pain (insidious neck pain, whiplash associated disorder (WAD)), and of a corresponding group of healthy subjects. Mean values with standard deviation in brackets, except for the distribution of men and women in each group and for the prevalence of vertigo and unsteadiness, which are given in number of patients/subjects.**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Control (n=16)</th>
<th>Insidious neck pain (n=9)</th>
<th>WAD (n=9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td>3</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Women</td>
<td>13</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>Age (years)</td>
<td>41 (9)</td>
<td>40 (9)</td>
<td>44 (10)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>168 (8)</td>
<td>165 (7)</td>
<td>171 (10)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>70 (14)</td>
<td>73 (18)</td>
<td>79 (14)</td>
</tr>
<tr>
<td>Pain duration (months)</td>
<td></td>
<td>97 (68)</td>
<td>87 (77)</td>
</tr>
<tr>
<td>Pain intensity (mm)*</td>
<td>52 (16)</td>
<td>49 (23)</td>
<td></td>
</tr>
<tr>
<td>Vertigo**</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unsteadiness**</td>
<td>1</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

* the average pain intensity over the last week was assessed on a blank 100-mm visual analogue scale, where 0 mm corresponded to ‘no pain at all’ and 100 mm to ‘the worst imaginable pain’.

** the numbers of patients who through a questionnaire reported “vertigo” and “unsteadiness” as occurring “rather often” or “very often”. 

Procedure
The sensorimotor evaluation was completed before the rehabilitation program started. The same experimenter, who was blinded to the subjects’ neck pain status, executed all tests. The instructions given to the subjects during the tests were pre-recorded on a computer in order to provide identical instructions and time schedule for all subjects. The test procedure followed a standardised protocol in which the order of the individual tests was randomised across subjects. The instruction, ‘stand as still as possible’ was repeated before each balance and perturbation test. It took approximately one hour to complete the test procedure.

Balance
For the balance test the subjects were standing barefooted on the force platform with the feet in parallel to the y-axis of the platform. The balance tests involved quiet standing in the Romberg position with open and closed eyes (Lanska & Goetz 2000).

Perturbation tests
The perturbation tests were performed with the subjects standing on the force platform in Romberg position with closed eyes. The first perturbation test (Arm-Lift) consisted of a rapid bilateral shoulder flexion (‘as fast as possible’) from the vertical to the horizontal plane with the subjects holding a wooden rod in both hands. In the other perturbation tests, the subjects were instructed to hold the load-drop device with both hands positioned in the horizontal plane until the load was released, either intentionally by the subject (Drop-Self) or unexpectedly by the experimenter (Drop-Exp) as indicated in Fig. 2. In all three perturbation tests, a weight corresponding to 3% of the subjects’ bodyweight was applied. Each test contained six trials.

Fig. 2. The experimental set-up showing a subject standing on the force platform and the location of the FASTRAK™ receivers. While the subject maintained a 90 degree shoulder flexion, the load attached to the rod was dropped either intentionally by the subject or unexpectedly by the experimenter.
Cervical rotations
Before the test session started the subjects were instructed to “comfortably rotate the head as fast and far as possible”. Cervical rotations were performed in two separate conditions, rotation to the right and to the left, each containing eight consecutive rotations (trials) with a short resting interval between each trial. Prior to each set of rotations the subjects where instructed to “memorize the starting position”, which was a self-selected neutral position of the head, and to “reproduce this position as accurately as possible after each head rotation”.

Apparatus
A static force platform (Kistler Force Measurements, type 9807, Kistler Instrumente AG, Switzerland) was used for evaluation of the postural sway. Movement of the cervical spine was measured by an electromagnetic tracking system (FASTRAK™, Polhemus Inc, USA). One receiver was positioned on the forehead by a specially constructed helmet, and another taped on the skin above the dorsal spinal process of Th1 (Fig. 3). Each receiver recorded both the position (in Cartesian coordinates) and the orientation (Euler angles). The sampling frequency of each receiver was 60 Hz. The system has previously been demonstrated to have good reliability in studies of cervical motion (Pearcy & Hindle 1989; Swinkels & Dolan 1998).

![Fig. 3. Schematic illustration of the location of the receivers of the electromagnetic tracking system (FASTRAK™) that were used to collect angular data of the cervical spine.](image)

The kinematic data during the shoulder flexion in the Arm-Lift test was recorded by a FASTRAK™-receiver on a wooden rod (see Perturbation tests). Another rod, the load-drop device was equipped with a hook to which a bag was attached (Fig. 2). The hook could be disengaged using switches operated either by the subject or by the experimenter.

Signals from the force platform, the switch controlling the hook, along with a synchronisation signal from the FASTRAK™-system and angular data from the FASTRAK™-receivers were displayed on-line and stored on files.
Data processing and analyses

Custom-made software was used to organise the data, and MatLab codes were used for data processing (ver 5.3, 1999, MathWorks Inc., USA).

For the quiet standing tests, the area of the migration of centre of pressure (CoP) (i.e., the point of application of the resultant reactive force acting on the body from the support surface) was used as the outcome variable. For each of the three perturbation tests the maximal anterio-posterior CoP displacement ($CoP_{pp}$ in Paper 2; Posture-Stability in Paper 4) and cervical translation ($Head_{pp}$ in Paper 2; Cervical-Stability in Paper 4) within one second after initiation of perturbation were analysed (Fig. 6).

Kinematic variables were calculated from the orientation of the head in relation to the trunk. In order to maximize the range of rotation, the data was transformed by an algorithm that slightly adjusted the orientation of the coordinate system of the receivers. The data from the receiver were smoothed using a quintic spline filter with a cut-off frequency of 10 Hz. The start and the stop of rotation were defined as the time when the angular velocity passed 5% of peak velocity (Fig. 4).

**Fig. 4.** Typical examples of position, velocity, acceleration and jerk for a control subject and a patient with chronic insidious neck pain during the cervical rotation test. Dotted lines indicate the start and the stop of the rotations.
The smoothness of movement was assessed by calculating a jerk index using the algorithms described by Kitazawa (Kitazawa et al. 1993), which normalizes the jerk cost with respect to angular excursion and movement time (Jerk index in Paper 3; Jerk in Paper 4). Repositioning $VE$ and $CE$ were calculated as follows: For each trial the algebraic repositioning error was calculated as the difference between the target position and the position reached after the cervical rotation. A constant error ($CE$) and a variable error ($VE$) were calculated from the algebraic errors of eight trial (Schmidt & Lee 1999). The $ROM-V$ was defined as the average standard deviation of the final position of the outward cervical rotations.

Range of motion ($ROM$), peak velocity and jerk index were calculated separately for outward rotation to the right (Out-Right), inward rotation from the right (In-Right) outward rotation to the left (Out-Left) and inward rotation from the left (In-Left). The $VE$, $CE$ and $ROM-V$ were separately analysed for both directions (right and left).

The patients self-rated functional disability was assessed by the Neck Disability Index (NDI) (Vernon & Mior 1991), and the frequency of vertigo and unsteadiness was indicated on a scale with six alternatives ranging from ‘never’ to ‘very often’. The patients were considered to suffer from vertigo/unsteadiness if the incidence was rated as “rather often”, “often” and “very often”.

Selection of variables (Paper 4)
Several of the sensorimotor variables in Paper 2 and 3 displayed significant differences between the groups (control, insidious, WAD). These variables were included in the factor- and regression analyses, i.e. separate mean values of $VE$, $ROM$-Variability and Jerk for rotations to the left and right, sway area in Romberg with closed eyes (Posture-Standing), peak velocity of shoulder flexions (Arm-Velocity) and the mean values of the three perturbation tests, separately for anterio-posterior sway and cervical stability (Posture-Stability, Cervical-Stability).

Statistics
All analyses were restricted to the patients from which complete sets of baseline variables were obtained. All statistics were done using SPSS (ver 11.0, SPSS Inc, USA), and a $p$-value below 0.05 was considered statistical significant.

Differences between groups (Paper 2-3)
Differences between the groups were evaluated by multivariate analyses of variance (MANOVA) and multivariate analysis of covariance (MANCOVA; ROM as covariate). The latter was done to adjust for, and to evaluate potential effects of reduced $ROM$ on peak velocity, repositioning acuity and $ROM-V$ (Keele & Ells 1972; Neu-feld 1981). To compare results between the groups regarding the specific conditions
(Out-Right, In-Left etc.), one-way analysis of variance (ANOVA) and one-way analysis of covariance (ANCOVA; ROM as covariate) were used. For post-hoc tests in ANOVA, Tukey’s Honest Significant Difference test was used. To ensure that the basic assumptions for MANCOVA and MANOVA were fulfilled, all models were tested with Box’s test of equality of covariance matrices, and Levene’s test of equality of error variances (for ANOVA, ANCOVA). If any of these tests showed significant results, the variables were transformed using natural logarithms. Outliers were identified by Cook’s distance test and excluded from the analyses (Srivastava & Sen 1990). For clarity and comparisons only non-transformed data are presented in the result section.

**Association between different variables (Paper 4)**

A factor analysis was applied to investigate relationships between the sensorimotor variables. The basic requirements for factor analysis was fulfilled by the Kaiser-Meyer-Olkin measure of sampling adequacy (0.59) and the Bartlett’s test of sphericity ($p<0.000$) (http://www2.chass.ncsu.edu/garson/pa765/factor.htm). The number of variables in relation to number of patients/subjects (7:31) fulfilled the criteria of a minimum ratio of 3:1 for an acceptable factor analysis (Kline 1993). Three components were significant according to Kaiser’s criterion (eigen value above 1) and Catell’s criterion (the “elbow structure” of the scree plot). The cut-off limit for loadings was set to 0.50. The factor analysis was performed by principal component analysis (PC) on a correlation matrix and varimax rotation.

**Correlation of variables and classification of patients (Paper 1 and 4)**

The predictions of group memberships were performed using multinomial logistic regression analysis. The regression models were built by adding one variable at a time (enter-procedure), with the criteria of keeping/removing the variable by a $p$-value of <0.05, until all variables were tested. In Paper 1, a sequential rejective multiple test was applied on each regression model to minimize effects of alpha inflation (type 1 error) (Holm 1979).

The correlation analyses between sensorimotor variables and self-reported functional disabilities were assessed by the Spearman’s rho correlation coefficient (Paper 4).
RESULTS

Prediction of altered pain intensity (Paper 1)

Variables predicting pain alteration in chronic LBP and neck pain

For patients with LBP, altered pain intensity was predicted by almost identical variables after the treatment period as at the 12-month follow-up. Significant variables were average pain intensity, MPI-pain severity and MPI-affective distress (Table 3). For the patients with chronic neck pain, the significant variables were the optimism and sociability indices along with the endurance index and pain intensity (Table 3).

Table 3. Variables predicting pain reduction in the primary pain region after 4 weeks multimodal treatment and at 12-month follow-up, separately shown for patients with chronic low back pain and chronic neck pain.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Low back pain</th>
<th>Neck pain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>After treatment</td>
<td>12-month follow-up</td>
</tr>
<tr>
<td>MPI-pain severity</td>
<td>0.40 0.24-0.67</td>
<td>0.42 0.25-0.70</td>
</tr>
<tr>
<td>MPI-affective distress</td>
<td>2.33 1.25-4.33</td>
<td></td>
</tr>
<tr>
<td>Optimism index</td>
<td></td>
<td>3.00 1.45-6.19</td>
</tr>
<tr>
<td>Sociability index</td>
<td>0.13 0.04-0.42</td>
<td>0.18 0.04-0.73</td>
</tr>
<tr>
<td>Endurance index</td>
<td>1.08 1.04-1.12</td>
<td></td>
</tr>
<tr>
<td>OS-index</td>
<td></td>
<td>0.92 0.87-0.96</td>
</tr>
<tr>
<td>Age</td>
<td>0.91 0.86-0.97</td>
<td></td>
</tr>
<tr>
<td>Average pain intensity</td>
<td>1.09 1.05-1.12</td>
<td>1.06 1.03-1.09</td>
</tr>
</tbody>
</table>

\(MPI = \text{Multidimensional Pain Inventory}, \ OS = \text{Other symptoms.}\)

Prediction of reduced and unchanged pain intensity

For LBP, the regression model correctly classified 73%, \((R^2 32\%)\) of the patients after the treatment period, and 69% \((R^2 20\%)\) of the patients at the 12 month follow-up. Both models showed high specificity but low sensitivity (Table 4). The regression model on the patients with chronic neck pain was slightly better, i.e., an overall classification of 77% and 82%, respectively \((R^2 42\%)\) The sensitivity was low but the specificity high (Table 4). Common to all four regression model was the poor capacity of identifying those with decreased pain intensity, while the regression models was good at identifying those with unchanged or elevated pain intensity (Table 4).
Table 4. Numbers of correctly classified patients with chronic LBP and chronic neck pain according to the logistic regression models.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Back</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment</td>
<td>73%</td>
<td>46%</td>
</tr>
<tr>
<td>12-month</td>
<td>69%</td>
<td>34%</td>
</tr>
<tr>
<td>Neck</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment</td>
<td>77%</td>
<td>66%</td>
</tr>
<tr>
<td>12-month</td>
<td>82%</td>
<td>59%</td>
</tr>
</tbody>
</table>

Sensorimotor functions in chronic neck pain (Paper 2–3)

Balance

Fig. 5 shows examples of CoP displacement from a control subject and a patient with WAD. There was a noticeably larger area covered by the trajectory of the patient with WAD compared to the healthy control.

![Graph showing CoP displacement](image)

**Fig. 5. Typical centre of pressure migration patterns for a representative control subject and a patient with whiplash associated disorder (WAD) during standing in the Romberg position with closed eyes for 20 seconds.**

For the three groups, the average sway areas recorded in the Romberg position with open and closed eyes are shown in Table 5. The MANOVA-model for these conditions revealed significant effects of groups (F[4,54]=2.87; p<0.05). The one-way ANOVA was significant for Romberg with closed eyes and the post-hoc tests showed significant differences in sway area between the control- and WAD-groups (Table 5).
Table 5. Average sway area (in cm²) and standard deviation (SD) in Romberg position with open and closed eyes, separately shown for the control subjects and patients with insidious neck pain or WAD. F- and p-values of one-way ANOVAs.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Control</th>
<th>Insidious neck pain</th>
<th>WAD</th>
<th>F</th>
<th>Post-hoc</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Effect of vision in Romberg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>16</td>
<td>9</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open Eyes</td>
<td>6.6 ±4.7</td>
<td>10.5 ±7.3</td>
<td>9.6 ±5.7</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>Closed Eyes</td>
<td>10.9 ±6.5</td>
<td>16.6 ±11.7</td>
<td>26.9 ±14.7</td>
<td>5.4*</td>
<td>Control vs. WAD**</td>
</tr>
</tbody>
</table>

* p<0.05
** p<0.01

Effects of perturbations

An example of a perturbation induced by the experimenter (Drop-Exp) is shown in Fig. 6. Both the CoP_{pp} and the Head_{pp} showed characteristic amplitude shifts in the anterio-posterior direction after the load release.

![CoP migration and Cervical translation graphs](image)

**Fig. 6.** Example of CoP trajectory (CoP_{pp}) and cervical translation (Head_{pp}) recorded from a patient with WAD during the Drop-Exp test. The perturbation effects were quantified as the maximal peak-to-peak amplitudes in the anterio-posterior direction within one second immediately after the load was dropped.
The perturbation in the Arm-Lift test was induced by executing a voluntary fast shoulder flexion. The ANOVA-models revealed no difference in ROM between the groups. However, the control subjects moved their arms significantly faster than the patients (F[2,29]=4.3).

The average $CoP_{pp}$ and the $Head_{pp}$ obtained for the three groups in the perturbation tests are shown in Fig. 7. The MANOVA-models on $CoP_{pp}$ and the $Head_{pp}$ demonstrated significant differences between the groups, i.e. larger anterio-posterior sway ($CoP_{pp}$ F[6,50]=3.03) and increased cervical translation ($Head_{pp}$ F[6,50]=2.83) for the two groups of patients, especially for the WAD-group.

In the Drop-Self and Drop-Exp tests, the post-hoc statistics of the one-way ANOVAs revealed significantly larger $CoP_{pp}$ and the $Head_{pp}$ for the WAD-group compared to the control group. In all three tests significantly larger $CoP_{pp}$ and $Head_{pp}$ were found for the patients with WAD as compared to those with insidious neck pain (post-hoc).

![Graph showing average peak-to-peak anterio-posterior sway (CoP_{pp}) and cervical translation (Head_{pp})](image)

**Fig. 7.** Average peak-to-peak anterio-posterior sway ($CoP_{pp}$) and cervical translation ($Head_{pp}$) with standard deviation, separately shown for the groups of control subjects ($n = 16$) and of patients with insidious neck pain ($n = 9$) and whiplash associated disorders (WAD, $n = 6$). Results from the three perturbation tests: Arm-Lift, Drop-Self and Drop-Exp.

**Cervical kinematics**

**Peak velocity**

Although the patients on average showed lower peak velocity during cervical rotations than the controls, there was no statistically significant differences between the groups (MANCOVA F[8,46] = 1.3).

**Smoothness of movement**

The cervical rotations were often smoother in the asymptomatic subjects than in the patients, which is clearly indicated in Fig. 4. A MANOVA-model on jerk index re-
revealed significant differences between the groups (F[8,50] = 2.5). Analyses by ANOVA of the separate directions of rotation showed statistically significant differences between the groups with larger jerk indices for cervical rotation towards and from the left (Table 8). The movements during outward and inward cervical rotations to the left were significantly less jerky for the control group compared to the group with insidious neck pain. The post-hoc tests for outward rotations to the left demonstrated significantly larger jerk indices for the WAD group compared to the control group.

**Table 8.** Jerk index, repositioning acuity (CE=constant error; VE=variable error) and the variability of range of motion (ROM-Variability) obtained from the cervical rotation test. Mean values with standard deviation (SD) are separately shown for the control subjects and the patients with insidious neck pain and whiplash associated disorders (WAD), respectively. F- and p-values for jerk index from one-way ANOVA-models, and for CE, VE and ROM-Variability from one-way ANCOVA-models (ROM as covariate).

<table>
<thead>
<tr>
<th>Condition</th>
<th>Control</th>
<th>Insidious neck pain</th>
<th>WAD</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td><strong>Jerk Index</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>15</td>
<td>9</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Out-Right</td>
<td>7.7 ±4.2</td>
<td>14.1 ±9.7</td>
<td>13.6 ±9.1</td>
<td>2.5</td>
</tr>
<tr>
<td>Out-Left</td>
<td>7.5 ±4.4</td>
<td>15.9 ±9.5</td>
<td>13.1 ±5.1</td>
<td>7.1**</td>
</tr>
<tr>
<td>In-Right</td>
<td>9.4 ±7.1</td>
<td>17.3 ±11.3</td>
<td>15.2 ±10.6</td>
<td>2.1</td>
</tr>
<tr>
<td>In-Left</td>
<td>8.6 ±4.9</td>
<td>16.2 ±8.7</td>
<td>11.1 ±6.1</td>
<td>4.5*</td>
</tr>
<tr>
<td><strong>Constant Error</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>16</td>
<td>9</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Right (º)</td>
<td>0.1 ±0.5</td>
<td>0.4 ±0.5</td>
<td>-0.4 ±0.8</td>
<td></td>
</tr>
<tr>
<td>Left (º)</td>
<td>0.1 ±0.6</td>
<td>0.4 ±0.8</td>
<td>0.7 ±1.1</td>
<td></td>
</tr>
<tr>
<td><strong>Variable Error</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>16</td>
<td>9</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Right (º)</td>
<td>2.0 ±0.7</td>
<td>2.9 ±1.4</td>
<td>3.3 ±1.7</td>
<td>5.6**</td>
</tr>
<tr>
<td>Left (º)</td>
<td>2.2 ±1.0</td>
<td>2.7 ±1.0</td>
<td>4.1 ±2.2</td>
<td>6.1**</td>
</tr>
<tr>
<td><strong>ROM-Variability</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>16</td>
<td>9</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Right (º)</td>
<td>3.2 ±1.3</td>
<td>3.7 ±1.5</td>
<td>5.8 ±2.3</td>
<td>8.2**</td>
</tr>
<tr>
<td>Left (º)</td>
<td>4.1 ±1.9</td>
<td>4.2 ±1.3</td>
<td>6.7 ±3.0</td>
<td>6.2**</td>
</tr>
</tbody>
</table>

* p<0.05; ** p<0.01.

Repositioning acuity

There was no differences between the groups regarding CE (MANCOVA: F[4,50] = 2.3). However, the MANCOVA-model on VE revealed significant differences between the groups (F[4,52] = 3.9). Neither of the covariates was significant in this
model. Both the one-way ANCOVA-models on $VE$, for rotations from the right and left, demonstrated statistically significant differences between the groups with larger $VE$ for the groups of patients compared to the control group (Table 8).

ROM-Variability
The consistency of the performed cervical rotations was assessed by calculating ROM-Variability. The MANCOVA-model on ROM-Variability revealed statistically significant differences between the groups ($F[4,52] = 4.8$). The covariates were non-significant in the model. Both one-way ANCOVA-models, for rotations to the right and to the left, showed significant larger ROM-Variability for the patients, particularly the WAD group (Table 8). Both models were significantly influenced by the covariates.

Objective evaluation of sensorimotor functions (Paper 4)
Association between different sensorimotor parameters
The factor analysis generated three significant principal components. The first component explained 31%, the second 24.6% and the third 20.8% of the variance, generating a total explained variance of 76.4%.

The balance and the perturbation variables ($Posture-Standing$, $Cervical-Stability$, and $Posture-Stability$) loaded strongly on the first component (Fig. 8A and B), indicating close relations between these variables. The second component was mainly determined by $VE$ and $ROM-V$ and to some extent by $Posture-Stability$, while the third component was explained by $Jerk$ and $Arm-Velocity$ (Fig. 8B).

Differences between patients with chronic neck pain and asymptomatic subjects
The plots of the principal components (PC1-3) in Fig. 8C and D show the distribution of the patients and control subjects based on the seven variables used in the analysis. Ten out of 15 patients deviated considerably from the control group on at least one of the investigated sensorimotor variables (labeled 1-10 in Fig. 8C and D). The general differences between patients and control subjects were confirmed in a regression model that correctly classified 87% of the patients and subjects, with both high sensitivity and specificity (both 87%). The model was based on $Cervical-Stability$ (OR 4.7, 95% CI 1.4-15.6) and $Arm-Velocity$ (OR 0.97, 95% CI 0.95-0.99), and explained 64% of the variance.
Relation to aetiology and other symptoms

As indicated in Fig. 9A, vertigo did not seem to be particularly related to any of the sensorimotor variables and no significant correlation between self-reported vertigo and the sensorimotor variables were found. However, self-reported unsteadiness was significantly related to poor balance (Spearmen’s rho, 0.55) and reduced cervical stability (Spearmen’s rho, 0.72) (cf. Fig. 8A).

As can be seen in Fig. 9B, patients who reported the largest functional disability according to the NDI were mostly characterised by poor cervical stability (Spearmen’s rho 0.55, $p < 0.05$). Interestingly, four out of the five patients with seemingly normal sensorimotor abilities reported high levels of functional disability (>30 on NDI: cf. Fig. 8C).
In general there was a good correspondence between the NDI scores and the QTF classification (Fig. 9B and C). Patients with WAD grade III showed pronounced disturbances of balance and cervical stability, and for two of them also of repositioning acuity. The latter was also found for one patient with WAD grade II, whereas the other with grade II was characterized by slow movements.

Patients with insidious onset neck pain were characterized by somewhat slower and jerkier movements, sometimes in combination with poor balance, cervical stability and/or movement acuity (Fig. 9C). However, the heterogeneity in sensorimotor disturbances among the two groups of patients indicated that they cannot be separated based on sensorimotor variables. This was confirmed in a multinomial regression model showing poor sensitivity for both patients with insidious pain (44%) and with WAD (67%).

**Fig. 9:** Associations between objectively assessed sensorimotor disturbances and self-reported unsteadiness and vertigo (A), self-reported neck disability (NDI) (B), etiology (insidious onset or whiplash-related; WAD) and Quebec Task Force Classification for the WAD-patients (C). The diagrams show the same score plot as in Fig. 8C. For the corresponding variable loadings, see Fig. 8A.
DISCUSSION

The following discussion is organized along the papers upon which this thesis is based.

Prediction of altered pain intensity (Paper 1)

Predictors of pain alteration in chronic low back and neck pain

Even though pain alteration in both the chronic LBP- and neck pain- groups was best predicted by psychosocial and behavioural variables (Table 3), the specific predictors were not identical for the two groups. This finding supports the suggestion that the development of symptoms in chronic LBP and neck pain is predicted by partly different variables (Leclerc et al. 1999).

High pain intensity at admission, low level of life disruption due to pain together with high affective distress predicted altered pain intensity for patients with LBP. Significant predictors among the patients with neck pain were high endurance, low age, high pain intensity, scarcity of other symptoms, low need of being social and to do things with others and to be helped, along with optimistic attitudes as to how the pain would interfere with daily life, and scarcity of vegetative syndromes. For neither back nor neck pain, variables like gender, sick leave history, working status, pain duration, potential trauma and depressive symptomatology, shows any predictive power. These findings on neck pain resemble some of the findings for LBP reported by Bendix (Bendix et al. 1998), and indicates that pain reduction is more likely to occur in patients who try to continue life as it was before the pain condition started, and who also recognize the fact that in order to change the pain condition, nobody but himself/herself has to do the work.

The same set of variables predicted pain alteration both on the short and long-term follow-up, which is largely in agreement with previous studies showing that short- and long-term functional improvements in LBP might be predicted by the same pain and psychological variables (Cherkin 1996).

The dominating predictors of the present study were psychosocial-behavioral and physical in nature, which is in contrast to previous studies reporting socio-demographic and physical variables as the prime predictors (Turner et al. 1983; Fredrickson et al. 1988; Hildebrandt et al. 1997; Bendix et al. 1998). Furthermore, prognostic effects of high endurance and young age were previously reported for patients with LBP (Fredrickson et al. 1988; Hildebrandt et al. 1997; Bendix et al. 1998), whereas in the present data these variables predicted pain reduction in chronic neck pain but not in chronic LBP. The discrepancies are most probably a combined result of differences in selection of patients, baseline variables, treatment, outcome measures, and statistical methods. Yet, taken together, the available data on
factors predicting treatment related pain reduction in chronic LBP and neck pain seem to indicate that the important predictors are found among physical and psychosocial characteristics, rather than among demographic and socioeconomic factors.

Methodological considerations
A safety-margin implying a reduction of at least 25 mm on the VAS-scale was adopted in order to increase the probability that the pain alterations were considered as meaningful by the patients (Carlsson 1983; ter Kuile et al. 1995; Campbell & Patterson 1998; Rahme 1998). This was confirmed in less stable regression models when more narrow safety-margins were adopted. Yet, a consequence of the rather large safety-margin was that the actual numbers of patients who perceived a change in pain intensity might have been underestimated.

Although the baseline variables were chosen with regard to previous predictors (Turner et al. 1983; Fredrickson et al. 1988; Hildebrandt et al. 1997; Bendix et al. 1998), the set of variables used in the present study might not have been the most relevant. The dominance of psychosocial and behavioural characteristics as predictors of treatment success found in previous studies has been used to stress the importance of psychosocial and behavioural factors in development and maintenance of CMPS (Keefe et al. 1986; Rudy & Turk 1991; Gatchel et al. 1995; Klapow et al. 1995; Linton 1995). However, this view disregards the possibility that functional disabilities, more related to disturbed neuromuscular mechanisms might serve as potent indicator of treatment success.

There are a number of potential neuromuscular mechanisms that might be involved in genesis, maintenance and spread of pain and dysfunctions in CMPS (e.g., Curatolo et al. 2001; Johansson et al. 2003; van Dieen et al. 2003; Banic et al. 2004; Falla 2004; Sterling et al. 2004). Several mechanisms predict disturbances of sensorimotor functions, such as reduced proprioceptive acuity and deranged motor control. Indeed, patients with back and neck pain have been found to demonstrate poor balance, deranged muscle coordination and poor proprioceptive acuity (e.g. Revel et al. 1991; Hodges & Richardson 1996; Karlberg et al. 1996; Luoto et al. 1996). The combination of objectively assessed dysfunctions and psychosocial and behavioural characteristics will certainly improve the precision, by which treatment-induced effects can be predicted.

Pain perception as an outcome variable
Numerous authors have argued that pain perception is poorly correlated with underlying tissue damage, etiology and disability (Hazard et al. 1991; Rudy & Turk 1991; Waddell et al. 1993; Hazard et al. 1994; Manniche et al. 1994; Gatchel & Gardea 1999; Leclerc et al. 1999). Also, pain perception appears to be poorly related to ROM, muscular strength and fatigability (Falla 2004; Ylinen et al. 2004). Pain inten-
sity is an outcome modality influenced by many variables, e.g., psychological, behavioural, medical and socio-demographic parameters. As a consequence, self-reported pain has been suggested to be a poor outcome measure in the evaluation of treatment efficacy on patients with CMPS (Cairns et al. 1984; Lackner & Carosella 1999). However, the results of the present study show that changes in pain intensity could be predicted with reasonably good accuracy (see also Fredrickson et al. 1988; Hildebrandt et al. 1997; Bendix et al. 1998). The regression models correctly classified between 69 and 82% of the patients, which are compatible with the predictability previously reported for work resumption and functional improvements (Cairns et al. 1984; Hildebrandt et al. 1997; Baker 1998). More importantly, the accuracy of predicting unchanged or increased pain intensity was even better (84-91%). This might be used to identify patients with poor possibilities of pain reduction in a standardized multimodal rehabilitation programme. It is suggest that such patients are offered complimentary treatment within the multimodal program, e.g. psychological-behavioural and pharmacological therapy, to gain optimal effects of the physical rehabilitation.

The patients who perceived significant reduction of their pain intensity were poorly predicted by the baseline variables used in the present study (34-66%). An implication of this is that poor and good pain outcome is predicted by partly different variables, which emphasises the importance of identifying relevant predictors for pain reduction and other desirable treatment effects. Improved knowledge on such variables, along with variables predicting poor outcomes, would increase the possibility of deliver realistic expectations to the patients as well as the probability of accomplish the desired treatment effects. The risk for unnecessary personal distress and high costs due to ineffective therapy would be considerably reduced if the content of the rehabilitation programmes were tailored to the patients’ individual dysfunctions and expectations.

Sensorimotor functions in chronic neck pain (Paper 2-4)

Sensorimotor variables

It has been proposed that the rehabilitation should be based on processes causing the dysfunctions rather than towards identification of the pathoanatomical origin of the pain (Woolf & Decosterd 1999). One prerequisite for such an approach is availability of objective and quantitative measures of dysfunctions that correlate with clinical findings and self-reported complaints. Another is knowledge on the mechanisms underlying the dysfunctions. The main aims of the present study were to explore sensorimotor characteristics in chronic neck pain by objective and quantitative means, and to gain information on possible mechanisms behind such dysfunctions.
Balance and responses to perturbations

The balance was evaluated by analysing the sway area. In agreement with previous studies patients with chronic neck pain showed increased sway areas as compared to the control subjects (Alund 1993; Karlberg et al. 1995; Rubin et al. 1995; Karlberg et al. 1996; Sjostrom et al. 2003; Madeleine et al. 2004). This difference between the groups was more pronounced when visual input was excluded, in accordance with previous results from patients with LBP (Mok et al. 2004), suggesting that visual input to some extent compensates for disturbed proprioceptive information in chronic neck pain (cf. Ghez et al. 1995).

The effects of expected and unexpected perturbations on the standing balance and the cervical stability represent novel and objective measures of sensorimotor functions in chronic neck pain. Yet, the findings of increased cervical translation during perturbations, most pronounced in WAD, support observations of delayed activation of deep cervical flexor muscles following a rapid shoulder flexion in patients with WAD (Falla et al. 2004). Similar disturbances of preparatory muscle activation have been reported for patients with LBP (Hodges 2001; Leinonen et al. 2001). Falla and coworkers suggested that the alternation in the temporal activation pattern of cervical muscles could be due to deficits of the automatic feedforward control (Falla 2004; Falla et al. 2004). Although the importance of proprioceptive information for accurate feedforward based movement has been stressed (Ghez et al. 1991; Ghez & Sainburg 1995; Sjölander et al. 2002), it remains to be clarified whether deranged sensory input or central motor control processes initiate and maintain such motor disturbances.

A close relation between the standing balance and the cervical stability was indicated in the factor analysis since Posture-Standing together with Cervical-Stability and Posture-Stability loaded strongly on the same component. Thus, if reduced cervical stability is caused by disturbed feedforward control of neck muscles, then it seems likely that poor balance also reflects disturbed preparatory muscle activation. However, it has been suggested that a major cause for balance dysfunctions are altered proprioceptive input to the CNS (e.g. Karlberg et al. 1995; McPartland et al. 1997; Bränström et al. 2001). The factor analysis of Paper 4 shows that balance and position sense acuity loaded on different components, implying partly different underlying mechanisms between these sensorimotor functions (Fig. 8A). Yet, the poor balance, cervical stability and position sense acuity might all be due to disturbed proprioception if they are differently influences by various proprioceptive sub-modalities. That is, theoretically it is possible that the repositioning acuity is determined by information on joint positions while, for instance, the balance is more dependent on dynamic components of the proprioceptive input (Clark et al. 1985; Sittig et al. 1985).
The sensorimotor disturbances in chronic neck pain are also influenced by psychological factors. Recently, Moseley and co-workers investigated effects of experimental pain and perturbations on motor responses in healthy subjects (Moseley et al. 2003; Moseley et al. 2004). It was found that the reaction time was reduced and the muscle activation pattern altered when unpredictable perturbation or pain stimuli were anticipated. This effect was larger for subjects who reported anxiety about the impending pain, suggesting that psychological factors can contribute to motor disturbances observed in chronic pain (Moseley et al. 2003). Interestingly, there was a pronounced variability in the reaction time-anxiety relation among the individual subjects, perhaps indicating that there are psychological traits which may predispose some individuals for subsequent pain and motor dysfunctions.

Position sense acuity
ROM-Variability was defined as the variability of the end position of the cervical rotations, and represents a measure of movement irregularity. The factor analysis displayed a strong relation between ROM-V and VE (Fig. 8A), which indicate poor position sense acuity causes both large VE and large ROM-V. Interestingly, while VE reflects the outcome in a cognitive task with a clearly defined goal, the ROM-V reflects unconscious movement variability. Thus it seems most likely that large VE:s in chronic neck pain are an effect of disturbances of sub-conscious proprioceptive mechanisms, rather than to poor ability to concentrate on the tasks or to reduced sincerity of effort (cf. Crombez et al. 1996).

In agreement with previous findings, the repositioning error was larger for patients with chronic neck pain as compared to health subjects (Revel et al. 1991; Heikkilä & Åström 1996; Loudon et al. 1997; Kristjansson et al. 2003; Treleaven et al. 2003). In the present study the repositioning errors were evaluated by calculating the CE and the VE. The VE is believed to represent the noise in the proprioceptive system, and would thereby provide an indirect measure of the position sense acuity (Clark et al. 1995; Schmidt & Lee 1999). No bias towards over- or underestimation of the target positions was found (i.e., no differences in CE between patients and controls), which is in agreement with recent reports from patients with WAD (Treleaven et al. 2003). Taken together these observations suggest that large repositioning errors in chronic neck pain reflect poor position sense acuity due to disturbed proprioceptive input to the CNS, although a deranged motor control mechanisms at central levels cannot be excluded as a contributing factor.

It has been shown that afferent input from muscle spindles is crucial for optimal movement precision (e.g., Gandevia et al. 1983; Bergenheim et al. 2000; Roll et al. 2000). Without excluding other contributing factors, disturbed proprioceptive input, as a result of altered input from muscle spindles, could constitute an important pathophysiological mechanism in chronic musculoskeletal pain of various origins (Johansson et al. 1999; Johansson et al. 2003). It is known that muscle spindle affer-
nts convey position and movement information in ensembles of afferents (Gandevia et al. 1983; Bergenheim et al. 1996; Bergenheim et al. 2000; Ribot-Ciscar et al. 2003) and that the information content in such ensembles is reduced when the fusimotor control of the muscle spindles is disturbed by high activity in group III and IV muscle afferents (Pedersen et al. 1998). In an animal model, the excitation of chemosensitive nociceptors in cervical facet joints and muscles induces reflex activation of static fusimotor neurones, whose activity in turn alters the static and dynamic sensitivities of the innervated muscle spindles (Pedersen et al. 1997; Thunberg et al. 2001). Thus, if the signal-to-noise ratio of the information transmitted in the muscle spindle afferents is reduced as a result of increased noise mediated by the static fusimotor activity it could be reflected in larger $\text{VE}$. The $\text{CE}$ would not be expected to be influenced by generally increased noise, however. A noisier fusimotor activity could be triggered by, for instance, a massive activation of mechanosensitive nociceptors, which may result from the soft-tissue injuries occurring in whiplash trauma (Jonsson Jr et al. 1991; Krakenes et al. 2002; Krakenes et al. 2003), or by activation of chemosensitive joint and muscle receptors which is likely to occur during inflammation or when muscle blood flow is reduced (Sjölander et al. 2002).

It should be noted that an increased fusimotor activity causing reduced signal-to-noise ratio in the muscle spindle afferents does not necessarily predict hyperactivity in painful muscles, which was assumed in the pain-spasm-pain model by (Travell et al. 1942). A deranged fusimotor control might trigger vicious circles by which muscle pain are maintained and spread, in similarity with the pain-spasm-pain model, but predicts proprioceptive and motor control disturbances rather than increased muscle activity. A detailed description of potential vicious circles in the pathophysiology of chronic neuromuscular pain has recently been presented in a comprehensive review by Johansson et al. (Johansson et al. 2003).

**Movement velocity and smoothness of movement**

The peak velocity during cervical rotations was lower in the group of patients than in the control group, but in contrast to in a recent study on patients with WAD (Öhberg et al. 2003), the differences were not statistically significant. One reason for the discrepancy might be that Öhberg et al. did not adjust their velocity-data for differences in ROM. Another reason could be the small sample size in combination with large inter-individual variability in the present study. Nonetheless, it seems likely that voluntary movements are slower in chronic neck pain, which was supported by significantly slower shoulder flexions in comparison to the control group (Paper 2).

The jerk index represents a novel attempt to describe smoothness of movements in patients with neck pain. It was found that cervical rotations were performed significantly smoother in asymptomatic subjects than in the patients. These findings are consistent with previous reports of movement inconsistencies in neck pain assessed

The factor analysis in Paper 4 indicates that jerk index and peak velocity might be influenced by the same underlying mechanisms. Even though these remain to be clarified, there are at least three possible mechanisms. Slow movements with low active ROM might indicate motor control strategies developed to avoid pain (cf. Lund et al. 1991; Vlaeyen & Linton 2000). It has also been shown that chronic neck pain causes increased co-activation of superficial muscles in the affected region (Jull 2000) which might generate slow and jerky movements. Finally, such movement disturbances could also be a reflection of strategies dominated by feedback control as a consequence of reduced acuity of proprioceptive input and ongoing feedback corrections, or as a result of disturbed feedforward mechanisms (Paper 3).

**Associations between various sensorimotor variables (Paper 4)**

Variables that show high loadings on the same component in a factor analysis indicate close association between these variables, while variables loading highly on different components are unrelated or weakly related. In the present study all variables loaded strongly on at least one of the three components, and each of the components explained a considerable part of the variance in the data set. The balance variables and cervical stability loaded significantly on the first component (*Posture-Standing, Posture-Stability and Cervical-Stability*), position sense acuity on the second component (*VE and ROM-V*), and smoothness and velocity of movement on the third component (*Jerk and Arm-Velocity*). These results indicate that there are several contributing mechanisms behind sensorimotor disturbances in chronic neck pain, and that some dysfunctions are influenced by the same mechanism while other dysfunctions reflect different mechanisms.

**Individual patterns of sensorimotor disturbances**

A major finding was the large diversity in the pattern of sensorimotor disturbances observed among the patients (Fig. 8). Peak velocity during arm movements was the most commonly affected variable, however, often in combination with other disturbances. Patients with poor balance sometimes showed reduced ability to stabilize the body and cervical spine during perturbations, whereas those with poor position sense acuity often demonstrated large *ROM-V*. A combination of poor balance/cervical stability and position sense acuity was evident in some patients.

An expected result in the light of the heterogeneity was that neck pain of traumatic and non-traumatic origin could not be easily separated. Similar observations have been reported by studying the coordination pattern of cervical muscles in patients with chronic neck pain of different etiology (Nederhand et al. 2002; Kristjansson et al. 2003; Jull et al. 2004; Sterling 2004). Thus, whether the neck pain is initiated by a whiplash trauma, has an insidious onset or is caused by work environment
factors, appears to be of little relevance for the sensorimotor disturbances observed in the chronic condition.

A modified version of the QTF-classification of WAD was recently presented by Sterling to account for the diversity of disturbances in motor, sensory and psychosocial functions (Sterling 2004). In the new classification system, WAD grade II was divided into three separate groups (IIA-C). Large repositioning errors were added as a prominent characteristic in grade IIC and III, which is supported by the present findings (Fig. 9C). Moreover, as deemed from the disturbances observed in this thesis, the classification system could also be complemented by slow movements, poor balance and poor cervical stability.

Methodological considerations
The studies on sensorimotor function could in some aspects be regarded as pilot studies due to the small sample size and should be repeated on larger groups. Yet, the results were largely similar to previous findings (e.g., Revel et al. 1991; Karlberg et al. 1995; Treleaven et al. 2003), indirectly suggesting valid data. The sensorimotor variables applied in the study seemed to be relevant since they distinguished patients with neck pain and healthy subjects with good precision in the regression analysis. Separation of patients and asymptomatic controls has previously been demonstrated based on joint position errors, ROM, balance and peak velocity (Revel et al. 1991; Dall'Alba et al. 2001; Sjostrom et al. 2003; Öhberg et al. 2003).

Reasonably good relations between self-reported dysfunctions and different sensorimotor disturbances were recently reported in WAD (Sterling et al. 2003; Sandlund et al. 2004). This was supported in the present data by significant correlations between self-reported unsteadiness and measured cervical stability/balance, and between NDI-score and cervical stability. These findings suggest that the variables represent important and valid measures of sensorimotor dysfunctions in chronic neck pain.

It might be argued that some of the sensorimotor variables could have been influenced by differences in sincerity of effort between the patients and the asymptomatic subjects. If so, the outcome of these variables would have been affected by psychological factors, and consequently the validity of the variables as objective measures of sensorimotor functions could be questioned. For instance, patients who are investigated for early retirement or prolonged sick leave might deliberately try to perform poorly during the tests (Fishbain et al. 1999). Indeed, for three of the variables (Arm-Velocity, VE and Posture-Standing), it was possible for the patients to predict the expected outcome due to the verbal instructions given during the tests. However, the participants could not predict the expected outcome on Jerk, ROM-V and Cervical-Stability since they did not know what was measured. The fact that these variables were closely associated with Arm-Velocity, VE and Posture-Standing suggests that
all variables do represent objective measures of sensorimotor abilities, rather than being distorted by sincerity of effort.

Implications for rehabilitation

In order to improve rehabilitation, it has been proposed that emphasis should be directed towards rehabilitation approaches that are based on mechanisms and processes causing current dysfunctions, rather than towards identification of the original pathoanatomical causes of the pain (Woolf & Decosterd 1999). The present thesis describes tests developed for objective and quantitative measures of sensorimotor disturbances that correlate with clinical findings and self-reported dysfunctions. Since such disturbances appear shortly after the onset of neck pain (Sterling et al. 2004), the functional assessment should preferably be carried out as early as possible. It is suggested that objective sensorimotor tests should be used to assess sensorimotor disturbances in patients with neck pain, at the initial assessment as well as in response to subsequent rehabilitation.

It is quite obvious that a patient with, for instance, poor balance and movement precision could be treated with the goal to improve these dysfunctions. However, caution should be taken when rehabilitating patients with chronic neck pain with the primary goal of restoring a normal muscle activation pattern (van Dieen et al. 2003). This might be impossible due to irreversible alterations of the sensory input to the CNS as a result of lesions of soft tissue and nerves or changed biomechanics (Ashton-Miller et al. 2001). If the sensorimotor system is irreversibly modified in chronic pain conditions, the rehabilitation should rather be aimed at adjusting the control of movements to the altered sensory situation. Such ‘sensory-motor’ adjustments could very well imply that the coordination between different neck muscles have to be altered to compensate for reduced or absent sensory input. In that case the rehabilitation process should be focused on achieving appropriate and efficient movements and postures, rather than on relearning of ‘normal’ coordination patterns (cf. Kalund et al. 1990).

In spite of the fact that a number of different treatment regimes are applied in neck pain disorders, the knowledge on efficient rehabilitation programs is scarce (Gross et al. 2000). An important reason for this is the heterogeneity in dysfunctions observed among patients who suffer from neck pain (e.g. present thesis, Falla 2004). As the complexity behind the chronic pain condition starts to unfold, the necessity of developing new rehabilitation strategies becomes clear. Dysfunctions such as poor balance, reduced cervical stability and decreased position sense acuity are pertinent symptoms in chronic neck pain, but data on efficient rehabilitation approaches for such dysfunction is limited. Yet, in a few studies, improved sensorimotor functions have been reported in response to specially designed exercise regimes (Revel et al. 1994; Hides et al. 1996; O'Sullivan et al. 1997; O'Sullivan et al. 1998; Hides et al. 2001; Jull et al. 2002; Cowan et al. 2003). For example, Revel (Revel et al. 1994)
showed that exercise of eye-head coordination increases the cervical repositioning accuracy as well as improves the self-assessed dysfunctions. Methods for objective evaluation of sensorimotor functions, as those presented in this thesis, should be used in the development of specific rehabilitation programs for different disturbances (Schaufele & Boden 2003).

It seems likely that applying pattern recognition methods to depict individual and complex patterns of disturbances could provide a rational tool in deciding on the appropriate rehabilitation content (cf. Fig. 8 and 9). For instance, patients demonstrating disturbances of the balance and cervical stability, along with motor control strategies influenced by pain avoidance, would be easily identified and should be offered a multidimensional rehabilitation focused on these dysfunctions. Moreover, close relations between different dysfunctions are recognised in multivariate factor analyses, implying that the number of tests used in the assessment of sensorimotor functions can be reduced without loosing much information on the extent of the disturbances. This would make the test procedure more efficient and enhance the applicability of objective evaluation of sensorimotor disturbances in clinical practice.
MAIN RESULTS AND CONCLUSIONS

- The results of Paper 1 demonstrate that patients who will experience unchanged or increased pain intensity after a multimodal rehabilitation programme could be predicted with good accuracy both on the short- and the long-term. However, patients who reported reduced pain intensity were more difficult to predict.
- Altered pain intensity in chronic LBP was predicted by high pain intensity, low levels of pain severity and high affective distress, while in chronic neck pain it was predicted by high endurance, high pain intensity, low need to be social or to do things with others or to be helped, along with optimistic attitudes as to how the pain would interfere with daily life.
- By using such information it is possible to provide the patient with more accurate and realistic expectations on the rehabilitation outcome. In addition, patients, who are likely to experience poor rehabilitation results after a standardized multimodal treatment programme, could be offered alternative therapy or complementary measures.
- In Paper 2-3 it is shown that patients with chronic neck pain were characterised by increased body sway during quiet standing, reduced cervical stability and balance during perturbations, and reduced position sense acuity and jerkier movements during cervical rotations.
- There was a large diversity of sensorimotor disturbances among the individual patients, indicating that the disturbances were weakly related to whether the neck pain had a traumatic or non-traumatic origin.
- It was suggested that objective sensorimotor tests should be used to assess sensorimotor disturbances in patients with neck pain, at the initial assessment as well as in response to subsequent rehabilitation.
- In the factor analysis of Paper 4, strong associations were found between some variables and weak between others.
- The balance variables and cervical stability loaded significantly on the first component of the factor analysis, position sense acuity on the second component, and smoothness and velocity of movement on the third component.
- Correlation and regression analyses indicated that the sensorimotor variables represent important and valid measures of dysfunctions in chronic neck pain.
- The results indicate that there are several contributing mechanisms behind sensorimotor disturbances in chronic neck pain, and that some dysfunctions are influenced by the same mechanism while other dysfunctions reflect different mechanisms.
- It was suggested that methods for objective evaluation of sensorimotor functions, as those presented in this thesis, should be used to assess functional capacity of patients with chronic neck pain as well as in the development of specific rehabilitation programs for different disturbances.
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