Cervical influence on dizziness and orientation

Malmström, Eva-Maj

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LUND UNIVERSITY

PO Box 117
221 00 Lund
+46 46-222 00 00

Department of Otorhinolaryngology, Head and Neck Surgery, Clinical Sciences, Lund and
Department of Health Sciences, Division of Physiotherapy
Lund University, Sweden

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Eva-Maj Malmström

LUND UNIVERSITY
Faculty of Medicine

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Contact address
Eva-Maj Malmström, RPT
Lund University Hospital
Department of Otorhinolaryngology and
Department of Rehabilitation Medicine
22185 Lund
Sweden
E-mail: eva-maj.malmstrom@med.lu.se

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"... to move things is all that mankind can do … for such the sole executant is muscle, whether in whispering a syllable or in felling a forest."

Charles Sherrington, Linacre Lecture, 1924

To my family

Contents

Abbreviations and definitions

Accuracy How close a repositioning is made to an introduced target; here analysed in terms of constant error (CE)

AE Absolute error; error of unsigned differences between an introduced and reproduced target

AMA American Medical Association

BMI Body mass index

BV Bilateral vestibulopathy; an impairment or loss of function of peripheral labyrinths or the vestibular nerves

CE Constant error; mean error of signed differences between an introduced and reproduced target

Cervicogenic dizziness – Dizziness where the suspected impaired mechanism is proprioceptive

Concurrent validity – Part of criterion validity; the extent to which one measure is systematically related to other measures; in this thesis comparison between two contemporaneous measurements

Coupled movements – All motions that take place other than the main (primary) motion

CROM Cervical range of motion (studies I, III, IV, V), cervical range of movement (study II)

CV Coefficient of variation

Disability Umbrella term for impairments, activity limitations and participation restriction; contrast to function

Dizziness Sensation of motion involving either oneself or one's environment; sensation of rotation, swaying or tilting

Full-cycle cervical range of motion – Maximal range from one end point of motion to opposite end point in the same cardinal plane

Half-cycle cervical range of motion – Maximal range from neutral head position to one end point of motion

ICC Intraclass correlation coefficient

LOA Limits of agreement

MVC Maximal voluntary contraction

MVE Maximal voluntary electrical activity

Motion Progression from one place to another

Neck pain Discomfort or more intense forms of pain that are localized to the cervical region; this term generally refers to pain in the posterior or lateral regions of the neck

Postural orientation – The ability to maintain appropriate relationships between the body segments and between the body and the environment to accomplish a task

Precision A measure of variability, for the reproduced targets; here analysed in terms of variability error

Primary movements – Main motion in the same direction as the applied load; movements described using a coordinate system

Proprioception – The sense of position and movement of one's own limbs and body without using vision; from L proprius = own, belonging to oneself

Reliability The degree to which test scores are free from errors of measurement

RMS Root mean square

Signed values – Positive and negative values as directional description for measurements; positive values for extension, right rotation, right lateral flexion, and overshoot; negative values for flexion, left rotation, left lateral flexion, and undershoot

VAS Visual analogue scale

VE Variability error; standard deviation of signed differences between an introduced and a reproduced target

List of publications

This thesis is based on studies reported in the following papers, referred to in the text by their respective Roman numerals.

I. Malmström EM, Karlberg M, Melander A, Magnusson M. Zebris versus Myrin: A comparative study between a three-dimensional ultrasound movement analysis and an inclinometer/compass method: Intradevice reliability, concurrent validity, intertester comparison, intratester reliability, and intraindividual variability. Spine 2003;28:E433-40.

II. Malmström EM, Karlberg M, Fransson PA, Melander A, Magnusson M. Primary and coupled cervical movements. The effect of age, gender, and body mass index. A 3-dimensional movement analysis of a population without symptoms of neck disorders. Spine 2006;31: E44-50.

III. Malmström EM, Karlberg M, Melander A, Magnusson M, Moritz U. Cervicogenic dizziness – musculoskeletal findings before and after treatment and long-term outcome. Disabil Rehabil 2007;29:1193-205.

IV. Malmström EM, Karlberg M, Holmström E, Fransson PA, Hansson GÅ, Magnusson M. Influence of unilateral cervical muscle fatigue on head repositioning – decreased overshoot after a 5-minute fatiguing task. Submitted for publication.

V. Malmström EM, Karlberg M, Fransson PA, Lindbladh J, Magnusson M. Cervical proprioception is sufficient for head orientation after bilateral vestibular loss. Submitted for publication.

Thesis at a glance

	Questions	Methods	Results	Conclusions
I	Are Zebris® and Myrin, two devices for measurement of cervical range of motion, reliable and comparable?	Comparison between two devices, one computerized, with 3-dimensional evaluations, and one manual.	Both devices showed good reliability and agreement; the computerized method, Zebris®, showed less variability.	The two devices can be used interchangeably. Myrin can be used in routine clinical work; Zebris® adds information with 3-dimensional evaluations.
II	How do age, gender and body mass index influence primary and coupled cervical movements? How do primary and coupled movements relate?	Test of cervical range of motion in 120 neck-healthy subjects using a computerized device with 3-dimensional evaluations.	Age influences the majority of primary and coupled cervical movements, especially the coupled movements of primary rotation and primary lateral flexion.	Coupled movements are a natural part of cervical motion together with primary movements. Cervical motion alters throughout life in specific patterns with individual variations.
III	What musculoskeletal findings are common in subjects with suspected cervicogenic dizziness? Does treatment based on these findings reduce symptoms of neck pain and dizziness in the long-term?	Musculoskeletal examination in 22 patients and long-term follow-up in 17 patients with suspected cervicogenic dizziness.	Tenderness in muscles and joints, postural imbalance and poor neck stability were common findings and were reduced after treatment. After 2 years, neck pain symptoms were reduced in 7/17 subjects and dizziness was reduced in 11/17 subjects.	Patients with suspected cervicogenic dizziness have some musculo-skeletal findings in common. Treatment based on these findings reduces both neck pain and dizziness. Some patients need a maintenance strategy.
IV	Does unilateral cervical fatigue influence head on trunk position sense?	Head repositioning tests before and after a unilateral cervical fatiguing task.	Accuracy of head repositioning improved significantly with less overshoot after acute fatigue.	Unilateral acute neck muscle fatigue might increase the sensitivity of cervical proprioceptors.
V	Do subjects with bilateral vestibulopathy maintain their ability to reproduce head on trunk positions?	Head repositioning tests in subjects with bilateral vestibulopathy compared to a healthy control group.	Subjects with bilateral vestibulopathy maintain their ability to reproduce head positions.	Vestibular information is less important for head repositioning and/or cervical somato-sensory input is up-regulated after bilateral vestibular loss. In either case, or both, cervical proprioception is important for head orientation.

Introduction

Cervical movements and cervical influence on dizziness and orientation

The importance of cervical proprioception for balance control has been confirmed in both animal and human studies[35,47,50,85,130,155,157]. Perception of head position and head on trunk movements is a prerequisite for optimal postural orientation, which requires cervical sensory information in close interaction with the other sensory inputs[88]. Neck pain and dizziness are both common complaints in patients seeking medical care[30,58,145]. When those symptoms coincide, it is difficult to ascertain if there is a causal relationship. Such a causal relationship must be present and corroborated to assert a condition of 'cervicogenic dizziness'. The entity is controversial since there are no specific tests to confirm cervicogenic dizziness [14,17]. The hypothesis holds that erroneous cervical proprioceptive input may contribute to a mismatch between different sensory inputs, creating distorted orientation and the experience of dizziness.

Postural orientation

The human postural control continuously integrates proprioception, vestibular information, vision and hearing, i.e., sensory information on movements

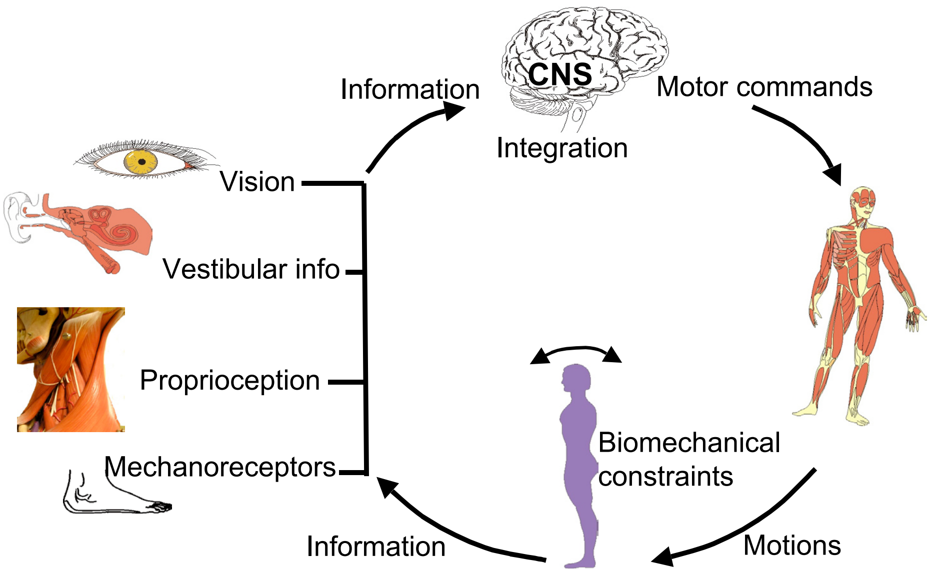

Figure 1. Schematic illustration of human postural control.

and orientation (Figure 1)[88,108,110]. The purpose of sensory-motor interaction during head movements is to stabilize head and eyes in space. A close interaction between vision, cervical proprioception and vestibular information supply optimal orientational cues under normal conditions[90].

Head position and movements of head on trunk are sensed by the vestibular end-organs and by cervical proprioceptors. The vestibular end-organs sense angular and linear head movements in space, as well as head position relative, to gravity[19]. The vestibular end-organs of the inner ear consist of three semicircular canals and two otolith organs. These end-organs sense head movements in space, but since they are located within the base of the skull, they cannot detect if the head moves on or with the trunk. To discriminate between those situations and to utilize vestibular information for postural control of the entire human body, cervical proprioception is necessary[7,143]. In this thesis, cervical sensory information on movement is assumed to be equivalent to cervical proprioception, although direct experimental evidence of cervical proprioception is not available under normal conditions since head movements are always detected by cervical proprioception and the vestibular organs working together[109]. Interaction between cervical proprioception and vestibular information during horizontal yaw rotation can be both additive and subtractive in interpreting whether the head is moved relative to a stable trunk or if the trunk is moved under a head that is held still in space[109]. The vestibular semicircular canals react to angular acceleration and the vestibular otolithic organs sense linear acceleration and hence static head position relative to gravity[86]. Cervical proprioception has both dynamic and static sensitivity and is assumed to sense positions and movements through sensory input from receptors in muscles, tendons and joints[48].

The deep upper cervical muscles contain twice as many muscle spindles per gram of muscle as the opponens pollicis muscle[153]. The importance of detailed cervical proprioception may be inferred from the large number of proprioceptors in the muscles[126] and zygapophyseal joints[104,125,156] of the upper neck. However, as yet there is no objective method to measure cervical proprioception in humans.

To gain insight into the capacity and relative contribution of the different sensory inputs, it is useful to investigate subjects with a temporary or permanent loss of one or another of the sensory systems. This can be achieved by excluding information from subjects (e.g., asking them to close their eyes or to wear blindfolds) or by testing patients who have lost function in one or more of their sensory organs.

Sensory mismatch and dizziness

If the inputs from the different sensory systems do not concur, a conflict may occur in the interpretation, a 'sensory mismatch', leading to a sensation of dizziness[16]. Most dizziness conditions are due to disorders of the vestibular system and can be diagnosed by specific tests. There are several otoneurological examinations utilized to detect different impairments of the vestibular end-organ. These include head impulse tests[53] and caloric tests[131] for the lateral semicircular canals, vestibular myogenic potentials[29]for the saccules, and test of the subjective visual horizontal and/or vertical[9] for the utricules. Sometimes brain imaging can verify lesions in the central nervous system. However, it is common to find no obvious objective explanation for the dizziness and different concepts should be considered. When there are no obvious objective diagnostic findings, one may use criteria diagnoses. One broad diagnosis of dizziness based on criteria is 'chronic subjective dizziness' [26,138,140] (Table 1), another is 'phobic postural vertigo' (PPV), established by Brandt et al.[15,18] (Table 2).

Table 1. Criteria for 'Chronic subjective dizziness' [26,138,140].

Criterion
Subjective dizziness and imbalance: Persistent (≥3 months) sensation of non-vertiginous dizziness, light-headedness, heavy headedness, or subjective imbalance that are present on most days.
Hypersensitivity to motion: Chronic hypersensitivity to one's own motion, which is non direction specific, and the movements of objects in the environment.
Visual vertigo: Exacerbation of symptoms in settings with complex visual stimuli such as in grocery stores of shopping malls or when performing precision visual tasks (reading or using a computer).
Otoneurological examination: Absence of active physical otoneurological illnesses, definite medical conditions, or medications that may cause dizziness. Past history may include episodes of true vertigo or ataxia as long as the conditions causing those symptoms have resolved. Normal radiographic imaging of the brain and normal or non-diagnostic findings in balance tests.

Table 2. Criteria for 'Phobic Postural Vertigo' [15,18].

Criterion	
1	Dizziness and subjective disturbance while standing or walking despite normal clinical balance tests.
2	Fluctuating unsteadiness in episodes lasting for seconds to minutes or momentary perceptions of illusory body perturbations.
3	Although the attacks can occur spontaneously, there is usually a perceptual stimulus or social situation from where the patients have difficulty withdrawing and they recognize as provoking factor. There is a tendency for rapid conditioning, generalization and avoidance behaviour to develop.
4	Anxiety and distressing vegetative symptoms occur during or after vertigo. Most patients have attacks both with and without anxiety.
5	Obsessive-compulsive type personality, labile affect or mild depression.
6	Onset of the condition frequently follows a period of particular emotional stress, after serious illness of falling an organic vestibular disorder.

The concept of PPV is mostly based on emotional reactions accompanying the dizziness. The outstanding feature of the diagnosis is hypervigilance for postural control[63]. PPV patients often suffer from pain in the postural muscles. Caution has been expressed that often there may be too much focus placed on the patient's anxiety and that not enough attention is paid to other possible explanations[63,140].

Since a diagnosis leads to the subsequent treatment interventions, an accurate diagnosis is vitally important to the patient's recovery. Different dizziness diagnoses and causes of dizziness have been studied, debated and revised throughout the years, all with the aim of finding the best interventions for the dizzy patients[15,17,26,44,63,71,140]. Patients with dizziness without objective findings of disturbed vestibular or central nervous function can be expected to be found in several fields of health care. Nonetheless, there is no consensus on how to categorize the many dizzy patients without objective findings.

Disturbed cervical sensory input as a possible cause of dizziness

Cervicogenic dizziness is considered when a cervical disorder is believed to be the cause of the experienced dizziness[17]. The main criterion for this condition is neck disability together with the perception of dizziness. The hypothesised aetiology is a sensory mismatch caused by erroneous cervical sensory input due to a cervical proprioceptive disturbance. There is well-founded theoretical support for the assumption that cervical sensory information is important for head orientation[88,108,110,111,124,134,143] and postural control[1,81,132]. Disturbance in the cervical sensory input can therefore be assumed to affect postural mechanisms[112] and to cause dizziness.

Patients with neck disability frequently suffer pain in both cervical joints and neck muscles, but also show signs of postural abnormalities[51]. Thus, several neuromusculoskeletal factors are affected in patients with neck pain, but there is no consensus on what specific mechanism or mechanisms are responsible for the erroneous signalling causing the hypothetical sensory mismatch. Because only a minority of patients with neck pain suffers from dizziness, other factors may be important. The causal relationship between neck pain and dizziness has been debated[16]. This is reasonable since neck pain may occur secondary to dizziness[82].

Dizziness of any origin is a very threatening and disabling symptom which may induce anxiety[139]. As neck pain by itself is quite a common complaint, the neck pain could coincide with anxiety and dizziness. One might contemplate a psychogenic aetiology in patients with no detectable organic causes to their dizziness. A more pragmatic way to approach patients with suspected cervicogenic dizziness would be to treat cervical musculoskeletal findings. If the dizziness then subsides, one may assume that the diagnosis was correct, i.e., a diagnosis ex juvantibus.

Influence of cervical sensory input on head orientation and vestibular loss

Orientation is dependent on the combined information from vestibular, visual and proprioceptive input. There is substantial evidence that cervical information interacts with the other senses in the central integration and modulation of motor commands[47,93,98,106,107,109,116].

A chronic malfunction in one sensory system may be compensated for by re-weighting the sensory information gathered from the remaining systems[32,134,142], although complete restitution of capacity is less common[32,80,162]. Studies of subjects with well defined loss of function in discrete sensory systems may reveal the importance and shortcomings of the remaining systems. A total proprioceptive loss is extremely uncommon but there are subjects with loss of vestibular function[32,161]. A bilateral vestibulopathy (BV) is a rare condition with impairment or loss of function of either both peripheral labyrinths or both vestibular nerves[161]. The key symptoms of BV are unsteadiness, especially during gait and blurred vision due to oscillopsia during head movements[13]. When one or both of the vestibular end-organs fail, vestibular rehabilitation with general and specific programmes can hasten the recovery, by both central habituation and sensory compensation[60].

Absent vestibular function emphasizes the importance of the remaining sensory inputs. Under such circumstances, the importance of proprioception, vision and hearing are set in focus and can be investigated[11,31,39,67,80].
It is well known that vision is important for orientation after a vestibular loss[37], but it is less well understood how proprioceptive input substitutes and contributes after a vestibular loss. Previous studies mainly concern postural sway parameters and body orientation[2,43,89,103,141,157], whereas the importance of cervical proprioception for head on trunk orientation is less studied.

Disturbance of cervical sensory input by muscle fatigue

Presently there are no accepted objective tests for cervical proprioception. However, psychometric head repositioning tests make indirect evaluations possible[97,124]. The rationale for head repositioning tests is that head on trunk movements are sensed by cervical proprioception. Subjects in such tests are examined on their ability to reproduce different head on trunk positions accurately.

Subjects with cervical disorders have in some studies been found to have impaired cervical position sense[46,59,87,97,124,146], while other investigators have found no effects[3,127,144], or even a sensitized cervical position sense[95]. In conditions with both neck pain and muscular manifestations of tenderness, fatigue, tightness and impaired stability, it is not obvious which factors affect position sense and to what degree. Studies on experimentally induced pain or muscle fatigue could contribute to the understanding of the impact of cervical disorders on position sense. Such studies may also provide insights into the roles of pain and fatigue in cervicogenic dizziness.

Muscle fatigue can be induced by muscular work. When fatigue is induced experimentally, the load must be controlled and maintained to generate the expected effect. A percentage of maximal voluntary contraction (MVC) is an expression of load in fatiguing tasks. Muscular fatigue can also be monitored by electromyography (EMG), and complementarily assessed by the subject's own reporting of fatigue. Surface EMG is easily applied over the superficial cervical muscles and EMG manifestations can both confirm the level of muscle activation and indicate the appearance of muscle fatigue. Subjective muscular fatigue can also be assessed by the Borg CR 10 scale[12].

Cervical movements and recordings

Head on trunk movements are executed by the neck. The biomechanical conditions of the zygapophyseal joints and the uncovertebral joints together with the vertebral discs and the immense muscular differentiation allow a large freedom of head movements relative the trunk[8,151,158]. These biomechanical conditions, together with cervical sensory information provide the basis to perform precise head movements and consequently, the ability to direct the face, eyes and ears toward a point of interest. The head can be moved in several ways relative to the trunk. Primary movements are performed in the three cardinal planes, and are flexion/extension in the sagittal pitch plane, rotation in the horizontal yaw plane, and lateral flexion in the frontal roll plane. In daily activities these primary movements are often accompanied by movements out of the cardinal planes, the so-called coupled movements. Coupled movements consist of both rotation and translation and are consistently associated with movements around another axis[151]. Coupled movements are most common in the cervical spine due to geometrical and ligamentous conditions.

Cervical range of motion (CROM) is the range of motion in the cervical spine in a given plane. Cervical range of motion depends on joint structures, extra-articular ligaments and tension of the musculature. In the cervical spine a multitude of joints contribute to a large range of motion with a natural variation[25] at end-range due to viscoelastic components[68]. Biomechanical conditions, such as posture, have also been shown to influence movement performance[57,118,150], as have age[36,38] and, to some extent, gender[147].

CROM is measured in order to evaluate the neck function[28], to estimate disability[28,33,40,94,122] and to compare function before and after treatment[92,117]. CROM in the cardinal planes, i.e. primary movements, have frequently been used in clinical evaluations, most often by the use of a one-dimensional inclinometer[160]. When primary and coupled movements are analysed they must be measured concurrently since they are performed simultaneously[151]. To do this, movements have to be analysed in three dimensions during motion. This is possible with computerized motion analysis[102]. Three-dimensional (3-D) movement analyses can evaluate the influence of different cervical conditions and treatment effects on movement performance[105]. However, more easily available and less expensive one-dimensional measurement devices[159,160] are often used in everyday clinical work. The question then arises as to whether these methods are comparable and if the new 3-D methods contribute to the further understanding of movement performance.

Cervical sensory information seems to be important for postural orientation, but dizziness caused by disturbed cervical proprioception and the relative contribution of cervical sensory input on perception of head on trunk position is not yet fully understood. A closer analysis of head on trunk movements thus seems warranted.

Aims

The studies were designed to attain the following aims:

– to evaluate the reliability and validity of two instruments that measure cervical range of motion: Zebris®, a three-dimensional, computerized ultrasound cervical motion device, and Myrin, a manual gravity-reference goniometer (I).

– to examine primary and coupled cervical movements and analyse how they are related, and how primary and coupled cervical movements are related to age, gender and body mass index in a 'neck-healthy' population (II).

– to describe the musculoskeletal findings in patients with suspected cervicogenic dizziness and to evaluate treatment effects on these findings; to analyse how the musculoskeletal findings are related to neck symptoms and dizziness; to evaluate the long-term effects on the neck symptoms and dizziness after a treatment intervention; and to describe emotional findings that accompany patients with suspected cervicogenic dizziness (III).

– to investigate how a unilateral cervical fatiguing task affects head-on-trunk position sense and to evaluate the test-retest reliability of head repositioning tests (IV).

– to evaluate the relative importance of cervical proprioception compared to vestibular input for head on trunk position sense and to test the reliability of the position identification procedure of the head repositioning test (V).

Subjects and methods

Subjects

Study I

Sixty neck-healthy volunteers (35 women, 25 men, ages 22–58).

Study II

Sixty neck-healthy volunteers from study I complemented with another 60 volunteers, resulting in 120 neck-healthy volunteers (60 women, 60 men, ages 20–79).

Study III

Twenty-two patients (20 women, 2 men, ages 25–49) with suspected cervicogenic dizziness, defined as dizziness due to sensory mismatch from erroneous cervical proprioceptive input, referred by practitioners in the Lund health services during a period of 3 years and 3 months (for musculoskeletal findings).
Seventeen of the original 22 patients (15 women, 2 men, ages 26–49) for treatment effect and long-term follow up.

Study IV

Seven healthy subjects in the EMG study (4 women, 3 men, ages 32–62).
Twenty healthy subjects in the main study (10 women, 10 men, ages 25–55).

Study V

Eleven subjects with bilateral vestibulopathy (3 women, 8 men, ages 24–74; time since diagnosis 6 months–9 years) and 15 healthy subjects (7 women, 8 men, ages 29–74).

The healthy subjects were recruited through advertisements or personal invitation at their place of work or site of recreational activity; the patients were seeking medical care in the Lund area.

The healthy subjects were included if they had no current neck pain, no history of long periods of constant or intermittent neck disability and no symptoms from the vestibular system (no dizziness and no vestibular disorder). The neck-healthy statement was complemented with a short examination of cervical function and status (studies IV and V).

Methods

Measurement of cervical range of motion with the Myrin device *(Studies I & III)*

A gravity-reference goniometer, RR Parir, Bålsta, Sweden (Myrin*),* was used. It consists of an inclinometer to measure flexion/extension and lateral flexion and a compass for the measurement of horizontal yaw rotation[4,159]. The Myrin was attached with Velcro strips to the subject's head. The Myrin was set to zero when the head was in neutral head position (NHP) with face forward and imaginary lines intersecting the ears, shoulders and hips parallel to the frontal plane and one imaginary vertical line close to external auditory meatus, shoulder joint and great trochanter, in the sagittal plane.

Measurement of cervical range of motion and head position with the Zebris® device *(Studies I, II, IV & V)*

The 3-D motion analyser, Zebris®-CMSHS, with software WinSpine, version 1.78; Zebris® Medizintechnik GmbH, Isny, Germany (Zebris®) [41,96,148] consists of a helmet and a shoulder cap, each fitted with 3 ultrasound microphones. The helmet was attached on the subject's head with a Velcro closing, and the shoulder cap was attached to the right shoulder. The ultrasound microphones on the helmet and shoulder cap received signals from three transmitters on a frame positioned approximately 1 m to the right of the subject. The sampling frequency was 50 Hz. The Zebris® measures the distances to the microphones by timing the intervals between the emission and the reception of ultrasound pulses. The absolute 3-D coordinates are then calculated by triangulation.

Calibration to zero was made with head in NHP (see Myrin) before first CROM measurement (flexion/extension) and before each repositioning test.

Cervical range of motion (CROM) *(Studies I, II, III, IV & V)*

Primary movements were measured with the two measurement devices, Myrin and Zebris®, in studies I and II, with Myrin in study III and with Zebris® in studies IV and V. The coupled movements were recorded by 3-D recordings with Zebris® in study II (Figure 2). All movements were active, maximal and aimed to be in the cardinal planes (flexion/extension, rotation right and left, and lateral flexion right and left). All cardinal planes were measured in studies I, II and III and rotation was measured in studies IV and V. The subjects performed four movements in each test direction before measurement recordings in order to warm up, to control the device attachment and to control movement performance (studies I, II, IV & V).

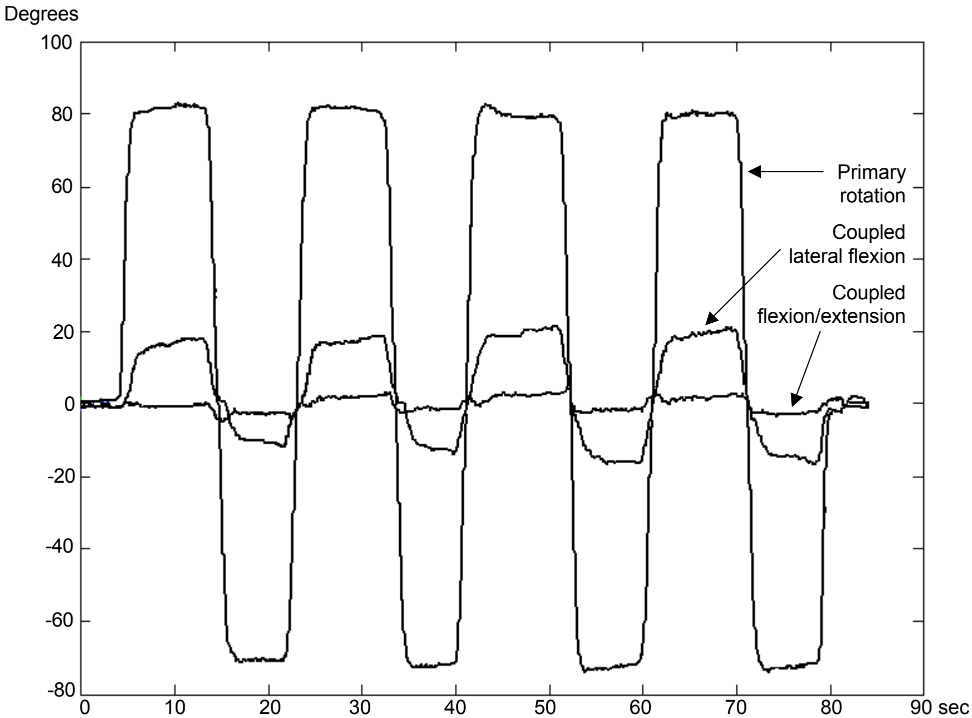

Figure 2. Recording of primary rotation with coupled flexion/extension and coupled lateral flexion with Zebris®, a three-dimensional ultrasound-based movement analyser. Positive values for right primary rotation, right coupled lateral flexion and coupled extension.

Two testers examined CROM with Myrin while simultaneously recording with the Zebris® device (study I).

Head repositioning tests *(Studies IV & V)*

The test procedure began with an introductory video designed to inform subjects about the test procedure. In both studies the subjects were blindfolded, with eyes closed in study IV and with eyes open in study V. Ear plugs were inserted to minimize information from hearing cues. In study IV a neck hood, and in study V a bathing cap, prevented direct contact between the subject's head and the tester's hands and minimized information from the tester's hands during manual introduction of positions.

The targets were 10° (V), 30° [97] (IV, V), 30° with oscillating movements when approaching the target position (V) and NHP[124] (IV, V). In study IV, the side for starting the position test and the side of activation in the fatiguing task were randomized into 4 equal groups, and the two targets, 30° and NHP, were repositioned in the same test sequence. The four targets were randomly introduced in study V and the test order was decided by drawing lots before each test occasion. In study V, the starting side for repositioning was equally distributed by randomization with lots (13 right and 13 left). Before each repositioning test, the neutral head position was calibrated and set to zero.

The actual target position was introduced by the tester, guided by simultaneous 3-D recording (Zebris®). This position was explicitly designated as the target position and held for more than 3 seconds. The subjects were asked to memorize the introduced target positions. The target positions were then reproduced actively six (IV) or three (V) times by the subjects at their own speed. The subjects signalled verbally when they considered themselves to be at target and the positions were defined in the recordings by the tester interrupting the ultrasound waves with a hand motion. This interruption caused spikes that could later be used to identify the reproduced positions. Identification of the introduced positions was made from the plateau in the recordings, when the head was held still during the introduction (mean value of 1 second registration during this plateau).

Device for measurement of muscle force *(Study IV)*

A metallic frame (Universal Frame, Rodby Elektronik AB, Enhörna, Sweden) fitted with a force transducer (AB Bofors, Electronic division, Bofors, Sweden) with a bridge amplifier and with an analogue feedback display was used for the application and measurement of muscle force. A neck hood was applied to the subject's head with a Velcro band and was connected with a bellyband to the frame. The vertical position was adjusted to apply horizontal force to the head. The lateral part of the shoulder and upper arm were directed towards the frame and were held closely against the padded support on the frame in order to stabilize the trunk.

Maximal voluntary contraction and fatiguing task *(Study IV)*

Three isometric maximal voluntary contractions (MVC) in cervical lateral flexion were performed for each side. The subjects were asked to activate as much as they could against resistance from the Universal Frame and to increase the force gradually up to maximal level without jerk. Verbal encouragement and a display of real time registration of force supported the effort. The level of muscle force for the fatiguing task was set to 30% of the MVC[34] and the subjects were instructed to maintain this muscle activation for 5 minutes. During the fatiguing task the subjects were guided by visual display of real time measurement of force and were, when necessary, corrected by the tester. The subjects were informed in advance about the length of the fatiguing task. All tested subjects maintained the 30% MVC level throughout the fatiguing task. During the fatiguing task in the EMG study, the subjects reported their subjective experience of fatigue on the Borg CR10 scale[12].

***Electromyography** (EMG) (Study IV)*

EMG surface electrodes were applied bilaterally over the paraspinal muscles (preferably the splenii muscles)[133] and over the levator scapulae muscles[133] with an inter-electrode centre-to-centre distance of approximately 20 mm. Sites were identified by palpation of lateral flexors during a short-time contraction.

Continuous EMG recordings were made from the right and left sides during a test of maximal voluntary contraction (MVC) of the cervical lateral flexors, and thereafter during a fatiguing task on the right side. The sampling frequency was 1024 Hz. Amplitude (root mean square [RMS], normalized to maximal voluntary electrical activity [MVE; µV], elicited during MVC) was analysed from EMG recordings[55]. An increase of RMS values over time is considered to be a myoelectric manifestation of fatigue[56].

The EMG recordings were transferred to MATLAB (The MathWorks Inc., Natick, MA, USA) and limitations were set at each outermost end of the EMG plateau, automatically spliced in MATLAB with 3 seconds in each end to exclude transients in the EMG. Maximal voluntary electrical activity and noise were identified in each EMG recording during MVC; thereafter we calculated RMS in MATLAB. RMS values were calculated for each separate electrode site.

***Assessment of subjective symptoms** (Study III)*

The patients were asked for duration of neck pain and dizziness in time intervals: 0–3 months, 4–6 months, 7–12 months, 13–24 months, and 25 months–5 years. Intensity at worst of neck pain, and whenever applicable, headache were asked for and rated on a vertical 100 mm visual analogue scale (VAS)[5]. Intensity at worst of dizziness was graded on a 5-point scale (0=no; 1=mild; 2=moderate; 3=severe; 4=very severe). Long-term follow-up was accomplished with a questionnaire, sent to the patients 6 months and 2 years after the end of treatment. The questions concerned current complaints of neck pain and dizziness and patients were asked if they had benefited from the treatment.

***Physical examination** (Studies III, IV & V)*

Study III: The physical examination was performed by a physiotherapist, not involved in the treatment intervention (Table 3). The tester had no access to earlier results when retesting.

Table 3. Main musculoskeletal findings and treatment modalities. Number *(n)* of patients (total n=17) treated with each modality reported.

	Musculoskeletal findings					
Treatment modality (*n*)	Posture imbalance	Poor dynamic stability	Cervicothoracic decreased mobility	Cervical local hypermobility/ pain	Muscle tenderness	Muscle tightness
Posture balance (7)	X	X	X	X	X	X
Muscular endurance (postural muscles/coordination of postural stability & movement) (13)	X	X				
Cervical stability (15)	X	X		X		
Mobilization, cervicothoracic region (4)			X			
Mobilization, thoracic spine (11)	X		X			
Mobilization, costae (4)			X			
Mobilization cervical hypomobile segments (4)			X	X		
Soft tissue treatment (16)					X	
Cervical muscle stretch (13)	X					X
Body awareness (3)	X	X			X	
Relaxation, general/local (7)					X	
For compliance – information, body awareness, home exercises						

Most treatment modalities comprised both manual techniques and performed exercises. Each exercise modality was reinforced by postural adjustments. Posture balance was considered as a fundamental condition for maintenance of achieved treatment result.

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A muscle tenderness score was evaluated by palpation of 18 neck and shoulder muscles and rated on a 4-point scale (0=no pain and no visible reaction; 1=light tenderness and no visible reaction; 2=painful tenderness and visible reaction; 3=severe pain and marked visible reaction, 'jump sign')[22,91].

Muscle tightness was evaluated on a 4-point scale (0=none; 1=low, 2= medium; 3=high)[27,75].

The zygapophyseal joints of the cervical spine were examined regarding pain and mobility [70,77,129].

Cervico-thoracic mobility was measured, palpating the spinal processes of the 7th cervical vertebra and thoracic vertebra 1 and 2 during maximal cervical rotation[78].

Cervial range of motion was tested with Myrin.

Postural alignment was assessed by comparing the longitudinal body axis to gravity[20].

Studies IV & V: A short neck examination was made in order to confirm the subject's neck-healthy statement. The examination consisted of a mobility test for upper cervical segments through lateral flexion of the head[78], a mobility test for cervico-thoracic rotation with manual palpation of the processus spinosus of C7[78] and palpation of tenderness[22,91] in the sternocleidomastoid, trapezius, levator scapulae and suboccipital muscles.

Mood Adjective Check List (MACL) *(Study III)*

In the latter half of study III the patients (11 of 22) answered a questionnaire offering a quantitative composite measurement of mental well-being. The adjectives are clustered in six bipolar dimensions: pleasantness/unpleasantness, activation/passivity, calmness/tension, extraversion/introversion, positive/negative social orientation and control/lack of control. Altogether 71 mood adjectives were graded from 1 to 4; a high value indicates positive mood (the three first dimensions regarded as basic mood factors = MACL 1–38)[137]. MACL for the study group (group level) was compared with a population-based reference group from a previous Swedish population study[120].

Treatment intervention *(Study III)*

Treatment intervention was guided by the musculoskeletal findings from the examination (Table 3). Clinical reasoning[76] and the multiplicity of findings individualized the intervention[149]. Responses from the patients determined treatment modalities, proceeding and intensity. Most treatment modalities comprised both manual techniques and exercises. Each exercise modality was reinforced by postural adjustments. Information and home training programmes supplemented the treatment. The treatment period lasted 5–20 weeks. The decision to end treatment was based on the patient's condition and outcome expectations. Treatment was ended if the patient became free from symptoms or if symptoms were significantly reduced and the patient was expected to maintain treatment results. Treatment was also ended if no further relief was expected.

Data processing and statistical analyses

The ability to reproduce targets was analysed as the difference between the reproduced position (set of 6 trials in study IV and set of 3 trials in study V) and the introduced position. A repositioning was considered as an overshoot (signed positive) when the reproduced position passed the introduced position and as an undershoot (signed negative) when the reproduced position was underestimated relative to the introduced position and the subjects stopped short of the target (Figure 3). The repositioning test was analysed in terms of constant error (CE) as a measurement of accuracy and directional bias, and in terms of variable error (VE) as a measurement of precision (Studies IV & V). CE is the mean error of the signed differences and VE is the standard deviation (SD) of the differences. CE and VE were complemented with absolute error (AE) in study V. AE is the mean error of the unsigned differences. AE was calculated for comparison to other studies and is not presented in the results.

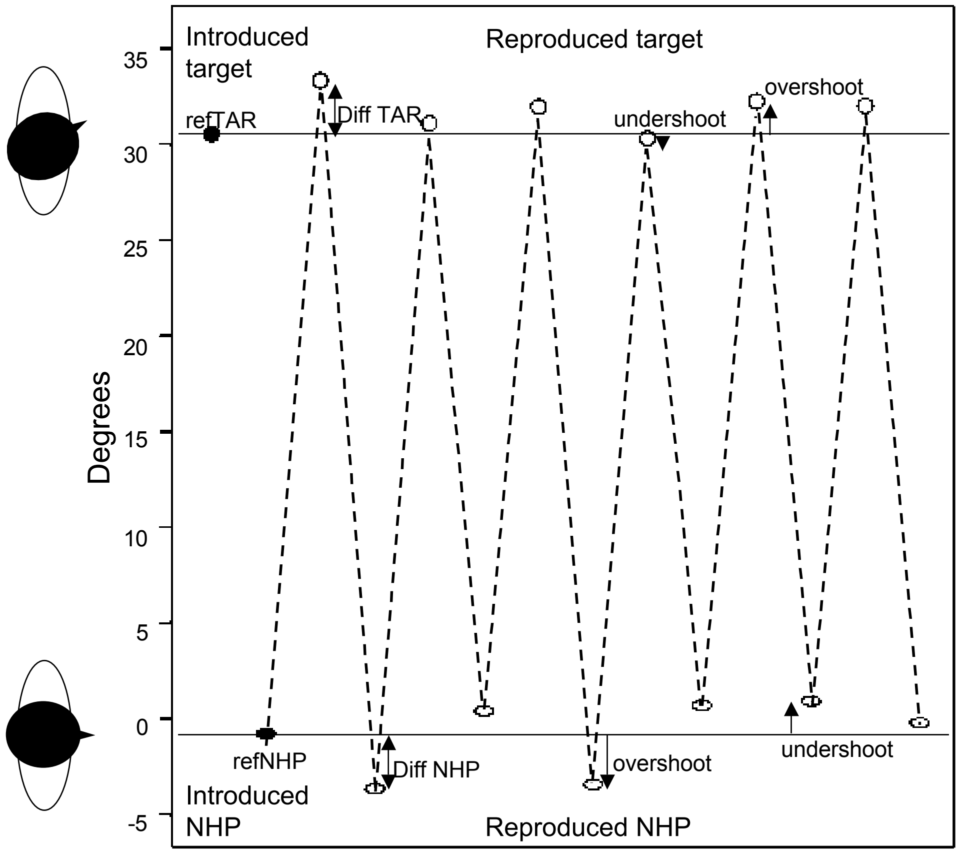

Figure 3. Introduction and repositioning of neutral head position (NHP) and 30° target (TAR). When the reproduced position passed the introduced position it was considered as an overshoot. When the reproduced position was underestimated relative the introduced position, and the subjects stopped short of the target, it was considered as an undershoot.

Continuous variables were checked regarding assumptions underlying parametric and nonparametric statistics and were described and analysed accordingly. Ordinal variables are described both parametrically and nonparametrically for information and are analysed with nonparametric statistics (Study III).

For agreement and consistency between tests, devices and testers, paired samples *t*-test with mean difference and 95% confidence interval (CI) (Studies I, IV & V), mean difference with 95% limits of agreement (LOA, i.e. mean difference±2SD of the difference)[6] (Studies I & V), intraclass correlation coefficient, two way random effect (Studies I & V) and coefficient of variation

(CV)(within-subject coefficient of variation with 2 CV corresponding to 95% of individual values: CV= ((SD of the difference between the two measurements/√2)/mean for observations from the compared tests) x 100)[121] (Study I) were used.

For variability, within-subject standard deviation was used (Studies II, IV & V).

The paired samples *t*-test was used for parametric intragroup comparison (Studies IV & V) and independent samples *t*-test was used for parametric intergroup comparison (Studies I & V).

Wilcoxon matched-pairs signed-ranks test was used for nonparametric intragroup comparison (Studies III & IV).

A linear-regression backward model with collinearity was used to assess the effects of age, gender and BMI on primary and coupled movements and enter model was used to explore the relationship between primary and coupled movements with primary movements and age as independent variables (Study II).

Spearman's rank correlation coefficient was used for nonparametric correlations (Study III).

A level of $p<0.05$ was considered statistically significant. All statistics were performed using SPSS 12.0–14.0 software (SPSS Inc., Chicago, IL).

Ethics

In all studies the subjects gave their oral or written informed consent to participate and were informed that they could stop their participation at any time, for any reason. The study designs were approved by the Regional Ethics Review Board in Lund (§LU189-00, §LU65-1989, 411/2006), Lund University, Sweden.

Results

Cervical range of motion and cervical movements

Study I

Zebris® returned somewhat higher values than did Myrin and had smaller dispersion. On average these differences were 5.7° for flexion/extension full cycle, 3.8° for rotation full cycle and 1.5° for lateral flexion full cycle. The intraclass correlation coefficient for full cycles in the three cardinal planes was between 0.93 and 0.96 for concurrent validity, between 0.90 and 0.96 for intradevice reliability and between 0.92 and 0.97 for intratester reliability. Interdevice variability assessed with within-subject coefficient of variation was lowest for flexion/extension and for rotation full cycles. Interdevice variability was highest for lateral flexion half-cycles. Measurements with the two devices agreed from 95% to 99% when AMA guidelines for consistency were considered[28].

For CROM in the sagittal plane, there was a larger difference between the devices for flexion than for extension.

In test-retest the Zebris® showed less variability than Myrin in all movements except half-cycle rotation. Full-cycle measurements showed less test-retest variability than did half-cycles for both devices. Retest demonstrated on average somewhat higher values for all CROM measurements except flexion (Myrin and Zebris®) and right rotation (Zebris®).

Intertester and intratester comparisons with Myrin showed measurements close to the simultaneous Zebris® registration, with an average difference between the testers of 0.6° for flexion-extension, 1.8° for full-cycle rotation and 0.05° for full-cycle lateral flexion.

Intra-individual variability did not increase with a greater CROM, but was dependent on the individual.

Study II

The study supply with normative CROM values for primary and coupled movements (Table 2, study II). Age influenced the majority of primary and coupled movements. Among primary movements the greatest decrease due to age was found for extension, with a 5.9° decrease per decade. There was a significant gender difference for primary extension, with greater CROM for women as compared to men in younger age. Decrease in extension was related to age, gender and BMI (R^2= 0.588). The decreased extension in women could be explained by both age and BMI.

Coupled movements were small for movements in the sagittal plane and were commonly leftwards for primary flexion and rightwards for primary extension. During primary rotation, there was coupled flexion and ipsilateral lateral flexion in the groups aged 20–69 years, while changes to contralateral lateral flexion were seen in the 70–79-year-old group (Figure 4). For lateral flexion coupled to primary rotation, there was a gender difference with men showing greater alteration to the contralateral lateral flexion. During primary lateral flexion there was also a direction alteration from coupled extension in younger subjects to coupled flexion in the eldest age group. Primary lateral flexion decreased with age with an increase of the accompanying coupled rotation. There was an individual variability for both primary and coupled movements.

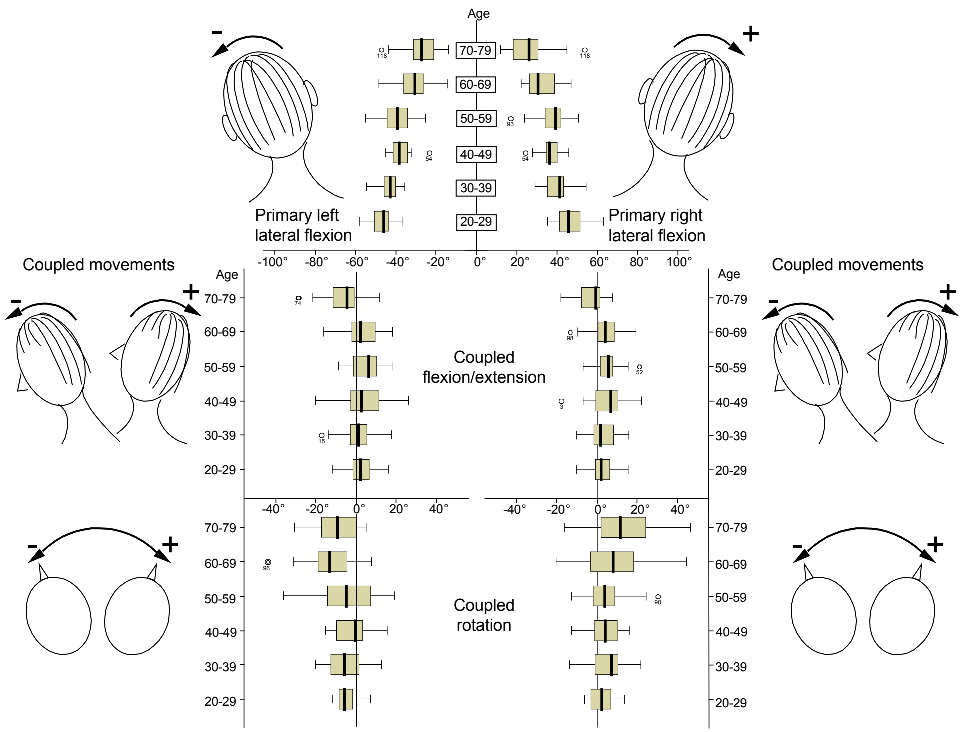

Figure 4. Primary lateral flexion with coupled flexion/extension and coupled rotation at different ages. Rightward and leftward movements are reported separately. Positive values for right primary lateral flexion, coupled extension and right coupled rotation.

Cervical sensory input as a possible cause for dizziness and cervical influence on head orientation

Study III

Musculoskeletal findings

A bilateral tenderness in several of the dorsal neck muscles was reduced after treatment. Tightness in the trapezius and suboccipital muscles was common, but the evaluation did not detect any significant reduction of tightness after treatment. Patients with some positive mobility findings often had tenderness in the zygopophyseal joints, which was reduced in the middle and lower cervical spine after treatment.

The patients in this study had normal or larger range of motion than expected age- and gender-matched values. Most patients had postural imbalance, and posture was found to be improved after treatment for 12 of 17 patients. Poor dynamic stability in trunk, neck and shoulders in these patients improved after treatment. Half of the patient group also reported temporomandibular symptoms, with some positive effects after treatment. Headache symptoms were reported to be frequent and were reduced somewhat in intensity and frequency after treatment. No significant correlation was found between the magnitude of symptom change for neck pain and dizziness directly after treatment. Significant correlation to neck pain relief was found for tenderness reduction of the middle paraspinal muscles. No reduction of any single muscle or zygopophyseal joint tenderness was found to correlate with dizziness relief. There were no significant differences for neck pain or dizziness between the initial examination and the examination after the waiting period. After treatment there was a significant reduction of both neck pain and dizziness.

Self-reported mood data

The patients with suspected cervicogenic dizziness did not differ from a population-based reference group in their mood according to Mood Adjective Check List[120]. The patients scored the lowest for the dimensions of calmness and control (Table 4).

Long-term follow up

Six months after treatment, 13 of the 17 patients had still no or less neck pain and 14 had no or less dizziness. Two years after treatment, 7 patients had no or less neck pain and 11 had no or less dizziness. Both 6 months and 2 years after treatment, 16 of the 17 patients stated that they had benefited from the treatment.

Table 4. Mood Adjective Check List (scaled 1-4, a high value indicating a positive mood): Patients with suspected cervicogenic dizziness, n=11, compared to a population based reference group[120]. Mean and 95% confidence interval (CI) are shown.

MACL	Cervicogenic dizziness group		Reference group
Dimensions	Mean	95 % CI	Mean
Pleasantness	3.11	2.72-3.50	3.11
Activation	2.94	2.68-3.21	3.06
Calmness	2.56	2.14-2.97	2.96
Extraversion	2.99	2.59-3.40	2.77
Social orientation	3.36	3.10-3.61	3.24
Control	2.85	2.48-3.21	3.13

Study IV

The EMG study ensured unilateral load during the fatiguing task. Test-retest for head repositionings was reliable and showed no significant intra-individual differences. Accuracy of head repositioning improved significantly after the fatiguing task. An average overshoot of 7.1° decreased to 4.6° after the fatiguing task for the 30° target and from 2.2° to 1.4° for neutral head position. The improved accuracy was most pronounced for movements towards the fatigued side. Precision for the 30° target did not change significantly after the fatiguing task but for the neutral head position it decreased with increased variable error.

Study V

The actual target identification procedure was found reliable with average ICC values between 0.985 and 0.998 and mean differences between 0.04° and 0.57° when two testers identified the four targets independently.

Subjects with bilateral vestibulopathy did not differ significantly from controls in their ability to reproduce different target positions, although after statistical adjustments for age and gender, the subjects with vestibulopathy somewhat underestimated the neutral head position when moving from the right side. When the 30° target position was introduced with oscillating movements, the overshoot diminished and accuracy improved in both groups, although only statistically significantly when performed towards the right side. The two groups did not differ in their precision for any of the four targets.

Discussion

Cervical range of motion

Concurrent agreement between instruments or procedures is the best validation of cervical range of motion measurements, because to date, there is no gold standard[24]. There is a natural variation of CROM in humans[25]. American Medical Association (AMA) guidelines recommend a 10% limit for consideration of consistency for mobility measurements[28]. In the present study, 95% to 99% of full-cycle CROM measurements were within this limit. Full-cycle CROM showed better reliability than did half-cycle CROM, as previously shown[21,24]. The fact of better agreement for full-cycle measurements emphasizes the importance, but also the difficulties, of starting from the same neutral head position. Nevertheless, measurement of half-cycle CROM is important because it can detect and evaluate unilateral CROM limitations[24,36].

In study I the Zebris® device recorded on average 4.7° higher values than Myrin for flexion, but only 1.0° higher for extension. The Myrin inclinometer records angular displacements of the head in relation to gravity, while the Zebris® records head movements relative to trunk. The latter might give a truer value of cervical movements. Intra-individual variability did not increase with larger CROM. Despite small discrepancies, the two measurement devices showed good agreement and the devices can be used interchangeably. The results support continued use of Myrin in routine clinical work; the more sophisticated 3-D Zebris® adds information and allows more detailed evaluation of natural movements in all three dimensions. The relative variation for maximal range of motion did not seem to depend on the total size of CROM, but it was approximately the same for primary movements in the three cardinal planes. The variation, in terms of test-retest reliability and intra-individual variability, suggests a physiological variation at the end-range of the motion. This might be explained by the viscoelastic properties causing a gradual increased resistance when approaching the limits of motion rather than a definite end-point[78].

Patients with cervicogenic dizziness in study III had greater average CROM for rotation and lateral flexion before treatment compared to normal values (study II and Youdas et al.[160]). However, the cervico-thoracic mobility was reduced in these patients. Mobilization techniques were thus performed at the cervico-thoracic junction, but the CROM values did not warrant mobility treatment of the cervical segment. Despite this, CROM values increased further after treatment. This increased CROM could be attributed to regained cervico-thoracic mobility.

Primary and coupled cervical movements

There is an age influence on primary cervical movements in the cardinal planes[23,24,36,38,62,135]. In the present study both primary and coupled movements were also significantly influenced by age, with a decrease in primary movements, but there was also a change in direction for the coupled movements. However, primary flexion was less influenced by age, corresponding to the findings of Doriot and Wang[38]. The relative reduction of extension and preservation of flexion could be explained by different starting positions due to posture. With increasing age a more pronounced kyphotic posture appears[54,152]. An increased thoracic and cervico-thoracic kyphosis, with a compensative cervical lordosis could result in increased flexion and lesser extension than a posture better aligned to gravity.

The functional application of 3-D movement analysis shows that coupled movements are a natural part of cervical motion and accompany primary movements in specific patterns. The coupled movements followed the expected pattern for subjects up to 69 years of age[8,73,74,151] but the coupled movements changed direction when complementing primary rotation and primary lateral flexion. This can be explained by adapting to optimal cervical mobility despite cervical spine degeneration. Since no radiological examinations were performed, speculations can only be made regarding degenerative processes by increased age. However, previous studies on specimens support the concurrence of cervical spinal degeneration with increased age[99]. Furthermore, increased coupled rotation accompanying decreased primary lateral flexion at higher age, have been confirmed by Demaille-Wlodyka et al.[36]. The influence of age on changed coupled movements of extension to flexion for primary lateral flexion could perhaps be explained by increased flexed posture in the cervico-thoracic junction and lower cervical spine[118]. Coupled extension in the middle cervical spine and coupled flexion in the lower cervical region has been previously shown using MRI[74]. Although this study of the spine examined primary rotation, the results suggest different coupling patterns due to spinal curvature. Increased coupled movements accompanying primary lateral flexion at higher age may be explained by osteophytes in the uncovertbral joints, with decreased primary movements in the frontal plane and increased coupled movements. However, preserved mobility at the C1-2 level in higher ages has been reported[42]. The relatively increased importance of function in the upper cervical spine to execute head movements may lead to a change in coupling patterns and explain the altered direction of these coupled movements. There is evidence of different directions for coupled movements in the higher cervical segments (occiput-C1-C2) compared with the segments beneath C2[73]. Different utilization of mobility of the upper and lower cervical spine in the elderly may explain the direction change of coupled movements at higher age. Such an altered coupling pattern may also alter cervical sensory input, which can be speculated to be a contributing factor for dizziness in elderly people.

There was a gender effect on CROM in the sagittal plane, in line with Trott et al.[147]. They reported equal CROM for women and men of younger age, but decreased extension with age among males. The present study (Study II) showed larger CROM for women at younger ages and an equalization between genders with increasing age. Trott et al. did not investigate subjects over 59 years of age. In the present study the equalization between genders was most prominent among subjects 60 to 79 years old. When gender, age and BMI were considered together in a regression analysis, the decreased extension in females was explained by age and BMI in our study. BMI has previously been found to be an influence on CROM [21,23]. In the present study, the most significant impact of BMI was found on movements in the sagittal plane in accordance with Caigne et al.[21]. Castro et al. reported an influence of BMI in all primary movements[23], a finding that study Il was unable to confirm.

Cervical influence on orientation

Previous research have shown increased repositioning errors in cervical disorders[46,59,87,97,124,146]. This thesis, however, has demonstrated decreased repositioning errors after a cervical muscle fatiguing task. Normally there is an overshoot, i.e., passing the aimed target, in head repositioning tasks[3], a result that study IV could confirm.

An explanation for this improved accuracy could be that muscle fatigue induces a perception of muscles being longer than they actually are[49]; leading subjects to stop short of the target[115]. Such perception of increased muscle length after experimental muscle fatigue has been shown for knee extensors[49] and experimentally induced fatigue in the cervical extensor muscles have similarly been found to produce undershoots[115]. Furthermore, a more sensitized proprioceptive position sense has been found in subjects with non-chronic neck pain[95]. Experimentally induced muscle fatigue, non-chronic neck pain and chronic neck pain may affect cervical muscles and joints differently. This could explain the differences in cervical repositioning tests.

Chronic pain can, by altering neural input, change muscle properties[45]. Connective-tissue infiltration in cervical muscles and atrophy of the upper cervical muscles has been found in chronic neck pain[45]. These changes in muscle properties[45] may cause decreased repositioning[46,59,87,97,124,146]. A combination of long-standing severe pain and disuse of the cervical muscles may influence proprioception, leading to a decreased position sense. Experimentally induced fatigue may be more akin to non-chronic neck pain, in which proprioception seems to be sensitized[95], since the motor program compares sensory information with the expected results[69]. The observations of reduced overshoot in a fatigued neck may also be interpreted as the products of sensory divergence.

Subjects with bilateral vestibulopathy did not differ significantly from controls in repositioning tasks in the horizontal yaw plane. This is consistent with cervical proprioception contributing significant information for head orientation during slow head movements in subjects with vestibular loss. The findings emphasize the importance of cervical proprioception and thus, the importance to treat any arising neck disabilities in subjects with vestibulopathy, as these patients may be dependent on well functioning cervical proprioception.

Cervical sensory input as a possible cause for dizziness

The rationale for cervicogenic dizziness is a 'sensory mismatch' caused by erroneous sensory input from the cervical segments. A disturbed muscle spindle function can derange proprioceptive information[119] which then can contribute to a sensory mismatch. Individuals also differ in their perceptions of external and internal inputs[113]. Since people may disregard sensory mismatch to varying extents[128], the individual variation for sensory conflict can possibly explain why some subjects experience dizziness of cervicogenic origin, while others do not.

The patients with cervicogenic dizziness exhibited several significant musculoskeletal findings that were addressed during treatment. The greater part of these neck symptoms can be found in most neck pain patients and cannot be considered to be specific for the patients with suspected cervicogenic dizziness. However, the large CROM values in these patients were different from CROM results in other studies of neck pain[10,21,33,52,59,61,94,114].

The multimodal treatment approach has been confirmed to be highly beneficial for patients with mechanical neck disorders[51]. Cervicogenic dizziness has been confirmed to be reduced with a combination of manual therapy and vestibular rehabilitation[154] and manual therapy has been recommended to treat cervicogenic dizziness[123].

Treatment intervention reduced both neck pain symptoms and dizziness in the patients. Neck pain intensity, stated at worst, as measured with VAS on a 100 mm scale was reduced from 55 mm before treatment to 33 mm after treatment, previously reported[81]. This reduction seems clinically meaningful after considering that 9–12 mm is suggested to be a significant change[83,84]. After treatment intervention, the VAS scores for headache symptom, stated at worst, were reduced from 63 mm before treatment to 56 mm after treatment. Such a reduction cannot be regarded as clinically significant. Information about headache was retrieved from patient history. Further knowledge about headache symptoms could have been achieved by using the classification according to international headache society[72] but this was not set as an aim at the time.

Before the treatment intervention, patients with suspected cervicogenic dizziness had higher body-sway parameters compared to healthy controls. Body-sway was evaluated with posturographic tests, previously reported[81]. Body-sway was reduced significantly after treatment intervention[81], although no balance training or vestibular treatment was applied. The regained balance, therefore, must arise from other conditions. The exclusion of vestibular rehabilitation was selected to detect whether treatment directed towards cervical findings could reduce the dizziness and thus confirm, ex juvantibus, the cervicogenic diagnosis. Cervical proprioception has been shown to affect postural control when altered[47,85,155]. The postural reactions of patients with suspected cervicogenic dizziness have been shown to distinguish themselves from patients with dizziness of other origin[79]. An improved neck, shoulder and trunk stability and better posture alignment could also contribute to improved body-sway parameters.

A significant number of referred patients had to be excluded based on other possible causes of dizziness[81]. The number of patients with identifiable causes for dizziness other than suspected cervicogenic, indicates that cervicogenic dizziness should be handled with caution and be thoroughly investigated before diagnosis. The cervicogenic dizziness diagnosis should be founded on a strong causal relationship and attributed only in conditions where impaired cervical proprioception is the most likely cause for the dizziness.

Alternative explanations to the dizziness

When no otoneurological findings can explain the origin of dizziness, other concepts are sought. Different causes are then derived from diagnosis by criteria or diagnosis ex juvantibus. Dizziness is hypothesised to arise from a conflict between converging inputs from different sensory inputs and the expected internal copy – the ‘sensory mismatch’ concept[16].

Chronic subjective dizziness is the broadest of these diagnoses and encompasses sensory mismatch from vision and proprioception[138]. Phobic postural vertigo (PPV) focuses on cognitive and emotional factors as the causative[15]. The PPV diagnosis has been emphasized and is considered a primary diagnosis with well defined diagnostic requirements[18]. Because dizziness is a strongly alerting symptom[101], it is important to consider the primary aetiology[139]. Dizziness may be expected to cause emotional reactions or anxiety[136] since the condition is usually felt to be threatening. Emotional reactions often remain even after dizziness is cured[100].

Long-term follow-up has found transient relapses for PPV patients after cognitive treatment intervention[65,71]. The results from long-term follow up in study III also indicated a relapse in some patients and suggested the need for a maintenance strategy. Holmberg et al. suggested a multidisciplinary analysis and treatment in patients with PPV in order to reinforce the outcome and to reduce relapse[63,66].

Since dizziness can lead to tensed cervical muscles[82] and secondary psychological reactions[136,140], it is necessary to analyse dizziness thoroughly. During study III, the emotional reactions accompanying dizziness were noted. In the latter half of the study, emotional status was evaluated with MACL[137]. No characteristic emotional states were found for the cervicogenic dizziness group, and they were comparable to a population-based control group (Table 4)[120].

Patients given the diagnosis of chronic subjective dizziness[138] or PPV[64] reported hypersensitivity to motion. The findings from study IV, that is less error and better discrimination of specific target positions after muscle fatigue, may indicate how tensed and fatigued muscles react to motion. All patients in study III had several findings with tender and tight muscles. Perhaps a tensed and tight muscle, due to altered proprioceptive sensitivity, can produce a sensory conflict interpreted as dizziness in subjects who are sensitive to internal sensory information[113]. If these subjects also have a reduced ability to disregard sensory mismatch[128] they might experience dizziness of cervicogenic origin.

Dizziness from cervicogenic and psychogenic origin could be subgroups under the broader chronic subjective dizziness concept. Subjects with cervicogenic dizziness seem to suffer less emotional stress than is reported for patients with PPV. These speculations suggest that cervicogenic dizziness and PPV may be seen as extremes on the continuum of a condition of high sensitivity to sensory inputs. Sensitivity to motion in patients with chronic subjective dizziness[138] and PPV[64], and the possible explanation of increased sensitivity in tensed cervical muscles (Studies III & IV) could render a more encompassing dizziness diagnosis, 'perceptive sensory dizziness', encompassing both cervicogenic dizziness and PPV with some different directions of reactions.

Although there are still no specific diagnostic procedures for cervicogenic dizziness or a defined pathogenetic mechanism, the present findings support such a diagnosis. Demonstrating that treatment of cervical problems relieve dizziness in certain patients, by the findings that muscle fatigue may produce a more sensitive cervical proprioceptive input and by demonstrating that subjects without vestibular function still can orient their heads, corroborate the hypothesis. It should be pointed out that great care must be taken before accepting the diagnosis in a given patient. To this day the most certain diagnosis would be a patient where dizziness subsides when a defined neck problem is corrected. However, the function of the cervical segment seems to be of importance for orientation and therefore have to be considered when assessing any patient with dizziness.

Conclusions

• Both Zebris®, the three-dimensional, computerized ultrasound cervical motion device, and Myrin, the manual gravity-reference goniometer, are reliable and show good agreement and can thus be used interchangeably. The results support the continued use of the Myrin in routine clinical work. The more sophisticated three-dimensional method adds information and allows evaluation of coupled movements in two and three dimensions and is suitable for research. Comparison of manual cervical motion measurements (Myrin) within two testers showed small differences in relation to the simultaneously computerized recordings (Zebris®). Variability did not increase with a greater cervical range of motion, but was dependent on the individual (I).

• Coupled movements together with primary movements are a natural part of cervical motion and follow specific patterns. Cervical motion changes with age for both primary and coupled movements according to specific patterns (II).

• Patients with suspected cervicogenic dizziness have some musculoskeletal findings in common. They have good cervical mobility, reduced cervico-thoracic mobility, are poorly stabilised with posture imbalance, have tender and tight neck muscles and have tenderness at several zygopophyseal joints. Treatment based on musculoskeletal findings reduced both neck pain and dizziness in the long-term but some patients might need a maintenance strategy. The mood of patients with suspected cervicogenic dizziness did not differ from a population based reference group (III).

• Acute unilateral neck muscle fatigue may increase the sensitivity of cervical proprioception. The head repositioning tests were reliable without systematic intra-individual differences (IV).

• Subjects with bilateral vestibulopathy do not differ significantly from controls with normal vestibular function in head repositioning tests. Cervical proprioception seems to be of greater importance than vestibular information for head-on-trunk position sense in the horizontal, yaw plane. The target position identification procedure was reliable (V).

Sammanfattning på svenska - Summary in Swedish

Känselinformation (sensorisk information) från nacken har stor betydelse för rumsorienteringen. För att kunna detektera kroppsrörelser korrekt och därigenom bibehålla balansen krävs ett samspel mellan nackens sensoriska information tillsammans med kroppens övriga led- och muskelsinnen (proprioceptionen), balansapparaterna i inneröronen (vestibularisorganen), synen samt känselreceptorerna i huden. Vestibularisorganen känner av huvudrörelser och huvudets position i förhållande till tyngdkraften. Synen informerar om hur omvärlden rör sig i förhållande till huvudet och hur huvudet rör sig i rummet. Eftersom sinnesorganen för både balans och syn är belägna i skallbasen är det av stor vikt att få information om hur huvudet rör sig i förhållande till resten av kroppen. Nackens sensoriska information har i detta sammanhang stor betydelse, vilket bland annat det faktum att ett stort antal känselreceptorer finns i nackens muskler och leder talar för.

Om informationen från de olika sensoriska organen inte stämmer överens, d.v.s. att det finns en sensorisk konflikt, kan det ge upphov till yrsel. Ett exempel på en sensorisk konflikt är sjösjuka då synen inte ger någon information om den faktiska rörelsen, eftersom omgivningen (båtens däck) gungar likadant som huvudet i övrigt, samtidigt som kroppens övriga känselorgan och framför allt vestibularisorganen uppfattar att båten gungar. En störning i informationen från nackens muskulatur och leder skulle kunna orsaka en liknande sensorisk konflikt ställt mot det sensoriska inflödet från vestibularisorganen och synen och således teoretiskt ge upphov till ’nackutlöst yrsel’. Både yrsel och besvär från nacken är vanligt förekommande varför det inte är självklart att symtomen har ett samband, även om patienter har båda symtomen samtidigt. Eftersom det dessutom saknas kliniska tester och klara kriterier för nackutlöst yrsel är diagnosen fortfarande kontroversiell. Nackutlöst yrsel kan endast bekräftas när andra orsaker till yrseln kan uteslutas och kanske alldeles säkrast när patienten blir symtomfri efter behandling av nackbesvären.

Ökad kunskap om nackens betydelse för balans och orienteringsförmåga skulle kunna förklara och stärka dess betydelse som en utlösande faktor för yrsel samt öka kunskapen om nackens betydelse när andra sensoriska inflöden fallerar. Dessa reflektioner står som bas för avhandlingen. Ett sätt att pröva nackens proprioceptiva betydelse för orienteringsförmågan är att trötta ut nackens muskulatur och därefter undersöka förmågan att återta i förväg specificerade målpositioner av huvudet relativt mot bålen. Ett annat sätt är att undersöka precisionen av huvudrörelser hos patienter som förlorat funktionen av de vestibulära organen.

För att studera nackens funktion behöver man kunna mäta dess rörelseförmåga med metodmässig stor säkerhet. I *studie 1* undersöktes detta hos frivilliga försökspersoner genom rörelsemätning med Myrin (inklinometer/kompassmetod, en manuell metod som ofta används i klinisk verksamhet) samtidigt med Zebris (tredimensionell ultraljudsbaserad rörelseanalys). En grundläggande skillnad mellan metoderna är att Zebris registrerar huvudets rörelser relativt bålen, medan Myrin mäter huvudets rörelser i förhållande till tyngdkraften och jordens magnetfält. Metoderna visade sig vara väl jämförbara, även om Zebris var något mer tillförlitlig och registrerade ett något större rörlighetsutslag. Detta beror troligen på att förmågan att detektera det absolut största rörelseutslaget är mer känsligt hos Zebris jämfört med Myrin som avläses manuellt. Sammantaget ger Zebris större möjligheter att registrera rörelser i tre dimensioner, vilket gör det möjligt att utföra analyser av nackens kombinerade rörelsemönster.

I *studie 2* undersöktes nackens tredimensionella rörelsemönster vid maximalt rörelseuttag hos frivilliga försökspersoner i olika åldrar. Resultaten visade att nackrörelser ofta är kombinerade. Rörelser som var tänkta att utföras i frontalplanet (örat mot axeln) skedde oftast i kombination med kopplade rörelser i horisontalplanet (nackvridning), medan rörelser som var tänkta att utföras i horisontalplanet oftast kombinerades med kopplade rörelser i sagittalplanet (framåt-bakåt). Dessutom kunde det visas att vissa kopplade rörelser ändrar riktning hos äldre försökspersoner, vilket troligen kan förklaras av en ändrad förläggning av rörelserna i nackkotpelaren samt av en förändrad kroppshållning.

I *studie 3* undersöktes nackens muskler, rörlighet i nacke och bröstrygg, hållning och stabilitet hos en grupp av patienter, som misstänktes ha nackutlöst yrsel. Patienterna uppvisade stor rörlighet i nacken, närmast överrörlighet hos en del patienter. Dessutom hade de både muskulär ömhet och stramhet i de bakre nackmusklerna. Ihopsjunken hållning och stelhet i övergången mellan nacke och bröstrygg var också vanligt. Patienterna behandlades med riktade åtgärder mot de olika fynden och behandlingens effekt på studieparametrarna utvärderades direkt efter behandlingens avslut. Den bestående effekten av behandlingen på patienternas subjektiva nackbesvär samt yselupplevande utvärderades långsiktigt. Patienterna var förbättrade direkt efter avslutad behandling och vid uppföljning efter 6 månader och 2 år var besvären från nacken samt yrseln fortfarande lindrigare. Eftersom både patienternas nackbesvär och yrsel förbättrades av behandling som riktades mot nackbesvären, stärks misstanken om att yrseln var nackutlöst.

För att undersöka vilken komponent i nackbesvären som kan bidra till nackutlöst yrsel undersöktes i *studie 4* hur muskeluttröttning påverkar orienteringsförmågan. Friska försökspersoner fick trötta ut ena sidans nackmuskler genom att belasta nackmusklerna med 30 % av sin maximala kraft under 5 minuter. En förstudie där musklernas aktivering mättes med EMG (elektromyografi – registrering av de elektriska spänningsförändringar som muskelcellerna genererar) bekräftade att det bara var den ena sidan av nacken som engagerades under belastningen. Efter uttröttningen förändrades och förbättrades förmågan att hitta tillbaka till en tidigare introducerad målposition, visat genom att en tidigare tendens att gå förbi målet minskade efter uttröttningen. Resultaten tyder på att muskelsinnet, proprioceptionen, blir mer känsligt för att korrekt rapportera rörelser efter en akut tillfällig uttröttning.

I *studie 5* undersöktes betydelsen av nackens proprioception ytterligare genom att analysera orienteringsförmågan av huvudet relativt bålen hos en grupp patienter som förlorat funktionen i båda sidors vestibularisorgan jämfört med en kontrollgrupp med friska frivilliga personer. Patientgruppen skilde sig inte mot kontrollgruppen när det gäller förmågan att med nackvridning återta olika målpositioner av huvudets läge. Fyndet talar för att nackens proprioception kan ge tillräcklig information vid långsamma huvudrörelser så att förlusten av den vestibulära funktionen helt kan uppvägas. Detta stärker antagandet om att nackens proprioceptiva roll är betydelsefull för orienteringsförmågan.

Sammantaget bekräftar studierna att rörligheten i nacken och dess proprioception är av stor betydelse för orienteringsförmågan. Resultaten indikerar tillsammans med de positiva behandlingsresultaten vid förmodad nackutlöst yrsel att det kan finnas ett samband mellan nackbesvär och yrselupplevande.

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Abstract

The overall aim of the work was to examine the influence of cervical biomechanical conditions on movement performance, to study musculoskeletal findings accompanying possible cervicogenic dizziness and to evaluate the influence of cervical proprioception on head orientation.

Two devices, measuring cervical range of motion, were compared: Myrin, an inclinometer/compass method and Zebris®, a 3-dimensional ultrasound movement analyser. Both devices showed good reliability and agreement with less variability for the computerized method. The Myrin can be used in clinical routine work and the Zebris® adds information about 3-dimensional movements. (Study I).

Cervical range of motion was examined in three dimensions in 120 neck-healthy subjects. Movement patterns of combined primary and coupled movements and the influence of age, gender and body mass index on these movements were investigated.
Coupled movements are a natural part of cervical motion together with primary movements. Age affects the majority of primary and coupled cervical movements; the coupled movements of primary rotation and lateral flexion are especially changed with age (Study II).

Twenty-two patients with dizziness of suspected cervical origin were examined with a structured physical examination and carefully examined to exclude other causes of dizziness. The effects of physiotherapy, based on these musculoskeletal findings, were evaluated directly after treatment and again long-term with questionnaires.
Patients with suspected cervicogenic dizziness had some musculoskeletal findings in common, e.g., tenderness and tightness in the dorsal neck muscles, preserved cervical mobility and reduced cervico-thoracic mobility. Treatment based on these findings reduced both neck pain and dizziness. Some patients seem to need a maintenance strategy to avoid relapses in the long-term (Study III).

Twenty neck-healthy subjects were examined before and after a unilateral neck muscle fatiguing task with head repositioning tests.
An average overshoot before the fatiguing task decreased after acute muscle fatigue and the increased accuracy was significant and most pronounced for movements directed towards the fatigued side (Study IV).

Eleven subjects with bilateral vestibulopathy were compared to fifteen healthy subjects in their ability to reproduce different head on trunk target positions.
The subjects with bilateral vestibulopathy maintained their ability to recognize and fine-tune head on trunk movements (Study V).

Cervical movement performance changed with increasing age. Treatment of cervical musculoskeletal findings reduced both neck pain symptoms and dizziness; diagnosis ex juvantibus supports the diagnosis of cervicogenic dizziness. Cervical proprioception is an important factor in sensing head on trunk movements.