Tinnitus and the cervical spine

The role of the physical therapist in diagnosis and management of cervicogenic somatic tinnitus

Tinnitus en de cervicale wervelkolom

De rol van de kinesitherapeut in diagnose en behandeling van cervicogene somatische tinnitus

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by

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Synopsis

Tinnitus or ‘ringing in the ears’ is a very common disorder that often causes distress and decreases the patient’s quality of life. The ability to do intellectual work can be affected and sleeping difficulties are frequently reported. Various types and causes of tinnitus have been described. One specific type, somatic tinnitus, is of particular interest for physical therapists. In patients with somatic tinnitus, the intensity and the character of the tinnitus are altered, for instance by forceful muscle contractions of the neck or jaw muscles. Physiologically this phenomenon is explained by the presence of connections between the somatosensory system of the cervical spine and temporomandibular area on the one hand and the central auditory system on the other hand. It is however still unclear whether or not altered somatosensory information can actually cause tinnitus and no information is available on the altered cervical somatosensory afference. As such, the need for thorough cervical spine assessment rises, as well as the need for prognostic factors that can predict the effect of cervical physical therapy in patients with somatic tinnitus.

This thesis focuses on cervical spine related somatic tinnitus (cervicogenic somatic tinnitus CST), assessing several cervical functions and investigating the effect of a standardized cervical physical therapy treatment program on tinnitus complaints.

In the first part of this thesis the assessment of cervical sensorimotor control (cSMC) is highlighted. This cSMC might be affected in patients with CST, as cSMC includes the cervical somatosensory information that is thought to alter the tinnitus in patients with CST.

In order to assess cSMC in patients with CST, a reliable and valid measuring method was needed. The review in chapter 1 pointed out two methods (head repositioning accuracy to the neutral head position and The Fly™) as sufficiently reliable and valid, but important limitations were found for both. Therefore, we used a third method, the continuous linear movement test (CLMT), which had proven to have good discriminant and content validity, but needed further investigation of its reliability.

The reliability study of the CLMT (chapter 2) showed negligible to excellent test-retest reliability results, depending on the used outcome measure. Of all outcome measures, those recorded during rotation movements proved to be more reliable than during flexion-extension and lateral flexion. This consequently makes rotation the preferred movement for CLMT assessment.
In the second part of this thesis, we firstly used the CLMT and a set of clinical cervical spine tests to investigate cervical spine functions in patients with CST. Secondly, we wanted to identify prognostic indicators for cervical physical therapy treatment success in patients with CST.

Cervical spine complaints appeared to be very common in patients with CST as well as in patients with other types of tinnitus. Hence, cervical spine assessment is essential in the investigation of tinnitus patients. In addition to the diagnostic criteria for CST, that are mainly based on anamnestic features, the neck Bournemouth questionnaire (NBQ) can be used as a first indicator for CST. This questionnaire is especially useful to exclude CST in case of a score < 14 points. The absence of trigger points can confirm the exclusion of CST. A positive manual rotation and/or adapted Spurling test, on the other hand can be used to include CST.

Regarding cSMC, significant differences were found between patients with CST and asymptomatic control subjects. Using the CLMT, we found that patients with CST needed significantly more time to perform one movement cycle (e.g. left to right rotation). We also noted smaller range of motion figures in the patient group, although these differences were not statistically significant. Finally, patients with CST showed significantly jerkier movements during rotation compared to the asymptomatic subjects.

These findings showed us the presence of several cervical spine dysfunctions in patients with CST and the usefulness of clinical cervical spine tests in diagnosing CST, but could not explain why some patients benefit from cervical spine treatment and others don’t. Therefore, we searched for prognostic indicators for treatment success using a randomized controlled trial (RCT).

This RCT investigated the effect of a standardized cervical physical therapy treatment on tinnitus and neck related parameters in patients with suspected CST, recruited in a tertiary referral center. Immediately after treatment 53% of the patients experienced a substantial improvement of their tinnitus and all patients indicated a substantial improvement of their neck complaints. Further investigation of the baseline characteristics of the patients that experienced tinnitus improvement after cervical physical therapy, identified 3 prognostic indicators. Generally, patients with low-pitched tinnitus, covarying with neck complaints and increasing during inadequate cervical spine postures are most likely to benefit from cervical physical therapy.

Given the results of this thesis, the evaluation and treatment of CST should be a regular feature in the management of every patient suffering from tinnitus. Physical therapists can have a supportive role in the diagnostic process of CST given
their specific skills in the clinical evaluation and treatment of cervical spine dysfunctions. Consequently, physical therapists can contribute to a multidisciplinary treatment of CST.
Samenvatting

Tinnitus of ‘oorsuizen’ is een vaak voorkomende aandoening die bij veel patiënten zorgt voor onrust en een vermindering van de ‘quality of life’. Het vermogen van de patiënt om zich op intellectuele taken te concentreren kan verminderd zijn en vaak treden ook slaapproblemen op. Voor kinesitherapeuten is één specifiek type tinnitus, somatische tinnitus, bijzonder interessant. Bij patiënten met somatische tinnitus kan de intensiteit en het karakter van de tinnitus veranderen door bijvoorbeeld de nek- of kaakspieren krachtig aan te spannen. Fysiologisch kan dit fenomeen verklaard worden doordat connecties aanwezig zijn tussen het somatosensorisch systeem van de cervicale wervelkolom en de temporomandibulaire regio enerzijds en het centraal auditief systeem anderzijds. Het is echter onduidelijk of veranderde somatosensorische informatie ook effectief tinnitus kan veroorzaken en er is geen informatie over de aard van de veranderde somatosensorische afferentie. Zodoende is er nood aan grondig onderzoek van de cervicale wervelkolom bij deze patiënten. Daarnaast is er ook nood aan informatie rond prognostische factoren die het effect van een cervicale kinesitherapeutische behandeling bij patiënten met somatische tinnitus kunnen voorspellen.

In deze thesis ligt de focus op somatische tinnitus gerelateerd aan de cervicale wervelkolom (cervicogene somatische tinnitus CST). Verscheidene cervicale functies werden onderzocht en het effect van een standaard kinesitherapeutische nekbehandeling op de tinnitus klachten werd nagegaan.

In het eerste deel van deze thesis staat het meten van cervicale sensorimotorische controle (cSMC) op de voorgrond. De cSMC zou aangedaan kunnen zijn bij patiënten met CST, aangezien de cervicale somatosensorische informatie, die de tinnitus zou beïnvloeden bij patiënten met CST, een onderdeel is van de cSMC.

Om cSMC te kunnen objectiveren bij patiënten met CST, is een valide en betrouwbare meetmethode nodig. De review in hoofdstuk 1 bracht twee methoden (hoofd repositionings accuraatheid en The Fly™) naar voren die voldoende betrouwbaar en valide zouden zijn, maar beide hebben ook ernstige beperkingen. Daarom werd besloten om een derde methode, de ‘continous linear movement test CLMT’ te gebruiken. De discriminant en construct validiteit van deze test was reeds goed bevonden, maar verder onderzoek van de betrouwbaarheid was noodzakelijk.

De betrouwbaarheidsstudie van de CLMT (hoofdstuk 2) toonde verwaarloosbare tot zeer goede test-retest betrouwbaarheid, afhankelijk van de gebruikte
uitkomstmaat. Van de verschillende uitkomstmaten bleken deze die tijdens rotatie bewegingen opgetekend waren, het meest betrouwbaar. Bijgevolg is rotatie de voorkeurbeweging bij CLMT metingen.

In het tweede deel van deze thesis werd de CLMT, samen met een reeks klinische nektesten gebruikt om de cervicale functies te onderzoeken bij patiënten met CST. Daarnaast werd gezocht naar prognostische factoren die een positief effect van een kinesitherapeutische nekbehandeling bij patiënten met CST kunnen voorspellen.

Nekklachten bleken veel voorkomend te zijn bij zowel patiënten met CST als bij patiënten met andere vormen van tinnitus. Bijgevolg is nekonderzoek essentieel bij de evaluatie van patiënten met tinnitus klachten. Als aanvulling op de diagnostische criteria voor CST, die voornamelijk op anamnestische gegevens gebaseerd zijn, kan de ‘neck Bournemouth questionnaire (NBQ)’ gebruikt worden als eerste indicator voor CST. Deze vragenlijst is vooral nuttig om CST uit te sluiten in geval van een score < 14 punten. De afwezigheid van triggerpunten kan de afwezigheid van CST bevestigen. Een positieve manuele rotatie en/of adapted Spurling test kan anderzijds de diagnose van CST bevestigen.

Wat betreft cSMC werden significante verschillen gevonden tussen patiënten met CST en asymptomatische controle proefpersonen. Met de CLMT vonden we dat patiënten met CST significant meer tijd nodig hadden om één bewegingscyclus (vb.: volledige links tot rechts rotatie) uit te voeren. De range of motion bleek ook kleiner te zijn in de patiëntengroep, alhoewel dit verschil niet statistisch significant was. Tot slot bleken de patiënten ook significant onregelmatiger te bewegen dan de controle proefpersonen.

Deze bevindingen tonen de aanwezigheid van verschillende cervicale dysfuncties aan bij patiënten met CST en de bruikbaarheid van verschillende klinische nektesten bij het diagnosticeren van CST werd aangetoond. De bevindingen konden echter niet verklaren waarom sommige patiënten baat hebben bij een nekbehandeling en anderen niet. Daarom werd een randomized controlled trial (RCT) gebruikt om te zoeken naar prognostische factoren voor het voorspellen van een positief effect van de nekbehandeling.

Deze RCT onderzocht het effect van een standaard kinesitherapeutische nekbehandeling op tinnitus en nekparameters bij patiënten met CST, die geregistreerd werden in een tertiair centrum. Direct na de behandeling had 53% van de patiënten een substantiële verbetering van de tinnitus klachten en alle patiënten gaven een substantiële verbetering van hun nekklachten aan. Verder
onderzoek van de baseline karakteristieken van de patiënten die een positief effect van de nekbehandeling op hun tinnitus klachten hadden, toonde 3 prognostische factoren aan. Algemeen hebben patiënten met een ‘low-pitched’ tinnitus, die co-varieert met de nekklachten en toeneemt tijdens bepaalde houdingen van de nek het meeste kans om goed te reageren op een kinesitherapeutische nekbehandeling.

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Abbreviations

CST: cervicogenic somatic tinnitus
CSMC: cervical sensorimotor control
CLMT: continuous linear movement test
NBQ: neck Bournemouth questionnaire
RCT: randomized controlled trial
TRT: tinnitus retraining therapy
CBT: cognitive behavioral therapy
CN: cochlear nuclei
HRA: head repositioning accuracy
HRA-to-NHP: head repositioning to the neutral head position
κw: weighted kappa
NLMT: non-linear movement technique
HRA-to-target: head repositioning to a target position
HMD: head mounted display
JPE: joint position error
NHP: neutral head position
ROM: range of motion
ICC: intraclass correlation coefficient
WAD: whiplash associated disorders
t: (mean cycle) time
var-t: variation in time
peak-v: peak velocity
v: average velocity
acc: acceleration
Cj: Jerk index
SD: standard deviation
TQ: tinnitus questionnaire
ENT: otorhinolaryngology
VAS: visual analogue scale
AST: adapted Spurling test
PTA: pure tone average
LR: likelihood ratio
PTP: post-test probability
MRI: magnetic resonance imaging
DNF: deep neck flexors
CCFT: craniocervical flexion test
TFI: Tinnitus Functional Index
GPE: global perceived effect
General Introduction
Introduction

Tinnitus: Definition, Prevalence, Types, Causes

Tinnitus is derived from the Latin verb ‘tinnere’ (to ring) and describes the conscious perception of an auditory sensation in the absence of a corresponding external stimulus\(^1\). It occurs in 10 to 15\% of the adult population and 1.6\% of the tinnitus patients experience their tinnitus as severely annoying\(^1\). The sensation is generally described as: hissing, sizzling or ringing, although more complex sounds can be perceived\(^1\). Tinnitus can be of a pulsatile nature, eventually synchronous with the heartbeat, in which case a vascular origin is likely\(^1\). Additionally, tinnitus can be constant or intermittent, located in one or both ears or centrally within the head.

In general, two main subtypes of tinnitus exist: a subjective and an objective type. Tinnitus is in most cases subjective, meaning that the patient experiences the tinnitus in the absence of any auditory stimulus. In some cases an internal, measurable, stimulus can cause the tinnitus, for instance turbulences of the blood flow. In these cases it is considered an objective tinnitus\(^1\).

Several risk factors have been described, such as: hearing loss, ototoxic medication (e.g. salicylates), head injuries and depression\(^1\). Tinnitus can also occur in association with otological conditions, such as: noise exposure or presbyacusis\(^1\) and can co-exist with anxiety or depression\(^2\) and with dysfunctions of the cervical spine\(^3\) or temporomandibular joint\(^4\).

Because high-frequency hearing loss is one of the major risk factors for tinnitus, auditory phantom sensations are often considered to be a neuroplastic response to sensory deprivation\(^5\). Cochlear abnormalities can in these cases be the initial source of the tinnitus, but neural changes in the central auditory system are more likely to maintain the tinnitus\(^1\). One possibility for the neural substrate of tinnitus is an increased spontaneous firing rate of neurons in the central auditory system\(^6\). Another possibility is an increased temporal synchrony in the firing pattern across neurons in the primary auditory cortex, which has been described in noise-induced hearing loss\(^6,7\). Apart from these central auditory models, a third model suggests that tinnitus only reaches conscious awareness or annoyance levels when aberrant neuronal activity in the primary sensory cortex is connected to a wider cortical network involving frontal, parietal and limbic brain regions\(^8,9\).
**Tinnitus: Treatment**

Currently, an effective standard cure for tinnitus is lacking. After exclusion of treatable pathology (e.g., Meniere’s disease) associated with tinnitus, standard care consists of informing the patient about causation of tinnitus and the development of associated distress, combined with sound therapy (hearing aids or sound generators) and interventions to reduce the distress (relaxation therapy, tinnitus retraining therapy (TRT) or cognitive behavioural therapy (CBT)).

TRT is a habituation technique for reducing the impact of tinnitus on the patient’s life, using a combination of counselling and sound therapy. It involves manipulating the limbic, autonomic and auditory systems to reduce the response to the abnormal stimuli and aims to decrease the sensations, emotions and behaviour that are associated with tinnitus. CBT is a technique that was originally used to treat depression and aims to reduce the behaviours that are associated with tinnitus, changing the patient’s attitude to the tinnitus. Both TRT and CBT have proven to reduce the negative impact of subjective tinnitus on the patient’s quality of life.

Apart from the “standard care”, positive effects of several treatment options, mainly on subjective tinnitus loudness, annoyance and quality of life, have been described. These include the prescription of drugs (mainly for the management of concomitant psychological distress), cochlear implants to restore the patient’s hearing and transcranial direct current stimulation, a noninvasive neuromodulation technique, which can increase or decrease the cortical excitability in the brain region to which it is applied. Nevertheless, only a selected group of patients benefits from these treatments and adequate patient selection is needed to gain positive therapy effect.

**Somatic Tinnitus: Prevalence, Pathophysiology, Treatment**

Apart from well-known causes such as hearing loss or noise trauma, tinnitus can also be elicited by the somatic system of the cervical spine or temporomandibular area. In this case it is called somatic tinnitus. This type of tinnitus has been described in 36.7% of a population with subjective tinnitus. A physiological explanation is delivered by several animal studies, which have found connections between the somatosensory system of the cervical spine and temporomandibular area on the one hand and the cochlear nuclei (CN) on the other hand. Cervical and temporomandibular somatosensory information is conveyed to the brain by
afferent fibres, the cell bodies of which are located in the dorsal root ganglia or the trigeminal ganglion. Some of these afferent fibres also project to the central auditory system and more specifically to the dorsal CN. This makes the somatosensory system able to influence the auditory system by altering the spontaneous rates (i.e. not driven by auditory stimuli) or the synchrony of firing among neurons in the CN, inferior colliculus or auditory cortex. In this way, the somatosensory system is able to alter the intensity and the character of the tinnitus for instance by forceful muscle contractions of the neck or jaw musculature $^{19,20}$ or by increased muscle tension in the tensor tympani muscle$^{21}$. On the other hand, it is still unclear whether or not altered somatosensory information can actually cause tinnitus. Additionally, it must be noted that not all patients with cervical spine or temporomandibular dysfunction develop tinnitus complaints. Despite these uncertainties, several studies have found positive effects of cervical spine and temporomandibular joint treatments on somatic tinnitus $^{22,23}$. These studies use muscle relaxation in the jaw or neck region$^{23-26}$, cervical spine manipulations or mobilizations$^{27-29}$, exercises that evoke tinnitus modulation$^{30}$ and transcutaneous electrical nerve stimulation$^{31-33}$. Often however, inconclusive or contradictory results are found and the described studies frequently lack scientific quality due to very limited numbers of patients or lack of control groups and randomization. Therefore, the use of cervical spine treatment in tinnitus patients is still under dispute and no information is available on the tinnitus subtype that could benefit most from cervical spine treatment. Additionally, very little information is available on the type of cervical dysfunction that can cause or alter tinnitus.

**CERVICAL SENSORIMOTOR CONTROL**

In patients with CST, somatosensory afference is thought to alter the intensity and the character of the tinnitus. Changes in this somatosensory afference are assumed to be provoked by various impairments in cervical functions such as: range of motion, strength or endurance of cervical musculature and cervical sensorimotor control (cSMC).

CSMC incorporates afferent cervical somatosensory, visual and vestibular information, together with the efferent information from the central nervous system and the central integration and processing to provide functional stability of the cervical spine$^{34}$. Since, in patients with CST, changes in cervical somatosensory afference are thought to alter or even cause tinnitus, cSMC might be affected in these patients.
Currently, the most commonly used cSMC-measuring method is the head repositioning accuracy to the neutral head position (HRA-to-NHP) \textsuperscript{35, 36, 37, 38, 39, 40}. This HRA-to-NHP test has proven to provide reliable \textsuperscript{41, 42, 39} and valid measurements \textsuperscript{36, 37, 38, 39, 40}. The construct validity of the HRA-to-NHP test can however be questioned, as the HRA-to-NHP is static and only measures the position sense\textsuperscript{39, 43, 44}.

To quantify altered sensorimotor functions during the entire movement, several kinematic parameters can be used. A continuous linear movement test (CLMT), developed by Sjölander et al.\textsuperscript{42}, uses these kinematic measurements, but the reliability of this test had never been investigated.

**RESEARCH OBJECTIVES**

This thesis contains six aims: Firstly, to compare commonly used cSMC-measuring methods in terms of required tasks, measuring device and clinimetric properties. Secondly, to investigate the test-retest reliability of the CLMT. Thirdly, to assess, characterize and quantify cervical spine dysfunction in patients with cervicogenic somatic tinnitus (CST) (not temporomandibular related somatic tinnitus) in comparison with patients suffering from other forms of chronic subjective non-pulsatile tinnitus. Fourthly, to determine the diagnostic value of a set of clinical cervical spine tests in diagnosing CST. Fifthly, to identify prognostic indicators that can predict a high chance of decrease in tinnitus complaints after cervical physical therapy in patients with CST. And finally, to investigate the effect of a standardized cervical physical therapy treatment program on several tinnitus and neck related parameters using an RCT paradigm.

These aims resulted in the following research questions:

1. What is the preferred measuring method for cervical sensorimotor control, taking into account the required task, device and clinimetrics?
2. What is the test-retest reliability of the continuous linear movement test?
3. Which cervical dysfunctions are present in patients diagnosed with cervicogenic somatic tinnitus in comparison with patients suffering from other forms of chronic subjective non-pulsatile tinnitus? Is cervical sensorimotor control altered in patients suffering from cervicogenic somatic tinnitus compared to asymptomatic controls?
4. What is the diagnostic value of a set of clinical cervical spine tests in diagnosing cervicogenic somatic tinnitus?
5. Which prognostic indicators can predict a positive effect of cervical physical therapy on tinnitus complaints in patients with cervicogenic somatic tinnitus?
6. What is the effect of a standardized cervical physical therapy program on tinnitus and neck related parameters in patients with cervicogenic somatic tinnitus?

**OUTLINE OF THE DISSERTATION**

This dissertation contains two parts. Part I focuses on the measurement of cSMC, where part II discusses the influence of the presence and treatment of cervical spine problems on tinnitus complaints.

Part I concerns cSMC measurement and contains three chapters.

**In chapter 1**, a valid and reliable cSMC-measuring technique was selected based on a systematic review that compares commonly used cSMC-measuring methods in terms of required tasks, measuring device and clinimetric properties. At the start of this study, the HRA was commonly used for objectifying cSMC, but the construct validity of this test can be questioned\(^{39,43,44}\). Therefore, we searched a more suitable technique to use in the tinnitus study.

**In chapter 2** the test-retest reliability of the CLMT was investigated. In the following chapters this CLMT was used to objectify cSMC, but the reliability of this technique still had to be investigated. We used an ultrasound based tracking device (ZEBRIS™ CMS 20, Medizintechnik GmbH, Tubingen, Germany) for the reliability study in chapter 2, but because of limitations specific to this device, we decided to use a passive optical motion capture system (Vicon®, Vicon Motion Systems Ltd., UK) for objectifying the CLMT outcome parameters in our later studies. The CLMT measuring procedure using the passive optical motion capture system is therefore discussed in **chapter 3**.

Part II of this dissertation concerns the influence of cervical spine problems on tinnitus complaints and contains five chapters.

At the start of our study it was unclear which cervical spine dysfunctions are present in patients with CST, and no information was available on the presence of cervical spine dysfunction in non-CST patients. Therefore, we used a set of clinical cervical spine tests to objectify cervical spine dysfunction in patients with chronic subjective tinnitus. These results are presented in **chapter 4**.

Since the CST diagnosis is solely based on anamnestic data, additional tests for discriminating between patients with CST and patients with other types of tinnitus
would be very useful. In chapter 5 the diagnostic value of the cervical spine tests used in chapter 4, for diagnosing CST was investigated.

Apart from the clinical cervical spine tests, we were also interested in potential cSMC problems in patients suffering from CST, as cSMC problems can change the cervical somatosensory afference, which is thought to alter the intensity and character of the tinnitus in patients with CST. Therefore, chapter 6 investigates the differences in cSMC between patients with CST and asymptomatic controls.

As we wanted to investigate the effect of cervical physical therapy on the cervical spine dysfunctions described in the abovementioned chapters, a randomized controlled trial on the effect of cervical physical therapy treatment in patients suffering from CST was performed. Chapter 7 describes the study protocol of this randomized controlled trial, so detailed information on the used protocol, treatment and outcome measures could be provided.

Chapter 8 reports the results of the randomized controlled trial. Primarily, these results are used to identify prognostic indicators for predicting a high chance of decrease in tinnitus complaints after cervical physical therapy, as predicting therapy outcome in individual patients with CST is very hard. Secondary, the results answer research question 6 by describing the effect of the standardized cervical physical therapy program on several tinnitus and neck related parameters.

This randomized controlled trial differs from earlier studies, mainly by using an evidence-based physical therapy treatment that has already proven to have good results in patients with neck complaints. By using this evidence-based therapy to treat cervical spine dysfunctions in patients with CST, we wanted to maximize the effect of our therapy on the patient’s neck complaints. Decreasing cervical spine dysfunctions will then potentially also alleviate the tinnitus complaints.

CST has been reported as a frequently occurring type of tinnitus. Many questions regarding this type of tinnitus however, remain unanswered. Therefore, this thesis aims to investigate a number of these aspects.
PART I:
Cervical Sensorimotor Control

In this part we elaborate on cervical sensorimotor control measurement. It consists of three chapters:
one describing a systematic review of the literature concerning cSMC-measurement, a second concerning the reliability of the CLMT and a third describing the measuring protocol of the CLMT.
**PUBLICATIONS**

Chapter 1 has been published in:

Chapter 2 has been published in:
# The Assessment of Cervical Sensory Motor Control

## 1.1 Abstract

**Background:** Cervical sensorimotor control (cSMC) becomes increasingly important in the assessment and treatment of patients with neck pain. This review aims to compare commonly used cSMC measuring methods in terms of required tasks, measuring device and clinimetric properties.

**Search methods:** A systematic review of two databases, followed by methodological quality assessment (CBO guidelines).

**Results:** The methodological quality of 34 included articles was generally good (5 to 7 / 8), the inter-rater agreement was excellent (κw=0.966, p<0.01).

Following tasks were found: head repositioning accuracy to the neutral head position (HRA-to-NHP) and to a target position (HRA-to-target), a virtual reality test, a continuous linear movement technique (CLMT) and an object following non-linear movement technique (NLMT) (The Fly™).

Test-retest reliability was fair to excellent (ICC 0.35-0.87) for the HRA-to-NHP, very bad to excellent (ICC 0.01-0.90) for the HRA-to-target, fair to good (ICC 0.25-0.77) for the virtual reality test and moderate to excellent (ICC: 0.60-0.86) for The Fly™. The reliability of the CLMT was not documented.

The HRA-to-NHP, The Fly™ and the CLMT can discriminate between patients with neck complaints and controls (discriminant validity). Currently, only The Fly™ can discriminate between different patient populations (post-traumatic and non-traumatic neck pain).

The sensitivity, specificity and responsiveness of the methods have to be assessed in future research.

**Conclusions:** The dynamic method The Fly™ appears to be more reliable than the HRA-to-NHP and is able to discriminate between different patient populations. The diagnostic potential is to be confirmed in future research.
1.2 INTRODUCTION

Cervical sensorimotor control (cSMC) becomes increasingly important in the assessment and treatment of patients with neck pain, since rehabilitation programs, including cSMC exercises, have resulted in an improvement of cSMC, but also in alleviation of neck complaints.\(^48\)

The sensorimotor system incorporates afferent, efferent and central integration and processing involved in maintaining functional joint stability.\(^49\) Sensorimotor control depends on a continuous flow of sensory information to the different levels of the central nervous system.\(^49\)

To obtain a stable upright posture, one relies on afferent information from the vestibular, visual and proprioceptive systems, which converge in several areas throughout the central nervous system.\(^34\)

The importance of the cervical spine in providing proprioceptive input is reflected in the amount of cervical mechanoreceptors and their central and reflex connections with the vestibular, visual and central nervous system. Cervical muscles, and in particular the suboccipital muscles, contribute to the transmission of afferent and efferent information to and from the central nervous system.\(^34\)

In the past 20 years various measuring methods have been used to measure cSMC. These measuring methods seem similar, but differences in the required task or in the technique used to quantify the measurements make it hard to compare test results. Moreover, it is unclear whether the different measuring methods are equally reliable and valid and what would be the preferred method.

1.3 AIM

The aim of this review is to compare commonly used cSMC measuring methods in terms of required tasks, measuring device and clinimetric properties.

1.4 METHODS

1.4.1 Search strategy

An extended search strategy was developed by identifying all potentially relevant keywords, categorizing these terms into specific combinations. This search strategy was used in two different electronic databases: PubMed and Science Direct.
1.4.2 Electronic searches

PubMed and Science Direct were searched using the above-mentioned search strategy. The search strategy was limited to human studies published between 1991 and 2011.

1.4.3 Selection criteria

The review was restricted to studies in English. Wide inclusion and exclusion criteria were used to avoid limitation of potentially relevant papers.

The inclusion criteria were: studies with adult populations (≥ 18 years old), dealing with the assessment of cSMC.

Studies were excluded in case of patient reports, case studies and when focusing on treatment rather than on assessment. Articles dealing with evaluation of global sensory motor control during walking, standing balance or vestibular pathologies were excluded.

1.4.4 Data extraction and management

Two reviewers performed the search to avoid selection bias. The first is appointed as scientist (MSc in rehabilitation sciences, pre-doctoral student) the second reviewer is a co-worker (BSc in rehabilitation sciences). Relevant studies where identified, using the a priori defined in- and exclusion criteria. After inclusion the articles' methodological quality was assessed by both reviewers independently.

First, articles were selected based on title and abstract. Second, the selected articles underwent a full text screening. Third, the methodological quality of the included articles was assessed using the CBO guidelines. The results of both reviewers were compared and the inter-rater agreement of this comparison was calculated.

1.5 RESULTS

1.5.1 Literature search results

After the initial search and selection based on title and abstract, 57 articles were retained. Based on the full text screening 34 articles were selected for inclusion (Figure 1.1). The methodological quality of the selected articles was generally good...
with scores mostly ranging from 5 to 7 out of 8. The inter-rater agreement was excellent ($\kappa_w=0.966, p<0.01$).

**Figure 1.1: Selection procedure articles**

### 1.5.2 Study results

Five cSMC measuring techniques were found. Three methods can be considered as repositioning tasks and two methods can be considered as trajectory registrations.

#### 1.5.2.1 Required task

The most commonly used procedure is the head repositioning accuracy to the neutral head position (HRA-to-NHP), first described by Revel et al. $^{35}$ During this procedure the subject is seated with backrest. The subject is blindfolded to exclude

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$^a$ More detailed information on the methodological quality of the included articles can be found in Appendix 2.
visual input and wears a helmet with on top a light beam pointing at a target 90 cm in front of the subject. The subject is instructed to face the target straight ahead and to memorize this position, to duplicate it after an active movement. The movement directions are: flexion, extension, both rotations and lateral flexions 35.

A second method, the HRA-to-target test is similar to the abovementioned but the head is now relocated to a predefined target position (e.g. 30° rotation) 51, 52.

The third method, a virtual reality test, has a static as well as a dynamic part 53. During the test, the subjects are asked to follow a visual target in a virtual scene. The subjects are immersed into a virtual outer space environment via a head mounted display (HMD) equipped with a motion tracking system 53.

The fourth method, developed by Kristjansson et al. 54, is called ‘The Fly’™. It is an object following, non-linear movement trajectory (NLMT) registration method and concentrates on cervical motion sense instead of position sense. The subject is positioned in front of a computer screen with a tracking sensor placed on the head. During the procedure the subject is asked to follow a moving object on the screen by moving his / her head.

The fifth method, the continuous linear movement technique (CLMT), provided by Sjölander et al 42 is also a dynamic measuring method. These authors have asked the subject to perform a continuous movement of right and left rotation of the head.

1.5.2.2 Outcome measures

The abovementioned measuring methods are quantified by calculating the deviation from a predefined point or trajectory.

The joint position error (JPE) is used for quantifying the HRA-to-NHP, HRA-to-target and virtual reality test. The JPE is calculated by comparing the subject’s trials with the initial NHP or the target position.

The JPE can be measured using a laser pointer (Revel et al. 35) or more sophisticated tracking devices such as electromagnetic trackers (e.g. FASTRAK TM, Polhemus Inc, USA) 55, 56, ultrasound based trackers (e.g. Zebris system, Medizintechnik GmbH, Tubingen Germany) 57, 52 and electrogoniometers (e.g. CA 6000 Spine Motion Analyzer, O.S.I., Union City, CA) 36.

The Fly test™ 54 is a NLMT which registers the entire motion trajectory of the subjects head using an electromagnetic tracking device or a sensor using inertial sensing elements. Three main outcome measures can be seen after the test: the
amplitude accuracy, the directional accuracy and the Jerk index, a rate for the smoothness of the movement (Figure 1.2).

\[
C_j = \sqrt{\frac{1}{2} \sum_{i=1}^{n} J_i^2 t_i^5/D}
\]

Figure 1.2: Jerk Index

\(J\): vector of the jerk values over the movement; \(n\): number of samples of the vector; \(i\): vector index; \(t\): movement time; \(D\): movement distance

The CLMT, provided by Sölander et al. 42, registers the complete movement of the subjects' head, using an electromagnetic tracking device (FASTRAK TM, Polhemus Inc, USA). Several outcome measures are used: range of motion (ROM), peak velocity, smoothness of movement (Jerk Index) and ROM-variability.

### 1.5.2.3 Reliability

Both intra- and inter-rater reliability of the different cSMC measuring methods have been investigated by several authors (Table 1.1).

<table>
<thead>
<tr>
<th>Author</th>
<th>Task</th>
<th>Measuring device</th>
<th>Outcome measure</th>
<th>Reliability (ICC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pinsault, 2008</td>
<td>HRA to NHP</td>
<td>Laserpointer</td>
<td>JPE</td>
<td>0.59 – 0.87</td>
</tr>
<tr>
<td>Lee, 2006</td>
<td>HRA to NHP</td>
<td>Ultrasound trackers</td>
<td>JPE</td>
<td>Intra: 0.53 – 0.80</td>
</tr>
<tr>
<td></td>
<td>HRA to target</td>
<td></td>
<td></td>
<td>Intra: 0.42 – 0.90</td>
</tr>
<tr>
<td>Strimpakos, 2006</td>
<td>HRA to target</td>
<td>Ultrasound trackers</td>
<td>JPE</td>
<td>Inter: 0.15 – 0.64</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Intra: 0.01 – 0.50</td>
</tr>
<tr>
<td>Kristjansson, 2001</td>
<td>HRA to NHP</td>
<td>Electromagnetic trackers</td>
<td>JPE</td>
<td>0.35 - 0.82</td>
</tr>
<tr>
<td></td>
<td>HRA to target</td>
<td></td>
<td></td>
<td>0.52 – 0.74</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.67 (intra)</td>
</tr>
<tr>
<td>Kramer, 2009</td>
<td>Virtual reality test</td>
<td>Electromagnetic trackers</td>
<td>JPE</td>
<td>0.48 – 0.63 (intra)</td>
</tr>
<tr>
<td>Kristjansson, 2004</td>
<td>The Fly</td>
<td>Electromagnetic trackers</td>
<td>Jerk index</td>
<td>Controls: 0.60 – 0.77</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>WAD: 0.79 – 0.86</td>
</tr>
</tbody>
</table>

Table 1.1: The reliability of the cervical sensorimotor control measuring methods

HRA: Head repositioning accuracy; NHP: Neutral head position; Target: Target position; JPE: Joint position error; WAD: Whiplash associated disorders; Inter: inter rater reliability; Intra: intra rater reliability

The intra examiner reliability of the HRA-to-NHP test using a laser pointer was investigated by Pinsault et al. 41. In this study the HRA of 40 controls was investigated using the original laser pointer method introduced by Revel et al. 35. Pinsault et al. 41 found an ICC value ranging from 0.59 to 0.87 when using 8 trials.
Lee et al. \textsuperscript{52} investigated the inter and intra examiner reliability of the HRA-to-NHP in control subjects using an ultrasound based tracking device. Lee et al. \textsuperscript{52} found ICC values from 0.53 to 0.80 for the HRA-to-NHP using 3 trials.

The intra examiner reliability of the HRA-to-NHP test using an electromagnetic tracking device (FASTRAK TM, Polhemus Inc, USA) was investigated by Kristjansson et al. \textsuperscript{51}. In this study ICC values ranging from 0.35 to 0.82 were found using 3 trials.

Strimpakos et al. \textsuperscript{58} and Lee et al. \textsuperscript{52} both investigated the reliability of the HRA-to-target test using an ultrasound based tracking device (Zebris system, Medizintechnik GmbH, Tubingen Germany). Strimpakos et al. \textsuperscript{58} found ICC values varying from 0.01 to 0.50 for the intra examiner reliability and from 0.15 to 0.64 for the inter examiner reliability. Lee et al. \textsuperscript{52} found ICC values ranging from 0.42 to 0.90.

The reliability of the virtual reality test was investigated by Kramer et al. \textsuperscript{53}. In this study, ICC values from 0.25 to 0.77 were found for the static test and from 0.05 to 0.66 for the dynamic test, using 1 trial.

The reliability of The Fly™ was investigated by Kristjansson et al. \textsuperscript{54} in a population of controls and a population of whiplash patients (WAD I or II). The ICC values for this technique vary from 0.60 to 0.77 in controls and from 0.79 to 0.86 in whiplash patients.

The dynamic measuring method provided by Sölander et al. \textsuperscript{42} was not yet tested on reliability.

\textbf{1.5.2.4 Validity}

In determining the validity of the cSMC measuring techniques, mostly discriminant validity is used. The discriminant validity of the HRA-to-NHP technique, was investigated in 17 studies (Table 1.2).
<table>
<thead>
<tr>
<th>Author</th>
<th>Device</th>
<th>Population</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>De Hertogh, 2008</td>
<td>Laser pointer</td>
<td>44 cervicogenic headache</td>
<td>No significant differences</td>
</tr>
<tr>
<td></td>
<td>Electromagnetic device</td>
<td>23 controls</td>
<td></td>
</tr>
<tr>
<td>Feipel, 2006</td>
<td>Electromagnetic device</td>
<td>26 WAD</td>
<td>Significantly greater JPE in WAD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>26 controls</td>
<td></td>
</tr>
<tr>
<td>Grip, 2007</td>
<td>Laser pointer</td>
<td>20 nonspecific neck pain</td>
<td>No significant differences</td>
</tr>
<tr>
<td></td>
<td></td>
<td>21 WAD</td>
<td>More overshoot in WAD</td>
</tr>
<tr>
<td>Heikkila, 1996</td>
<td>Laser pointer</td>
<td>14 chronic WAD</td>
<td>Significantly greater JPE in WAD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>34 controls</td>
<td></td>
</tr>
<tr>
<td>Heikkila, 1998</td>
<td>Laser pointer</td>
<td>26 chronic WAD</td>
<td>Significantly greater JPE in WAD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>39 controls</td>
<td>WAD+D greater JPE than WAD-D</td>
</tr>
<tr>
<td>Heikkila, 2000</td>
<td>Laser pointer</td>
<td>14 cervicogenic dizziness</td>
<td>Significantly greater JPE in patients</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14 controls</td>
<td></td>
</tr>
<tr>
<td>Hill, 2009</td>
<td>Electromagnetic device</td>
<td>50 WAD+D</td>
<td>HRA (extension): Significantly greater JPE in patients</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50 WAD-D</td>
<td>Significantly greater JPE in WAD+D than WAD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50 controls</td>
<td>HRA (rotation): Significantly greater JPE in WAD+D than controls</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Significantly greater JPE in WAD+D than WAD-D</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>No significant differences between patient groups</td>
</tr>
<tr>
<td>Kristjansson, 2003</td>
<td>Electromagnetic device</td>
<td>21 controls</td>
<td>Significantly greater JPE in WAD after flexion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 neck pain</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>22 WAD</td>
<td></td>
</tr>
<tr>
<td>Pålmgren, 2009</td>
<td>Laser pointer</td>
<td>11 WAD</td>
<td>Significantly greater JPE in WAD after flexion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11 controls</td>
<td></td>
</tr>
<tr>
<td>Pinsault, 2009</td>
<td>Laser pointer</td>
<td>7 labyrinthine defective patients</td>
<td>Significantly greater JPE in neck pain patients</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 nontraumatic neck pain patients</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 controls</td>
<td></td>
</tr>
<tr>
<td>Pinsault, 2008</td>
<td>Laser pointer</td>
<td>7 labyrinthine defective patients</td>
<td>Significantly greater JPE in neck pain patients</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 nontraumatic neck pain patients</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 controls</td>
<td></td>
</tr>
<tr>
<td>Lee, 2008</td>
<td>Ultrasound trackers</td>
<td>127 neck pain patients and controls</td>
<td>No significant difference between labyrinthine defective patients and controls</td>
</tr>
<tr>
<td>Revel, 1991</td>
<td>Laser pointer</td>
<td>30 chronic neck pain patients</td>
<td>Significantly greater JPE in patients</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30 controls</td>
<td></td>
</tr>
<tr>
<td>Rix, 2009</td>
<td>Laser pointer</td>
<td>11 chronic neck pain patients</td>
<td>No significant differences</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11 controls</td>
<td></td>
</tr>
<tr>
<td>Roren, 2009</td>
<td>Laser pointer</td>
<td>40 neck pain patients</td>
<td>Significantly greater JPE in patients</td>
</tr>
<tr>
<td></td>
<td>Ultrasound device</td>
<td>41 controls</td>
<td></td>
</tr>
<tr>
<td>Treleaven, 2003</td>
<td>Electromagnetic device</td>
<td>105 WAD</td>
<td>Significantly greater JPE in WAD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>44 controls</td>
<td></td>
</tr>
<tr>
<td>Woodhouse, 2008</td>
<td>Electromagnetic device</td>
<td>59 WAD</td>
<td>Significantly greater JPE in WAD+D than WAD-D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>57 chronic neck pain</td>
<td></td>
</tr>
</tbody>
</table>

Table 1.2: Validity of the Head repositioning accuracy to the neutral head position

JPE: Joint position error; WAD: Whiplash associated disorders; WAD+D: Whiplash associated disorders with dizziness; WAD-D: Whiplash associated disorders without dizziness
In 13 out of 17 studies, the authors found a significant difference between patients and controls or between patient populations.

Eight studies compared the HRA-to-NHP of patients with Whiplash associated disorders (WAD) to controls or to patients with non-traumatic neck pain. Seven of these authors 36, 37, 38, 39, 66, 40, 55 found a higher JPE in patients with WAD compared to controls.

Three authors 43, 39, 44 also investigated the difference between patients with WAD and patients with non-traumatic neck pain, but none of them could find a difference in JPE between these groups.

Heikkila et al. 38, Hill et al. 55 and Treleaven et al. 40 found a supplementary difference between patients with WAD who also complained of dizziness, compared to patients with WAD without dizziness. Patients with WAD with dizziness showed higher JPE. These results were confirmed in a study of Heikkila et al. 60.

The discriminant validity of the HRA-to-NHP measurements was also tested in non-traumatic neck pain patients 39, 63, 35, 64, 65.

In four out of five studies, significantly greater JPE’s were found in non-traumatic neck pain patients, compared to controls. The study of Rix et al. 64 could not confirm these results.

The discriminant validity of the HRA-to-target measurements (Table 1.3) was investigated in two studies. Kristjansson et al. 39 found no differences between patient populations (WAD and non-traumatic neck pain) and controls and between WAD and non-traumatic neck pain patients.

Loudon et al. 67 on the contrary found significantly greater JPE’s in patients with WAD compared to controls.

<table>
<thead>
<tr>
<th>Author</th>
<th>Device</th>
<th>Population</th>
<th>Results</th>
</tr>
</thead>
</table>
| Kristjansson, 2003 39 | Electromagnetic device | 21 controls  
20 neck pain  
22 WAD | No significant differences |
| Loudon, 1997 67 | CROM             | 11 WAD  
11 controls | Significantly greater JPE in WAD |

Table 1.3: Validity of the Head repositioning accuracy to a target position

JPE: Joint position error; WAD: Whiplash associated disorders; CROM: cervical range of motion device
The validity of The Fly™ was investigated by Kristjansson et al. in two studies (Table 1.4). Significant differences were found using this test in patients with WAD compared to controls and compared to non-traumatic neck pain patients. Differences were also found between non-traumatic neck pain patients and controls.

**The Fly**

<table>
<thead>
<tr>
<th>Author</th>
<th>Device</th>
<th>Population</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kristjansson, 2004</td>
<td>The Fly</td>
<td>20 WAD</td>
<td>Significant differences between patients and controls</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 controls</td>
<td></td>
</tr>
<tr>
<td>Kristjansson, 2010</td>
<td>The Fly</td>
<td>18 controls</td>
<td>Significant differences between groups</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18 non-traumatic neck pain patients</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>18 WAD</td>
<td></td>
</tr>
</tbody>
</table>

*Table 1.4: Validity of The Fly*

WAD: Whiplash associated disorders

The validity of the CLMT measurements was investigated by Sjölander et al. (Table 1.5). These authors found a significantly greater Jerk index and ROM-variability in patients with WAD and non-traumatic neck pain, compared to controls.

**Continuous linear movement**

<table>
<thead>
<tr>
<th>Author</th>
<th>Device</th>
<th>Population</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sjölander, 2008</td>
<td>Electromagnetic device</td>
<td>7 WAD</td>
<td>Significantly greater Jerk index in patients</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9 non-traumatic neck pain</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>16 controls</td>
<td></td>
</tr>
</tbody>
</table>

*Table 1.5: Validity of the continuous linear movement measurements*

WAD: Whiplash associated disorders

The validity of the virtual reality test was not yet investigated.

### 1.6 DISCUSSION

The aim of this review was to compare the required tasks, the used measuring device and the clinimetric characteristics of commonly used cSMC measuring methods. Five different tasks are currently used in measuring cSMC. Three of them can be considered as repositioning tasks, two as trajectory registrations.

In general, the outcome used to measure cSMC is calculated as the deviation from a static position or from a trajectory. The outcome can be registered using different devices.
1.6.1 Reliability

The reliability of the different cSMC measuring methods was investigated by several authors.

For HRA-to-NHP measurements, a fair to excellent reliability\(^b\) has been reported. Its reliability is apparently not affected by the device used to register the deviation. Similar ICCs were found in studies using the laser pointer \(^{41}\), the electromagnetic trackers \(^{31}\) and the ultrasound based trackers \(^{52}\).

On the other hand, a good test retest reliability isn’t a synonym for good accuracy. In scientific research, where accurate values are needed and lots of data are being processed, the electromagnetic or ultrasound devices are preferable. The data provided by these devices are more accurate and can be processed using mathematical software. When using the laser pointer method, larger measurement errors can be seen and manual measurements of the JPE are needed. This makes the laser pointer method less accurate and more time consuming, especially when lots of data need to be processed. In clinical settings where less patients at a time are being assessed, the cheaper laser pointer method will suffice.

The reliability of the HRA-to-target test ranges from very bad to excellent. Therefore these measurements are more vulnerable for discussion. In contrast with the HRA-to-NHP, the chosen device apparently affects the reliability results. Measurements using electromagnetic trackers seem to be more consistent, with a moderate to good reliability. The ultrasound seems less reliable as the ICC values vary largely.

One reason for this difference can be found in the measuring accuracy of the devices. The electromagnetic device has an accuracy of 0.03° while for the ultrasound device the accuracy is 0.5° in each direction. As the JPE of asymptomatic control subjects mostly ranges from 0° to 6°, 0.5° of measurement error might be too much, resulting in more variation in ICC.

Apart from the used measuring device, variation in the predefined target position, the amount of trials and the used instruction can also be a possible reason for the variation of the reliability. The influence of these factors on the reliability of the test needs to be investigated in future research.

For both the HRA-to-NHP and HRA-to-target the reliability has been investigated in asymptomatic control subjects, so no information on the reliability of these methods in patient populations is available. Similar test-retest reliability results can

\(^b\) Classification according to Fleiss, 1986 (Appendix 1)
be expected in patient populations, but the influence of for example pain complaints on the reliability results should be investigated.

The reliability of The Fly™ can be considered as moderate to excellent. The reported ICC values vary less than those of other measuring methods. This can be caused by the uniformity of the patient instruction in the different test sessions. The Fly™ software produces a ready to read output. No further calculations are needed which reduces the risk of errors. This may have increased the reliability.

So far, the Fly™ is the only method whose reliability was studied in both controls and patients. In asymptomatic control subjects the reliability of The Fly™ is good. When studied in patients with whiplash, the reliability of The Fly™ appears to be good to excellent.

The reliability of the virtual reality test ranges from very bad to good. This inconsistency makes further research necessary before implementing the virtual reality test in clinical practice. A possible reason for the inconsistent ICC values may be the amount of trials. In most measuring methods 3 or more trials are used, in the virtual reality test, only one trial is used. According to Rix et al. 64 any error in the HRA usually occurs within the first 10 repetitions. Using only one repetition may result in causing errors in several subjects.

The reliability of the dynamic method used by Sjölander et al. 42 was not yet investigated and therefor needs further research.

The results of this review show that the ICC values of the cSMC measuring methods can vary, depending on the one hand on the measuring method, on the other hand on the way it is applied. For future research we recommend the HRA-to-NHP and The Fly™ as they seem to be reliable. We recommend sufficient training of the procedure for both the examiner and the subjects. When comparing groups, the homogeneity of groups for e.g. age and gender should be guarded.

1.6.2 Validity

The validity of the cSMC measuring methods is mostly based on discriminant validity by comparing various patient groups and controls. Most studies deal with whiplash patients or patients with non-traumatic neck pain.

The HRA-to-NHP measurements seem to have good validity. Differences between WAD patients and controls were demonstrated unanimously by seven authors. In four out of five studies the HRA-to-NHP could also demonstrate a difference between patients with non-traumatic neck pain and controls.
On the contrary, no differences could be demonstrated between patients with WAD and patients with non-traumatic neck pain using the HRA-to-NHP. Maybe, JPEs are equally increased in both patient groups and other outcome measures are needed to differentiate between these patient populations.

Significantly greater JPE’s are also found in WAD patients with dizziness compared to WAD patients without dizziness. Possibly, the disturbed cSMC causes the dizziness problems in these patients. Further research is needed to confirm this statement.

The discriminant validity of the HRA-to-target technique was investigated in two studies. Both studies provide contradictory results, what makes further research needed to find an agreement regarding the discriminant validity of this technique.

The discriminant validity of The Fly™ seems to be good when comparing patients with WAD with controls and with patients with non-traumatic neck pain. Differences were found between WAD and non-traumatic neck pain patients by using the following outcome measures: amplitude accuracy, directional accuracy and Jerk index. The ability of The Fly™ to detect differences between different patient populations suggests a diagnostic potential that is to be confirmed in future research.

Sjölander et al. 42, on the contrary, couldn’t find a difference in Jerk index between patients with WAD and patients with non-traumatic neck pain when using the CLMT. Possibly, the constant linear movements are too familiar to the patient and too predictable in comparison with the constantly changing movements of The Fly™. In addition, no feedback is given during the CLMT test and therefore not all aspects of SMC are being investigated.

Based on the included literature, the discriminant validity of the HRA-to-NHP, The Fly™ and the CLMT is good. All three methods are able to discriminate between patients with neck complaints and controls. Currently only The Fly™ is able to discriminate between different patient populations (WAD and non-traumatic neck pain).

1.6.3 Cervical sensorimotor control

Based on the definition of sensorimotor control provided by Lephart et al. 49, cSMC can be seen as the system providing functional stability of the cervical spine. This system incorporates the afferent information from the cervical structures, visual system and vestibular system, together with the efferent information from the central nervous system and the central integration and processing.
As described above, cSMC can be evaluated using different measuring techniques and different outcome measures.

The content validity of the different techniques has not yet been described. Taking into account the definition of cSMC, The Fly™ seems to test more aspects of cSMC compared to the HRA and CLMT techniques.

Regarding the HRA technique the outcome is a JPE, which gives information about the ability of a person to relocate the head to a predefined target position. No information is obtained about the way the subject moves. In addition, classically the patient is blindfolded during the test, to exclude compensations of the visual system, and no feedback is given to the patient between the trials.

As the HRA only registers positions and no feedback is given, only a part of the cSMC is assessed using this test. This limited assessment could be a reason why no differences between different patient populations were found using the HRA test.

During the CLMT test the complete movement is assessed, but no feedback is given during the performance as the subject is blindfolded. This lack of feedback limits the efferent information provided by the central nervous system. In addition, the linear movement might be too familiar and predictable to the subject, what might explain why no differences in Jerk Index were found between different patient populations using the CLMT.

The Fly™ test measures the cSMC using an unpredictable movement pattern and gives the subject constant visual feedback. As the movements are small, the test cannot be performed correctly using the global movers of the cervical spine, but the use of smaller stabilizing muscles is needed. All aspects of the CSMC are being addressed during this test, what might explain why The Fly™ is currently the only test which can discriminate between different patient populations.

As cSMC includes the adaptation of movements using the feedback provided by the visual and vestibular systems, feedback should be an essential part of cSMC measurements.

In general, The Fly™ test seems to be more reliable than the HRA-to-NHP and is able to discriminate between different patient populations. The reliability of the CLMT is not yet investigated, but its discriminant validity is promising. No literature was found regarding to the sensitivity, specificity and responsiveness of the described methods, these parameters need to be assessed in future research.
1.7 Conclusion

In conclusion, two tests have proven to be sufficiently reliable and valid to test cSMC.

Concerning the HRA-to-NHP, several studies have provided promising reliability results in control subjects, but further investigation is needed before these results can be generalized to patient populations. The technique can discriminate between patient populations and controls but doubt may arise regarding to content validity.

The Fly™ test seems to have good reliability and validity, in control subjects as well as in patient populations. Given the fact that these results are based on few studies, a confirmation of these results is recommended.

The Fly™ seems to have good content and discriminant validity.

At present, The Fly™ seems to be the most recommendable way to test cSMC, but the reliability and validity results need further confirmation. The diagnostic potential is to be confirmed in future research.
2 THE RELIABILITY OF A CONTINUOUS LINEAR MOVEMENT TEST ASSESSING CERVICAL SENSORIMOTOR CONTROL USING ZEBRIS® TECHNOLOGY

2.1 ABSTRACT

**Background:** Cervical sensorimotor control (cSMC) is traditionally assessed by head repositioning accuracy (HRA) measurements. A disadvantage of the HRA measurements is their static character and lack of visual feedback. In 2008, Sjölander et al. developed a continuous linear movement test (CLMT). This CLMT uses several kinematic parameters, such as reduced range of motion (ROM), velocity and movement smoothness, to quantify altered sensorimotor functions.

**Objective:** Investigate the inter and intra rater reliability of a CLMT.

**Design:** Reliability study.

**Methods:** 50 asymptomatic adults were recruited. Five outcome measures were obtained: the time (t) needed to perform one movement, variation in time (var-t), ROM, peak-velocity (peak-v) and Jerk index (Cj).

A 3D analysis of cervical movements during the CLMT was made using ZEBRIS™. MATLAB™ was used to process data provided by the ZEBRIS™ device. These data were used to calculate ICC or $\kappa_w$-values, depending on the normality of the distribution, using SPSS.

**Results:** The intra rater reliability shows slight to moderate agreement for t (ICC: 0.19–0.42 and $\kappa_w$: 0.42) and peak-v ($\kappa_w$: 0.27–0.47), moderate to substantial agreement for var-t (ICC: 0.54–0.73) and ROM (ICC: 0.43–0.65) and fair to substantial agreement for Cj ($\kappa_w$: 0.27–0.69).

The inter rater reliability shows moderate to almost perfect agreement for t (ICC: 0.54–0.93), almost perfect agreement for var-t ($\kappa_w$: 0.81–0.96) and ROM (ICC: 0.86–0.95), slight to moderate agreement for peak-v ($\kappa_w$: -0.03–0.44) and slight to fair agreement for Cj ($\kappa_w$: 0.00–0.31).

**Conclusion:** Time and ROM are presently the most reliable outcome measures. However it must be noted that the discriminant validity of the time parameters needs further investigation.
2.2 INTRODUCTION

Cervical sensorimotor control (cSMC) becomes increasingly important in the assessment of patients with neck pain. Since the first publication regarding the head repositioning test by Revel et al.\textsuperscript{35} in 1991, several authors have found changes in cSMC in patients with neck complaints compared to asymptomatic controls\textsuperscript{36, 37, 38, 39, 40}.

Based on the definition of sensorimotor control provided by Lephart \textsuperscript{69}, cSMC can be seen as the system providing functional stability of the cervical spine. This system incorporates the afferent information from the cervical structures (mainly muscle spindles), visual and vestibular system, together with the efferent information from the central nervous system and the central integration and processing \textsuperscript{34}.

CSMC is generally measured using repositioning tasks (measuring joint position errors) or trajectory registrations (monitoring the entire movement). The most commonly used cSMC measuring method is the head repositioning accuracy (HRA) to the neutral head position \textsuperscript{35, 36, 37, 38, 39, 40}.

These HRA tests have proven to provide reliable \textsuperscript{41, 42, 39} and valid measurements \textsuperscript{36, 37, 38, 39, 40}.

The HRA however is static and measures only the position sense. Apart from the position sense, sensorimotor control also includes the feedback and feed forward mechanisms during the entire movement trajectory. To quantify altered sensorimotor functions during movements, several kinematic parameters are used. In relation to cervical spine disorders, reduced range of movement (ROM) \textsuperscript{70, 71, 72}, altered activation patterns of cervical muscles \textsuperscript{73}, reduced maximal velocity \textsuperscript{74, 75} and movement smoothness \textsuperscript{42, 74, 76} are registered during cervical movements \textsuperscript{77}.

A test, developed by Sjölander et al.\textsuperscript{42}, a continuous linear movement test (CLMT), is in line with the abovementioned. In contrast with the HRA, the CLMT monitors the following kinematic parameters during the entire movement: ROM, peak velocity, jerk index, constant and variable repositioning errors. The Jerk index is the outcome measure for the smoothness of the movement. Several studies \textsuperscript{78, 79} have demonstrated that poor movement control, as e.g. children and patients with neurological diseases, is associated with a high jerk value \textsuperscript{42}. Since motor control disturbances can be expected in patients with neck disorders, due to altered afference from and efference to the cervical spine, jerkier movements can be expected \textsuperscript{42}. 
The CLMT has already proven to have good discriminant validity, as patients suffering from neck pain showed significantly larger ROM variability and Jerk Index compared to controls. The reliability however has never been investigated.

Therefore, the aim of this study was to investigate the test-retest reliability of the CLMT test.

2.3 MATERIAL AND METHODS

2.3.1 Experimental protocol

Two raters, both physical therapists, performed this reliability study. During a training period both raters were given instructions and feedback on the test procedure by an experienced researcher. This ensured that both raters were equally familiar with the test procedure and measuring device.

2.3.2 Subjects

For inclusion the participants needed to be at least 18 years old, without a recent history of neck complaints.

Participants were excluded if one or more of the following conditions were present: head- or neck complaints currently, or in the last 6 months, pain or stiffness of the neck or arms during the last 2 years, head or neck trauma in the last 5 years, history of spinal fracture or dislocation, history of head or neck surgery, known systemic inflammatory diseases, known metabolic diseases, known neurological disorders, history of vertigo or cervical arthritis.

Two groups of asymptomatic volunteers were recruited. One group was measured twice by the same rater to assess the intra rater reliability of the CLMT. To assess the inter rater reliability of the CLMT, a second group of asymptomatic volunteers was measured twice by two different raters independently. The interval between both measurements was 15 minutes.

2.3.3 Sample size

The sample size was determined using the table for estimating sample size for reliability studies provided by Walter et al. In our study, all subjects were observed twice and a minimal acceptable level of reliability was set at an ICC of 0.40 or \( \kappa_w \) of 0.40. According to Landis et al. an ICC of 0.41 represents a moderate agreement. An ICC or \( \kappa_w \) of 0.80 was used as the ideal level of agreement. Based on these variables minimally 15 subjects were needed in each group.
Because the sample size of 15 represented the absolute minimum we wanted to reach, we decided to include more patients than this absolute minimum.

2.3.4 Measurements

The 3D analysis of the subjects’ movements was performed by the ZEBRIS™ CMS 20 (Medizintechnik GmbH, Tubingen Germany). This device measures movements by tracking the position of six markers, at a rate of 20 Hz, using ultrasound waves.

The ZEBRIS™ consists of one headset with a triplet of markers on top, one back reference with a second triplet of markers and one microphone which collects the ultrasound signals produced by the markers.

![Measuring setup ZEBRIS™ headset and back reference](image)

Subjects were required to perform three series of ten repetitions of movements in a fixed order: flexion-extension, both rotations and lateral flexions.

Before every movement series, subjects were asked to maintain a neutral head position for 2 seconds, in order to calibrate the device. This position counted as the 0-position for all further movements. The possibility of a small variation in 0-position between the different movement series or subjects and a possible effect on the variables was taken into account by using the entire movement: eg. maximal left rotation to maximal right rotation as one variable.

The instructions given to the subjects were standardized since these were written down. The subjects were asked to move smoothly, which means at a comfortable pace without causing discomfort to the subject. Regarding the ROM, the instruction was given to move as far as possible without causing any discomfort. To ensure the registration of the subjects’ regular movements the first three movement cycles were not registered. By analogy, subjects were instructed to stop moving only after
the registration was stopped. Doing so, we avoided registering fluctuations caused by the initiation or termination of a movement.

2.3.5 Data processing

The 3D analysis of the cervical movements was made, using an ultrasound based tracking device (ZEBRIS™, Medizintechnik GmbH, Tubingen Germany).

The ZEBRIS™ provides 3D angular data, which are exported in Excel files. These Excel files, containing the rotation angle around the three axes for each time capture, were processed using MATLAB software (version R2011a, The MathWorks, Inc.).

The data were processed separately for each movement series. This resulted in five manageable categories of outcome measures per movement series (i.e.: flexion-extension): the time (t), variation in time (var-t), the range of motion (ROM), the peak velocity (peak-v) and the Jerk index (Cj).

The outcome measures are defined as follows:

The ‘t’ is the average time needed to perform one movement cycle (e.g. maximal flexion to maximal extension). ‘var-t’ is the average ‘t’-deviation of the different movement cycles. ‘ROM’ is the average ROM per movement direction. ‘Peak-v’ is the highest velocity during the movement trial. The ‘Cj’ is a measurement of the smoothness of the movement which is calculated using the algorithms described by Kitazawa et al.84. These algorithms calculate the sum of the different vectors of Jerk values over the movement (the size and direction of the deviation from the average movement trajectory), with respect to the average movement time and distance.

The Jerk index, Cj, was calculated as presented in figure 2.2.

\[ C_j = \sqrt{\frac{1}{2} \sum_{i=1}^{n} J_i^2 \frac{t^5}{D}} \]

*Figure 2.2: Jerk Index*

Where J is the vector of the jerk values over the movement (calculated from the kinematic data, as described above), n the number of samples of the vector, i the vector index, t the movement time, and D the movement distance13.
2.3.6 Statistical analysis

After processing, the reliability of the obtained outcome parameters was investigated as follows:

Firstly, the normality of the data’s distribution was investigated using the Kolmogorov–Smirnov test combined with a visual interpretation of the normality curves. Secondly, ICC values were calculated for the normally distributed data and weighted kappa (κw) values were calculated for the non-normally distributed data. Thirdly, the presence of systematic differences between the two measuring moments was investigated using a paired t-test for the normally distributed data and a Wilcoxon Signed Rank test for the non-normally distributed data.

Apart from the reliability analysis, the demographic features of the population were investigated using descriptive statistics.

SPSS for Windows (version 12.0, SPSS Inc.) was used for all statistical analyses, except for the κw calculations, where MedCalc (version 12.2.1, MedCalc Software bvba, Belgium) was used.

2.4 RESULTS

In total 50 asymptomatic volunteers were included, 23 for the intra rater group and 27 for the inter rater group. The demographic features of the two groups are presented in table 2.1.

<table>
<thead>
<tr>
<th></th>
<th>Intra rater</th>
<th>Inter rater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of subjects</td>
<td>23</td>
<td>27</td>
</tr>
<tr>
<td>Females</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>Males</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Age (mean ± SD)</td>
<td>27 ± 6 years</td>
<td>31 ± 12 years</td>
</tr>
</tbody>
</table>

Table 2.1: Demographic features

SD: Standard deviation

The intra rater ICC and κw-values are shown in table 2.2, the inter rater values are shown in table 2.3.

The ICC or κw is presented accompanied by its significance level for each outcome measure. In addition, the significance level of the paired t-test or Wilcoxon signed rank test is presented for each outcome measure.

For the interpretation of the ICC or κw values, the scale of Landis et al. was used. 

Using this scale, slight agreement is seen as a value between 0 and 0.20, fair
agreement has values between 0.21 and 0.40, moderate agreement between 0.41 and 0.60, substantial agreement between 0.61 and 0.80 and almost perfect agreement between 0.81 and 1.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Mean (SD)</th>
<th>MM2</th>
<th>ICC/κw value</th>
<th>p</th>
<th>t-test/Wilcoxon p</th>
</tr>
</thead>
<tbody>
<tr>
<td>t-FE (s)</td>
<td>1.97 (0.200)</td>
<td>1.96 (0.240)</td>
<td>0.42</td>
<td>0.023</td>
<td>0.89</td>
</tr>
<tr>
<td>t-LF (s)</td>
<td>2.15 (0.279)</td>
<td>2.32 (0.442)</td>
<td>0.19</td>
<td>0.166</td>
<td>0.09</td>
</tr>
<tr>
<td>t-R* (s)</td>
<td>2.11 (0.302)</td>
<td>2.26 (0.241)</td>
<td>0.42</td>
<td>0.010</td>
<td>0.01</td>
</tr>
<tr>
<td>var-t-FE (s)</td>
<td>1.05 (0.252)</td>
<td>1.17 (0.426)</td>
<td>0.62</td>
<td>0.000</td>
<td>0.05</td>
</tr>
<tr>
<td>var-t-LF (s)</td>
<td>1.17 (0.328)</td>
<td>1.32 (0.441)</td>
<td>0.73</td>
<td>0.000</td>
<td>0.02</td>
</tr>
<tr>
<td>var-t-R (s)</td>
<td>1.13 (0.276)</td>
<td>1.34 (0.388)</td>
<td>0.54</td>
<td>0.000</td>
<td>0.00</td>
</tr>
<tr>
<td>ROM-FE (deg)</td>
<td>108.43 (58.684)</td>
<td>85.35 (41.492)</td>
<td>0.47</td>
<td>0.005</td>
<td>0.04</td>
</tr>
<tr>
<td>ROM-LF (deg)</td>
<td>135.73 (53.662)</td>
<td>123.01 (51.324)</td>
<td>0.43</td>
<td>0.018</td>
<td>0.29</td>
</tr>
<tr>
<td>ROM-R (deg)</td>
<td>120.36 (64.878)</td>
<td>107.88 (68.828)</td>
<td>0.65</td>
<td>0.000</td>
<td>0.30</td>
</tr>
<tr>
<td>Peak-v-FE* (deg/s)</td>
<td>562.15 (595.631)</td>
<td>317.45 (384.425)</td>
<td>0.37</td>
<td>0.025</td>
<td>0.09</td>
</tr>
<tr>
<td>Peak-v-LF* (deg/s)</td>
<td>598.65 (504.380)</td>
<td>419.14 (494.432)</td>
<td>0.27</td>
<td>0.090</td>
<td>0.10</td>
</tr>
<tr>
<td>Peak-v-R* (deg/s)</td>
<td>671.06 (660.089)</td>
<td>473.04 (621.739)</td>
<td>0.47</td>
<td>0.008</td>
<td>0.11</td>
</tr>
<tr>
<td>Cj-FE*</td>
<td>5436.72 (4263.594)</td>
<td>3773.90 (2991.503)</td>
<td>0.27</td>
<td>0.087</td>
<td>0.12</td>
</tr>
<tr>
<td>Cj-LF*</td>
<td>6535.29 (5510.631)</td>
<td>6797.87 (7705.068)</td>
<td>0.36</td>
<td>0.048</td>
<td>0.93</td>
</tr>
<tr>
<td>Cj-R*</td>
<td>8603.01 (9014.751)</td>
<td>6770.40 (7618.695)</td>
<td>0.69</td>
<td>0.000</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Table 2.2: Intra rater reliability

*: values indicated with an * are non-normally distributed, the κw and Wilcoxon Signed Rank test are used in these values

SD: standard deviation from the mean; Mean: mean value; MM: measuring moment; t: average time; var-t: variation in time; Peak-v: peak velocity; ROM: range of motion; Cj: Jerk index; FE: flexion and extension movement; LF: lateral flexion; R: rotation; ICC: intraclass correlation coefficient; κw: weighted kappa; p: significance level; s: seconds; deg: degrees
<table>
<thead>
<tr>
<th>Outcome</th>
<th>Mean (SD) MM1</th>
<th>Mean (SD) MM2</th>
<th>ICC/κw value</th>
<th>p</th>
<th>t-test/ Wilcoxon p</th>
</tr>
</thead>
<tbody>
<tr>
<td>t-FE (s)</td>
<td>1.94 (0.231)</td>
<td>1.94 (0.196)</td>
<td>0.54</td>
<td>0.011</td>
<td>0.86</td>
</tr>
<tr>
<td>t-LF (s)</td>
<td>2.17 (0.324)</td>
<td>2.15 (0.362)</td>
<td>0.90</td>
<td>0.000</td>
<td>0.88</td>
</tr>
<tr>
<td>t-R (s)</td>
<td>2.02 (0.339)</td>
<td>2.04 (0.403)</td>
<td>0.93</td>
<td>0.000</td>
<td>0.34</td>
</tr>
<tr>
<td>var-t-FE* (s)</td>
<td>0.89 (0.276)</td>
<td>0.87 (0.203)</td>
<td>0.81</td>
<td>0.000</td>
<td>0.88</td>
</tr>
<tr>
<td>var-t-LF* (s)</td>
<td>0.96 (0.339)</td>
<td>0.96 (0.325)</td>
<td>0.96</td>
<td>0.000</td>
<td>0.74</td>
</tr>
<tr>
<td>var-t-R* (s)</td>
<td>0.91 (0.360)</td>
<td>0.90 (0.331)</td>
<td>0.93</td>
<td>0.000</td>
<td>0.83</td>
</tr>
<tr>
<td>ROM-FE (deg)</td>
<td>115.41 (23.68)</td>
<td>113.57 (23.91)</td>
<td>0.92</td>
<td>0.000</td>
<td>0.37</td>
</tr>
<tr>
<td>ROM-LF (deg)</td>
<td>138.43 (13.813)</td>
<td>139.05 (15.702)</td>
<td>0.86</td>
<td>0.000</td>
<td>0.47</td>
</tr>
<tr>
<td>ROM-R (deg)</td>
<td>78.65 (16.135)</td>
<td>78.41 (16.944)</td>
<td>0.95</td>
<td>0.000</td>
<td>0.84</td>
</tr>
<tr>
<td>Peak-v-FE* (deg/s)</td>
<td>221.40 (164.811)</td>
<td>210.22 (122.170)</td>
<td>0.06</td>
<td>0.358</td>
<td>0.41</td>
</tr>
<tr>
<td>Peak-v-LF* (deg/s)</td>
<td>388.31 (233.009)</td>
<td>318.27 (136.30)</td>
<td>-0.03</td>
<td>0.558</td>
<td>0.65</td>
</tr>
<tr>
<td>Peak-v-R* (deg/s)</td>
<td>103.67 (36.219)</td>
<td>103.65 (40.925)</td>
<td>0.44</td>
<td>0.002</td>
<td>0.09</td>
</tr>
<tr>
<td>Cj-FE*</td>
<td>3214.66 (1215.837)</td>
<td>3002.12 (1022.068)</td>
<td>0.09</td>
<td>0.297</td>
<td>0.21</td>
</tr>
<tr>
<td>Cj-LF*</td>
<td>3804.36 (726.397)</td>
<td>3416.74 (821.196)</td>
<td>0.00</td>
<td>0.503</td>
<td>0.18</td>
</tr>
<tr>
<td>Cj-R*</td>
<td>2750.27 (667.208)</td>
<td>2806.50 (994.898)</td>
<td>0.31</td>
<td>0.016</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Table 2.3: Inter rater reliability

*: values indicated with an * are non-normally distributed, the κw and Wilcoxon Signed Rank test are used in these values

SD: standard deviation from the mean; Mean: mean value; MM: measuring moment; t: average time; var-t: variation in time; Peak-v: peak velocity; ROM: range of motion; Cj: Jerk index; FE: flexion and extension movement; LF: lateral flexion; R: rotation; ICC: intraclass correlation coefficient; κw: weighted kappa; p: significance level; s: seconds; deg: degrees

2.4.1.1 Time

2.4.1.1.1 Intra rater reliability

All intra rater t-data were normally distributed but one, the t for rotation.

The ICC and κw values for the t range from 0.19 to 0.42, indicating a slight to moderate reliability. The var-t showed ICC values ranging from 0.54 to 0.73, indicating a moderate to good reliability.

The paired t-tests and Wilcoxon signed rank tests showed systematic differences between the two measuring moments for t for rotation and var-t for lateral bending and rotation.
2.4.1.2  Inter rater reliability

The inter rater t-data were normally distributed. The var-t data, on the contrary, were non-normally distributed.

The t shows moderate to almost perfect ICC values (ICC: 0.56 – 0.93). The ICC values of the var-t range from 0.81 to 0.96, indicating almost perfect reliability.

No systematic differences could be found between the two measuring moments.

2.4.1.2  Range of Motion

2.4.1.2.1  Intra rater reliability

All ROM data were normally distributed.

The ICC and $\kappa_w$-values range from 0.43 to 0.65, indicating a moderate to substantial reliability.

The paired t-test showed systematic differences between the two measuring moments for the flexion-extension ROM. No other systematic differences between the two measuring moments were found.

2.4.1.2.2  Inter rater reliability

All ROM data were normally distributed.

The ICC-values range from 0.86 to 0.95, indicating an almost perfect reliability.

No systematic differences between the two measuring moments could be found.

2.4.1.3  Peak velocity

2.4.1.3.1  Intra rater reliability

The peak-v data were all non-normally distributed. The $\kappa_w$-values range from 0.27 to 0.47, indicating slight to moderate reliability.

No systematic differences were found between the two measuring moments.

2.4.1.3.2  Inter rater reliability

All peak-v data were non-normally distributed. The $\kappa_w$-values range from -0.03 to 0.44, indicating no agreement to moderate agreement.

No systematic differences were found between the two measuring moments.
2.4.1.4 Jerk Index

2.4.1.4.1 Intra rater reliability

All Cj data were non-normally distributed. $\kappa_w$-values range from 0.27 to 0.69, indicating a slight to substantial reliability. No systematic differences could be found between the two measuring moments.

2.4.1.4.2 Inter rater reliability

All Cj-variables were non-normally distributed. The $\kappa_w$-values range from 0.00 to 0.31, indicating no to fair agreement. Systematic differences could be found for the Cj for the flexion and extension movement.

2.5 Discussion

The objective of this study was to investigate the inter and intra rater reliability of a CLMT for measuring cSMC using different outcome measures (t, var-t, ROM, peak-v and Cj).

The inter rater reliability values appear to be systematically higher than the intra rater values. These results are contradictory with the assumption that repeated tests are more reliable when performed by the same rater. Possibly, the systematically higher inter rater reliability in our study is due to the homogeneity of the test results in the intra rater group. As ICC’s are calculated using standard deviations, a homogeneous outcome will result in low standard deviations and therefore also in low ICC-values.

Another explanation for the systematically higher inter rater values was found by means of a post hoc analysis using Bland Altman plots. Several of these plots showed us the presence of a certain degree of heteroscedasticity in the intra rater group. This indicates that the variability of the first set of measurements is unequal across the range of values of the second set of measurements and might have resulted in an underestimation of the reliability using the $\kappa_w$.

The participant’s mean age is higher (31 years old) in the inter rater group than in the intra rater group and a large age dispersion can be noted compared to the inter rater group. As cSMC might change with the age, this age dispersion might have resulted in larger intra-group differences of the CLMT outcome measures in the inter rater group.

The results of the t, var-t, ROM, peak-v and Cj will be discussed consecutively.
The time-parameters (t and var-t) show moderate to excellent inter rater reliability results (t: ICC: 0.54-0.93, var-t: κw: 0.81-0.96). The t shows slight to moderate intra rater reliability (ICC: 0.19-0.42, κw: 0.42). The intra rater reliability of the var-t shows moderate to good reliability (ICC: 0.54-0.73).

The systematic differences in var-t in the intra rater group might be due to a learning effect in some of the subjects because of too little time between the two trials.

In scientific research and clinical practice, this test is generally used to evaluate long term therapy effects, so the issue of a learning effect will probably be less of a problem.

The validity of the time-variables has not been investigated in the study of Sjölander et al. The var-t needed to perform one movement cycle seems to be a reliable parameter when studying movement trajectories. The discriminant validity of this parameter, however, has not yet been investigated.

The ROM shows almost perfect inter rater reliability (ICC: 0.86 – 0.95) and moderate to substantial intra rater reliability (ICC: 0.43 – 0.65). In the intra rater group one out of three variables shows systematically lower ROM values during the second movement series. As, in the intra rater group, the test was performed twice by the same rater, the instruction given the second time might have been less detailed than the first time. In order to avoid influences by the rater’s instruction and to improve the reliability of the test, a detailed instruction is needed at each measuring moment.

In the validity study of the CLMT test, the ROM showed poor validity. In contrast with our study, however, only the rotation ROM was investigated, and left and right rotation ROM were calculated separately. The discriminant validity of the ROM using our approach (i.e. calculating one ROM around each of the three different axes) is to be investigated in future research.

Our results indicate that the ROM can be used as a reliable parameter in objectifying movement trajectories in future research. Since ROM changes with increasing age, an age representative control group is recommended for studies comparing patients and control subjects.

The peak-v shows negligible to moderate inter rater reliability (κw: -0.03 to 0.44) and weak to moderate intra rater reliability (κw: 0.27 to 0.47). These limited reliability results might be due to a learning effect occurring after the first trial. In the second trial, the subject already knows the movements, and possibly moves
faster. Further investigation of the peak-\(v\) data in both trials of the inter rater group shows that the peak-\(v\) for flexion and extension is averagely 7% higher during the second trial. The peak-\(v\) for lateral bending is even 8% higher during the second trial. On the other hand, this tendency was not observed in the peak-\(v\) for rotation (peak-\(v\)-R), which shows moderate reliability in both intra and inter rater groups.

A post hoc analysis of Bland-Altman plots was used to try to explain the differences between intra and inter rater reliability. These plots showed us the presence of a certain degree of heteroscedasticity in the peak-\(v\) for flexion-extension and lateral bending, which might have resulted in an underestimation of the reliability using the \(\kappa\).

The limited reliability of the peak-\(v\) might also be due to the rather low measuring frequency (20 Hz), which may have resulted in more erratic velocity values. Using the average-\(v\) instead of the peak-\(v\) may result in more realistic \(v\)-values.

The limited reliability of the peak-\(v\), corresponds to the low discriminant validity results shown in the prior study of Sjölander et al.\(^{42}\).

As the peak-\(v\) shows limited reliability, further investigation of these values, taking into account the limitations of our and prior studies, is needed before using this outcome measure. Replacing the peak-\(v\) by the average-\(v\) should be considered, since this average-\(v\) has shown good validity results in a study of Öhberg et al.\(^{75}\).

Apart from the average-\(v\), it might also be interesting to process the velocity and acceleration data using velocity-angular and acceleration-angular displacement plots. Further investigation of this technique is however necessary.

The \(Cj\) shows a very weak to weak inter rater reliability (\(\kappa\)-\(w\): 0.00 to 0.31) and weak to good intra rater reliability (\(\kappa\)-\(w\): 0.27 to 0.69). The \(Cj\) correlates with the \(t\) and \(v\), as the \(v\) is a parameter which largely affects the size of the \(Cj\).

As the movement is registered at 20 Hz, each second, 20 frames are captured by the measuring device. To calculate the \(Cj\), the size and direction of the deviation from the ideal smooth movement is calculated for each of these frames. The final \(Cj\)-value is calculated by summing the calculated values for each captured frame.

Therefore the velocity by which a subject performs ten repetitions of a certain movement will strongly influence the size of the \(Cj\), as slower movements result in more captured frames.

This theory explains the lower \(Cj\)- values in the inter rater group during the second measuring moment, as the subjects tended to move faster the second time. In the intra rater group, the tendency to move faster during the second measuring
moment was less pronounced. Consequently, in the intra rater group, the Cj tends to have better reliability results.

Bland-Altman plots showed us the presence of a certain degree of heteroscedasticity in the Cj-values, especially in the intra-rater group, which might have resulted in an underestimation of the reliability using the $\kappa_w$.

In the validity study of Sjölander et al., differences in Cj-values could be found between patients with neck complaints and asymptomatic controls.

Due to the contradictory reliability and validity results, this parameter needs further investigation before generalized use can be recommended.

The outcome parameters can also be used in clinical practice. A laser pointer can be attached to the patient’s forehead by means of a head band. Consequently, the patient is asked to follow a straight line on the wall with the light projected by the laser pointer by rotating his head. Since var-t and ROM are the most reliable parameters, the therapist should primarily focus on the consistency of the time needed to bring the laser light from the left to the right and on the distance as a measure for the ROM.

As t and ROM have proven to be reliable parameters, the use of these parameters to calculate the average velocity and acceleration of a subject’s movements is to be considered. It might also be considered to pay attention to the t and ROM in evaluating active movements in situations where no 3D movement analysis is possible.

Regarding the calculation of the outcome parameters in three cardinal planes, the results show that the var-t and ROM are most suitable for use in further research (var-t: $\kappa_w$: 0.47-0.96 and ROM: ICC: 0.43-0.95).

Further research is necessary to investigate the discriminant validity of the t and var-t values as well as the validity and reliability of the average velocity and acceleration values. Further research is also needed to investigate the number of repetitions that is minimally needed to gain good reliability.

### 2.6 Conclusion

The inter and intra rater reliability of the CLMT shows negligible to excellent reliability results, depending on the used outcome measure.

Based on the results of our study, the time (t and var-t) and ROM appear to be the most reliable outcome measures. However it must be noted that the discriminant validity of the time parameters has not yet been investigated.
3 A CONTINUOUS LINEAR MOVEMENT TEST: MEASURING PROTOCOL USING VICON® TECHNOLOGY.

3.1 INTRODUCTION

Cervical sensorimotor control (cSMC) is the system providing functional stability of the cervical spine. This system comprises the afferent information from the cervical structures, visual and vestibular system, together with the efferent information from the central nervous system and the central integration and processing.

CSMC can be measured using several parameters. The position sense is the best known parameter, but since sensorimotor control also includes the feedback and feed forward mechanisms during the entire movement trajectory, the content validity of this test can be questioned. To quantify altered sensorimotor functions during movements, several kinematic parameters are used. In relation to cervical spine disorders, reduced range of motion (ROM), altered activation patterns of cervical muscles, reduced maximal velocity, and movement smoothness are registered during cervical movements.

Based on a systematic review (chapter 1), The Fly™ was suggested as a promising technique for measuring cSMC as both test-retest reliability and discriminant validity were good. Using The Fly™, the subject is positioned in front of a computer screen with a tracking sensor placed on the head. During the procedure the subject is asked to follow a moving object on the screen by moving his / her head. In a pilot study we detected however, that the device accompanying The Fly™ software (InterSense InertiaCube™) was not reliable and the measuring errors too large for using the setup in scientific research. In particular the accumulating measuring errors, which occurred after continuous use of the device for a few hours, resulted in very low test-retest reliability figures. The measuring errors were acceptable during the first test, but when testing several subjects consecutively, the measuring errors increased dramatically, resulting in unrealistic numbers.

Therefore, an alternative needed to be sought. Since a continuous linear movement test (CLMT), like The Fly™, measures kinematic parameters during the entire movement to objectify cSMC, we decided to use this test. In contrast to The Fly™, the CLMT uses a simple movement (s.a. left-right rotation) where The Fly™ uses complex and unpredictable movements and where The Fly™ requires visual input, the CLMT is performed with the eyes closed.

The CLMT monitors the following parameters during a constant movement (e.g. left-right rotation): mean cycle time, variation in cycle time, ROM, velocity,
acceleration and jerk index. The Jerk index is the outcome measure for the smoothness of the movement. The reliability\textsuperscript{90} and validity\textsuperscript{42} of the CLMT has been investigated and shows promising results.

Several types of 3D measuring devices can be used to capture kinematic parameters during movement. Sjolander et al.\textsuperscript{42} used an electromagnetic tracking system (FASTRAK\textsuperscript{™}, Polhemus Inc, USA) to investigate the discriminant validity of the CLMT for differentiating between patients with neck complaints and asymptomatic controls. A transmitter generates an electromagnetic field, in which the position of the motion sensors can be determined at a rate of 120 Hz. Based on the properties of this field and the magnetic field of the earth, the sensors can determine where they are and what their rotation is. This system has the advantage that no free line is necessary between the transmitter and sensors, but the accuracy is negatively affected by sources of interference, such as metal objects or other equipment that generates an electromagnetic field.

Our group used an ultrasound based tracking device (ZEBRIS\textsuperscript{™} CMS 20, Medizintechnik GmbH, Tubingen, Germany) (figure 3.1) to investigate the test-retest reliability of the CLMT. The ZEBRIS\textsuperscript{™} uses ultrasound signals, produced by two triplets of markers and collected by one microphone, to determine the location and degree of rotation of the markers. This system is immune to interference from equipment or metal objects, but ultrasound systems do require a free line between the markers and microphone. Another disadvantage of the system we used was the fixation of the trunk triplet that tends to move relative to the subject’s skin, especially during flexion and extension movements of the cervical spine.

Figure 3.1: Measuring setup ZEBRIS\textsuperscript{™} headset and back reference
Therefore, we decided to use a third, passive optical motion capture system, a VICON® motion capture device in our latter research. This system is immune to interference from equipment or metal objects and the free line of sight needed, is less problematic than in the ultrasound based system, because 8 cameras are used.

3.2 Device

VICON® is used to capture the kinematic parameters of the CLMT in this protocol. This passive optical system uses the reflection of near infrared light on applied markers to perform a 3D movement analysis at a frequency of 100 Hz (100 frames/second). Our institution, the M²OCEAN laboratory of the University of Antwerp, uses a setup with 8 cameras. The mean absolute error of this measuring device in dynamic conditions is 0.48° (SD 0.05°).

In total, the CLMT requires 9 passive VICON® markers. The first 5 markers are mounted on a helmet that is placed on the subject’s head and the remaining 4 markers are mounted on a rhombic plate that is attached to the sternum, just below the jugular notch (Figure 3.2).

*Figure 3.2: Measuring setup Vicon®-markers*
3.3 Measuring Procedure

Before starting the actual tests, the VICON® equipment needs an active and passive calibration. Afterwards, the subject is positioned on a chair with backrest, with both hips and knees in approximately 90° flexion. The helmet and rhombic plate, carrying the markers, are then placed on the subject’s head and sternum. The subject is now asked to sit up straight without moving to perform a subject calibration.

After calibrating the VICON® system, cervical spine movements are performed in a fixed order with the eyes closed. Firstly, the subject is asked to perform a flexion-extension movement. Secondly, the left and right rotation of the cervical spine are measured and finally, the left and right lateral flexion are performed. The instructions given to the subjects are standardized, since these are written down. Subjects are asked to move smoothly, which means at a comfortable pace without causing discomfort to the subject. Regarding the ROM, the instruction is given to move as far as possible without causing any discomfort. During the CLMT, subjects perform three series of 10 repetitions of each movement.

3.4 Data Analysis

The captured data of the VICON® markers are first reconstructed and labeled using Nexus® software. Afterwards, a BodyBuilder® model is used to calculate angle positions for each captured frame. These data are then processed, using a custom made MATLAB® code (version R2014a, MathWorks Inc., USA).

The data are processed separately for each movement series. This results in six manageable categories of outcome measures per movement series (i.e. flexion-extension): mean cycle time, variation in cycle time, range of motion, velocity, acceleration and Jerk index. The outcome measures are defined as follows:

The ‘mean cycle time’ is the average time needed to perform one movement cycle (e.g. maximal flexion to maximal extension). The ‘range of motion’ is the average range of motion per movement direction. The ‘variation in cycle time’ is the average ‘cycle time’-deviation of the different movement cycles. The ‘velocity’ is the average velocity and the ‘acceleration’ the average acceleration during the movement trial. The ‘Jerk Index’ is a measurement of the smoothness of the movement which is calculated using the algorithms described by Kitazawa et al.\textsuperscript{84}. These algorithms calculate the sum of the different vectors of Jerk values over the movement (the size and direction of the deviation from the average movement trajectory), with respect to the average movement time and distance. The ‘Jerk Index’ was calculated as:
\[ C_j = \sqrt{\frac{1}{2} \sum_{i=1}^{n} J_i^2 \frac{t^5}{D}} \]

where the J is the vector of the jerk values over the movement (calculated from the kinematic data, as described above), n the number of samples of the vector, i the vector index, t the movement time and D the movement distance\(^{42,90}\).

This protocol was used for the cross-sectional study, comparing patients with tinnitus to asymptomatic controls, in chapter 6 and for the randomized controlled trial, on the effect of cervical physical therapy on tinnitus complaints, in chapter 7 and 8.
Part II:
Tinnitus and the cervical spine

In this part we elaborate on the influence of cervical spine dysfunctions on tinnitus complaints. It consists of five chapters: one concerning the presence of cervical spine dysfunctions in a population of patients with chronic subjective tinnitus, a second on the discriminant validity of a set of clinical cervical spine tests for diagnosing CST, a third concerning the presence of changes in cSMC in patients with CST, a fourth describing the study protocol of the RCT we used in the fifth chapter to investigate the effect of cervical physical therapy on tinnitus complaints in patients with CST and to identify prognostic indicators for positive therapy effect.
**PUBLICATIONS**

Chapter 4 has been published in:


Chapter 5 has been published in:

Michiels, S., Van de Heyning, P., Truijen, S., De Hertogh, W., *Diagnostic value of clinical cervical spine tests in patients with cervicogenic somatic tinnitus*, Physical Therapy 2015 Apr; 95

A publication on the results presented in chapter 6 is in preparation:


Chapter 7 has been published in:


Chapter 8 has been submitted and is currently under review:

Michiels S., Van de Heyning P., Truijen S., Hallemans A., De Hertogh W., *Cervical Physical Therapy in Patients with Cervicogenic Somatic Tinnitus: A Randomized Controlled Trial Assessing Prognostic Indicators*
4 CERVICAL SPINE DYSFUNCTION IN PATIENTS WITH TINNITUS

4.1 ABSTRACT

Objective: To assess, characterize and quantify cervical spine dysfunction in patients with cervicogenic somatic tinnitus (CST) compared to patients suffering from other forms of chronic subjective non-pulsatile tinnitus.

Study design: cross-sectional study.

Setting: Tertiary referral centre.

Patients: Consecutive adult patients suffering from chronic subjective non-pulsatile tinnitus were included. Exclusion criteria: Meniere’s disease, middle ear pathology, intra cranial pathology, cervical spine surgery, whiplash trauma, temporomandibular dysfunction.

Intervention: Assessment comprises medical history, ENT examination with micro-otoscopy, audiometry, tinnitus assessment, temporomandibular and cervical spine investigation and brain MRI. Patients were classified in CST and non-CST population. Cervical spine dysfunction was investigated using the Neck Bournemouth Questionnaire (NBQ) and clinical tests of the cervical spine, containing: range of motion (ROM), pain provocation (adapted Spurling test, AST) and muscle tests (tenderness via trigger points, strength and endurance of deep neck flexors).

Main outcome measures: Between group analysis were performed. The prevalence of cervical spine dysfunction was described for the total group and for CST and non-CST groups.

Results: In total, 87 patients were included, of which 37 (43%) were diagnosed with CST. In comparison with the non-CST group, the CST group demonstrated a significantly higher prevalence of cervical spine dysfunction. In the CST group, 68% had a positive manual rotation test, 47% a positive AST, 49% a positive score on both and 81% had positive trigger points. In the non-CST group these percentages were 36, 18, 10 and 50% respectively. Furthermore, 79% of the CST group had a positive NBQ versus 40% in the non-CST group. Significant differences between the both groups were found for all the above mentioned variables (all p<0.005).

Conclusions: Although a higher prevalence of neck dysfunction was found in the CST group, neck dysfunction is often present in non-CST patients.
4.2 INTRODUCTION

Tinnitus is the phantom sensation of sound, in the absence of overt acoustic stimulation\(^1\). It occurs in 10 to 15% of the adult population\(^1\).

Tinnitus can be related to many different aetiologies such as hearing loss or a noise trauma. Within the group of patients suffering from chronic subjective non-pulsatile tinnitus, a subgroup can be defined where the tinnitus is related to the somatosensory system of the cervical spine\(^1\). This type of tinnitus is named cervicogenic somatic tinnitus (CST).

The existence of CST is supported by several animal studies, which have found connections between the cervical somatosensory system and the cochlear nuclei (CN)\(^{17,18}\). Cervical somatosensory information is conveyed by afferent fibres, the cell bodies of which are located in the dorsal root ganglia or the trigeminal ganglion, to the brain. These afferent fibres also project to the auditory system. This makes the somatosensory system able to influence the auditory system by altering the spontaneous rates (i.e. not driven by auditory stimuli) or the synchrony of firing among neurons in the CN, inferior colliculus or auditory cortex. In this way, the somatosensory system is able to alter the intensity and the character of the tinnitus\(^19\).

Although animal studies have demonstrated the existence of neural connections that can cause CST, the diagnosis is challenging and is mainly based on medical history.

The diagnosis of CST is based on the diagnostic criteria for somatic tinnitus\(^22\). The primarily used diagnostic criterion for CST is the temporal coincidence of onset or increase of both neck pain and tinnitus.

CST is linked to myofascial dysfunction in the head and neck region comprising cervical dysfunction. To date however, it is unclear which structures of the cervical spine are affected in patients with CST and no information is available on the presence of cervical spine dysfunction in non-CST patients.

Therefore, the aim of this study is to assess, characterize and quantify cervical spine dysfunction in patients diagnosed with CST in comparison with patients suffering from other forms of chronic subjective non-pulsatile tinnitus.
4.3 MATERIALS AND METHODS

4.3.1 Patients

A prospective cohort of chronic subjective tinnitus patients was performed in the Antwerp University Hospital (UZA). During a six months period, all tinnitus patients who presented themselves at the tinnitus clinic were asked to participate in the study.

Patients were included when suffering from chronic subjective tinnitus (existing for > 3 months), regardless of the presence of neck complaints. Patients were excluded when suffering from Meniere’s disease, middle ear pathology, intra cranial pathology, cervical spine surgery, whiplash associated disorders and temporomandibular dysfunction.

4.3.2 Diagnosis

All patients were investigated by means of medical history, ENT examination with micro-otoscopy, audiometry, tinnitus assessment (comprising tinnitus loudness using VAS and tinnitus annoyance using Tinnitus Questionnaire TQ)\textsuperscript{c}, temporomandibular and cervical spine investigation and brain MRI to obtain a tinnitus workup. The diagnosis of CST is made when the predominant feature is the temporal coincidence of onset or increase of both neck pain and tinnitus\textsuperscript{22}.

4.3.3 Physical cervical spine examination

The examination of the cervical spine was performed by an experienced master in physical therapy and manual therapy (MS). At all times, the physical therapist as well as the patients remained blinded to the ENT diagnosis. The physical examination consisted of a set of clinical tests of the cervical spine and the Neck Bournemouth Questionnaire (NBQ).

First, the passive rotation movement of the cervical spine was investigated using the C0-C2 and C2-C7 rotation test\textsuperscript{92}. Using this test, the quality of the passive rotation movement is rated based on three parameters: range of motion (hyper-/normal/hypomobility), end feel (hard/normal/soft/empty) and pain provocation (visual analogue scale VAS). The test was found positive, when for at least one movement, two out of three parameters are aberrant.

Second, the adapted Spurling test (AST), a provocation test using a combination of cervical extension, lateral flexion and rotation, was used. This test was positive.

\textsuperscript{c} More detailed information is presented in appendix 3
when at least on one level, pain was provoked with a VAS > 2 cm. Both tests have shown high sensitivity (77.8) and specificity (77.3) in discriminating patients with neck dysfunction from asymptomatic controls.

Figure 4.1: Adapted Spurling test

Third, the strength and endurance of the deep neck flexor muscles were measured as described by Jull et al.\textsuperscript{93}

Finally, the tenderness of sixteen myofascial trigger points was tested by applying manual pressure. A trigger point was identified as positive when the patient scored more than 2 cm on a VAS for pain. The test was positive when at least one trigger point was positive. The locations of the trigger points were determined according to the findings of Teachey et al.\textsuperscript{3.d}

In addition to these clinical tests, the NBQ was used to assess self-reported pain intensity, limitations in activities of daily living, depression and self-control. The NBQ has shown high sensitivity (83,3) and specificity (90,9) in identifying patients with neck disorders\textsuperscript{92}.

All the above mentioned tests were scored dichotomously as negative or positive, based on the thresholds mentioned above.

4.3.4 Analysis

Two subgroups were created to verify the differences between the CST and non-CST patients.

Patient characteristics were described using descriptive statistics and frequencies from the total population and both subgroups. Differences between both

\textsuperscript{d} The location of the trigger points is presented in figure 5.2 and 5.3.
subgroups were analyzed using Fisher Exact tests in case of dichotomous variables and via independent samples t-tests for continuous variables. The significance level was set at $p < 0.05$.

All analyses were performed using IBM SPSS Statistics for Windows (version 22.0, IBM Corporation).

### 4.4 Results

In total, 87 adult tinnitus patients, with a mean age of 50 years old (SD 14), were included in the study. No significant differences in gender ($p=0.729$) or age distribution ($p=0.07$) were found between the CST and non-CST group. However, a tendency of the CST patients to be slightly older (53 years (SD 13)) than the non-CST patients (47 years (SD 15), can be noted. The demographic features are shown in table 4.1.

<table>
<thead>
<tr>
<th>Number of subjects</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (years)</td>
</tr>
<tr>
<td>Males</td>
<td>50.29</td>
</tr>
<tr>
<td>Females</td>
<td>49.21</td>
</tr>
<tr>
<td>Total</td>
<td>49.70</td>
</tr>
</tbody>
</table>

*Table 4.1: Demographic features*

SD: Standard Deviation

In our population, 43% was diagnosed with CST and 46% of the patients complained of a certain degree of neck pain. The average tinnitus loudness was 51 mm (SD 25 mm) on a VAS, the average TQ-score was 41 points (SD 14) and the average score on the hyperacusis questionnaire was 18 points (SD 8). Tinnitus was unilateral in 36%, bilateral in 48% and central in 3% of the patients. Tinnitus had a high frequency (> 2000 Hz) in 86%, hyperacusis was reported in 56%, difficulties concentrating in 78% and 60% complained of sleeping problems.
The results of the different subgroups are shown in tables 4.2 and 4.3.

<table>
<thead>
<tr>
<th>Test</th>
<th>Total population</th>
<th>CST</th>
<th>Non-CST</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAS- loudness</td>
<td>51 (25)</td>
<td>51 (25)</td>
<td>50 (25)</td>
<td>0.815</td>
</tr>
<tr>
<td>Tinnitus Questionnaire</td>
<td>41 (17)</td>
<td>44 (19)</td>
<td>38 (16)</td>
<td>0.122</td>
</tr>
<tr>
<td>Hyperacusis</td>
<td>18 (8)</td>
<td>19 (8)</td>
<td>17 (8)</td>
<td>0.208</td>
</tr>
<tr>
<td>PTA (R)</td>
<td>15 (11)</td>
<td>15 (10)</td>
<td>15 (12)</td>
<td>0.995</td>
</tr>
<tr>
<td>PTA (L)</td>
<td>18 (18)</td>
<td>16 (10)</td>
<td>19 (22)</td>
<td>0.439</td>
</tr>
</tbody>
</table>

Table 4.2: Tinnitus characteristics (average and (SD))

PTA: pure tone average; R: right ear; L: left ear

<table>
<thead>
<tr>
<th>Test</th>
<th>% from total</th>
<th>% from CST</th>
<th>% from non-CST</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulation</td>
<td>13</td>
<td>19</td>
<td>8</td>
<td>0.130</td>
</tr>
<tr>
<td>NBQ &gt; 14 points</td>
<td>56</td>
<td>79</td>
<td>40</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Manual rotation</td>
<td>49</td>
<td>68</td>
<td>36</td>
<td>0.004*</td>
</tr>
<tr>
<td>AST</td>
<td>30</td>
<td>47</td>
<td>18</td>
<td>0.004*</td>
</tr>
<tr>
<td>Manual rotation + AST</td>
<td>26</td>
<td>49</td>
<td>10</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Strenght DNF</td>
<td>32</td>
<td>39</td>
<td>27</td>
<td>0.252</td>
</tr>
<tr>
<td>Endurance DNF</td>
<td>67</td>
<td>61</td>
<td>71</td>
<td>0.350</td>
</tr>
<tr>
<td>Trigger points</td>
<td>63</td>
<td>81</td>
<td>50</td>
<td>0.003*</td>
</tr>
<tr>
<td>Hyperacusis</td>
<td>56</td>
<td>53</td>
<td>59</td>
<td>0.678</td>
</tr>
<tr>
<td>Concentration difficulties*</td>
<td>78</td>
<td>75</td>
<td>80</td>
<td>0.858</td>
</tr>
<tr>
<td>Sleeping problemsf</td>
<td>60</td>
<td>65</td>
<td>56</td>
<td>0.452</td>
</tr>
<tr>
<td>Location</td>
<td></td>
<td></td>
<td></td>
<td>0.388</td>
</tr>
<tr>
<td>Unilateral</td>
<td>36</td>
<td>38</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>Bilateral</td>
<td>48</td>
<td>54</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>Central</td>
<td>3</td>
<td>0</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Frequency (High)</td>
<td>86</td>
<td>88</td>
<td>84</td>
<td>0.658</td>
</tr>
</tbody>
</table>

Table 4.3: Percentage of appearance of cervical spine dysfunctions and tinnitus characteristics

* p < 0.05

Specifically in the CST group, 38% had a unilateral tinnitus, 54% a bilateral and non a central tinnitus. 88% had a high frequency tinnitus, 53% complained of hyperacusis, 75% of difficulties concentrating and 65% of sleeping difficulties. None of these parameters differed significantly from the non-CST group. Additionally, no

* Asked for during medical hystory taking
f Asked for during medical hystory taking
significant differences were found in VAS, TQ, hyperacusis and pure tone average (PTA) between the CST and non-CST groups.

Regarding the physical examination in the CST group, 79% had a positive score on the NBQ and 19% was able to modulate their tinnitus during one of the tests. 68% had a positive manual rotation test, 47% a positive AST and 49% had a positive score on both. The strength and endurance of the deep neck flexors showed abnormalities in 39% and 61%, respectively. Finally, in 81% one or more trigger points was sensitive on manual pressure.

Significant differences between the CST and non-CST groups were found for the NBQ (p<0.001), manual rotation (p=0.004), AST (p=0.004), manual rotation combined with AST (p<0.001) and the presence of sensitive trigger points (0.003).

4.5 DISCUSSION

The aim of this study was to assess, characterize and quantify cervical spine dysfunction in patients diagnosed with CST, and to compare these with patients suffering from other forms of chronic subjective non-pulsatile tinnitus. We hypothesized a higher prevalence of cervical spine dysfunction in patients with CST.

In this study, the diagnosis of CST was made when the predominant feature was the temporal coincidence of onset or increase of both neck pain and tinnitus. This diagnosis is more limited than the original criteria for somatic tinnitus by Sanchez et al.22, where the diagnosis is made when at least one of the following occurrences prior to the onset of tinnitus is present: (1) evident history of head or neck trauma, (2) tinnitus association with some manipulation of the teeth, jaw or cervical spine, (3) recurrent pain episodes in head, neck or shoulder girdle, (4) temporal coincidence of appearance or increase of both pain and tinnitus, (5) increase of tinnitus during inadequate postures during rest, walking, working or sleeping and (6) intense bruxism periods during the day or night.

In our study we decided to exclude patients suffering from whiplash trauma because of the complexity of the pathology and the heterogeneity of the clinical presentation. We also excluded patients suffering from temporomandibular disorders, as the population of interest in this study was the CST population.

For the abovementioned reasons, criteria 1, 6 and part of 2 were not used for the diagnosis of CST in this study. As we wanted to minimize the chance of including patients with tinnitus and cervical spine disorders, but without any relation between the tinnitus and the neck complaints in the CST group, we decided to primarily use criterion 4 for the diagnosis of CST.
In our study, the diagnosis of CST was made in 43% of the patients. This number corresponds with the percentages reported by Abel et al. They found that 36.7% complained of neck, jaw or facial pain. This was recently also confirmed by Ostermann et al.94 and Fabijanska et al.95. This implies that our patient sample was representative for the entire population.

No significant differences were found in tinnitus loudness, TQ, hyperacusis and hearing impairment between the CST and non-CST group. These results correspond to the findings of Vielsmeier et al.96 in patients with or without temporomandibular joint related tinnitus. Additionally, Schecklmann et al.97 could not find any differences in tinnitus characteristics in tinnitus patients with or without hyperacusis. These results favor an non-specific reaction pattern, regardless the tinnitus subtype.

Cervical spine complaints (positive NBQ) were present in 56% of all included patients. Significantly more patients in the CST group (79%) had a positive score on the NBQ, although still 40% in the non-CST group had cervical spine complaints. The possibility must be noted that in our non-CST population some of the patients with significant neck dysfunction actually are CST patients that did not notice or comment on a coincidental onset of neck pain and tinnitus symptoms. This indicates that the presence of cervical spine complaints can be a first indicator for the CST diagnosis, but additional tests are necessary as a substantial part of the non-CST population also complains of cervical spine problems.

In the clinical examination of the cervical spine, significantly higher prevalences were found in the CST group for the manual rotation, AST, the combination of both manual rotation and AST and the presence of trigger points. No significant differences between both groups were found in strength and endurance of DNF. Very little systematic research has previously been done on the clinical examination of the cervical spine in patients with tinnitus. A rotation deficit was equally found by Reisshauer et al.98. They also confirmed the presence of sensitive trigger points in the M sternocleidomastoideus, M trapezius and M levator scapulae in CST patients.

Regarding the treatment of somatic tinnitus, case studies 27,99 have suggested manipulations or mobilizations of the cervical spine. As, in our population, limited ROM of the cervical spine was present in only 68% of the CST population, a thorough examination of the cervical joints is suggested before using manipulations/mobilizations in tinnitus patients. Furthermore, the strength and endurance of the DNF was affected and sensitive trigger points were present in our CST population. These findings suggest the use of a multimodal physical therapy treatment of the cervical spine, combining mobilizations/manipulations with
mobilizing and stabilizing exercises and muscle relaxation. A similar multimodal physical therapy treatment has already proven to be effective in treating patients suffering from cervical spine problems\textsuperscript{45,46,47}.

One of the main characteristics of somatic tinnitus is the ability of the patient to modulate the tinnitus by for example strong muscle contractions. In our sample, only 13\% reported modulation of the tinnitus during one of the applied tests. This is significantly lower than the 83.3\% reported by Abel et al.\textsuperscript{16}. This can be due to several reasons. First, we examined exclusively the cervical spine, whereas Abel et al.\textsuperscript{16} also investigated the jaw and shoulder girdle. Second, in the study of Abel et al.\textsuperscript{16} a sound perception could be elicited during the clinical examination in 65\% of the asymptomatic control group. In our study the tinnitus was equally modifiable in both the CST and non-CST group. This indicates that modulation of the tinnitus is not unique for the CST population, but can also occur in other types of chronic subjective non-pulsatile tinnitus.

Although cervical spine dysfunction is significantly more present in CST patients, similar dysfunction was also found in a minority of the non-CST patients. Therefore the diagnostic potential of the applied clinical tests needs to be evaluated. Additionally, RCT’s evaluating the effect of cervical spine treatment in tinnitus patients are needed to identify the group of tinnitus patients that benefit from the cervical spine treatment. These results can also be used to provide more detailed diagnostic criteria for CST in resemblance with the diagnostic criteria for cervicogenic headache\textsuperscript{100}.

Langguth et al.\textsuperscript{101} already stated that the examination of the cervical spine is essential in the investigation of tinnitus patients. In addition to this statement, the authors advocate to include cervical spine tests and the NBQ in the diagnostic work-up of chronic subjective tinnitus patients.

4.6 CONCLUSION

Cervical spine dysfunction is highly prevalent in a chronic subjective non-pulsatile tinnitus population. The CST group was mainly characterized by: a positive score on the NBQ, a positive manual rotation and AST test and the presence of sensitive trigger points. No differences in ability to modulate the tinnitus were found between both groups. Although a high prevalence of cervical spine dysfunction was found in the CST group, cervical spine dysfunction can also be present in non-CST patients.
5 DIAGNOSTIC VALUE OF CERVICAL SPINE TESTS IN CERVICOGENIC SOMATIC TINNITUS

5.1 ABSTRACT

Background: Tinnitus can be related to many different aetiologies such as hearing loss or a noise trauma, but it can also be related to the somatosensory system of the cervical spine. The diagnosis of cervicogenic somatic tinnitus (CST) is made when the predominant feature is the temporal coincidence of appearance or increase of both neck pain and tinnitus.

Objective: To assess the diagnostic value of clinical cervical spine tests in CST.

Study design: cross-sectional study

Setting: Tertiary referral centre.

Patients: Consecutive adult patients suffering from chronic subjective non-pulsatile tinnitus were included. Exclusion criteria: vertigo, Meniere’s disease, middle ear pathology, intra cranial pathology, cervical spine surgery, whiplash trauma, temporomandibular dysfunction.

Measurements: Full ENT examination to classify patients in CST and non-CST population. Physical therapy examination included completion of the Neck Bournemouth Questionnaire (NBQ) and clinical cervical spine tests: manual rotation test, adapted Spurling test (AST), trigger points tests and strength and endurance of deep neck flexors.

Results: In total 87 tinnitus patients were included of which 37 (43%) were diagnosed with CST. CST diagnosis becomes less likely when NBQ scores <14 points (sensitivity 80%, likelihood ratio (LR):0.3, post-test probability (PTP):19%). Absence of trigger points corresponds with a LR of 0.3, a sensitivity of 82% and a PTP of 22%. A positive manual rotation and AST indicate a higher probability of CST (LR:5, specificity of 90%, PTP:78%)).

Conclusions: Clinical cervical spine tests can support the diagnostic process of CST. An NBQ score <14 points and the absence of trigger points can help to exclude CST. In contrast, a positive manual rotation and AST can help to include CST. We advise to include these test in a multidisciplinary assessment of patients with suspected CST.
5.2 INTRODUCTION

Tinnitus is the phantom sensation of sound, in the absence of overt acoustic stimulation. It occurs in 10 to 15% of the adult population. Tinnitus can be related to many different aetiologies such as hearing loss or a noise trauma. Within the group of patients suffering from chronic subjective non-pulsatile tinnitus, a subgroup can be defined where the tinnitus is related to the somatosensory system of the cervical spine. This type of tinnitus is named cervicogenic somatic tinnitus (CST).

The existence of CST is supported by several animal studies, which have found connections between the dorsal column of the spinal cord and the cochlear nuclei. The axons of the dorsal column originate from the C1-C8 dorsal roots of the spinal cord. Stimulation of the C2 dorsal root ganglion in particular generates responses from cells in the cochlear nuclei. Additionally, Matsushima et al. demonstrated that tinnitus improved in 52% of the patients after an occipital nerve block. Other recent studies in humans, found that in some patients, tinnitus could be evoked or modulated by input from the somatic system, for instance: by forceful muscle contractions of the head, neck and limbs and pressure on myofascial trigger points. These findings might explain the ability of some tinnitus patients to modulate their tinnitus by certain head or neck movements. For example: some patients indicate that their tinnitus worsens when performing a combined cervical spine extension and rotation.

As tinnitus often co-occurs with neck complaints, patients regularly seek help through cervical spine treatment. In these cases, physical therapy treatment can be considered as a treatment option, as suggested in several case studies. In previous research, a group of CST patients was characterized by: a positive score on the Neck Bournemouth Questionnaire (NBQ), a positive manual rotation and adapted Spurling test (AST) and the presence of sensitive trigger points. To date however, little information is available on the diagnostic value of these tests and the causal relation with the tinnitus.

Although animal studies have demonstrated the existence of neural connections that can cause CST, the diagnosis is challenging. The diagnosis of CST is based on the following diagnostic criteria: the diagnosis is made when at least one of the following occurrences prior to the onset of tinnitus is present: (1) evident history of head or neck trauma, (2) tinnitus association with movement of or pressure on the cervical spine, (3) recurrent pain episodes in head, neck or shoulder girdle, (4) temporal coincidence of appearance or increase of both pain and tinnitus and (5) increase of tinnitus during inadequate postures during rest, walking, working or
sleeping. The most important diagnostic criterion is the temporal coincidence of onset or increase of both neck pain and tinnitus. As these diagnostic criteria are based on medical history, the accuracy of the diagnosis depends partly on the memory of the patient. Therefore, all other causes of tinnitus need to be ruled out before CST can be diagnosed, which is very time consuming and expensive. A set of clinical cervical spine tests that can be used in the CST diagnosis next to the diagnostic criteria would thus be very useful.

Therefore, the aim of this study is to determine the diagnostic value of a set of clinical cervical spine tests in diagnosing CST.

5.3 MATERIALS AND METHODS

5.3.1 Patients

A prospective cohort study containing chronic subjective tinnitus patients was performed in the Antwerp University Hospital (UZA). During a six months period, all consecutive tinnitus patients who presented themselves at the tinnitus clinic were asked to participate in the study. Ethical approval for our study was obtained from the local ethics comity.

Patients were included when suffering from chronic subjective tinnitus (existing for >3 months), regardless of the presence of neck complaints. Patients were excluded when suffering from vertigo, Meniere’s disease, middle ear pathology and intracranial pathology because these conditions result in tinnitus subtypes that are easily diagnosed. Therefore these tinnitus subtypes can easily be distinguished from CST. Patients were also excluded after cervical spine surgery, as some of the cervical spine tests in the examination might be contra-indicated in these patients. Patients suffering from whiplash associated disorders were also excluded because of the heterogeneity of the cervical spine complaints and the risk of influence due to central sensitisation in these patients. Finally, patients with a temporomandibular dysfunction were excluded, because these patients compose a different somatic tinnitus subtype that was beyond the interests of this study.

5.3.2 Diagnosis

All patients were investigated by means of medical history, complete ENT examination with microscopic otoscopy, audiometry (comprising standard hearing tests and tests to objectify the tinnitus loudness, pitch and unilateral, bilateral or central character of the tinnitus), tinnitus assessment (comprising tinnitus loudness using VAS and tinnitus annoyance using Tinnitus Questionnaire), temporomandibular and cervical spine investigation and brain MRI to obtain a
tinnitus workup. Based on this complete ENT and audiologic examination and the brain MRI, the ENT doctor diagnoses the tinnitus subtype. The diagnosis of CST is made when the predominant feature is the temporal coincidence of onset or increase of both neck pain and tinnitus.

5.3.3 Physical examination

The examination of the cervical spine was performed by a master in physical therapy (MS) with an additional master’s degree in manual therapy and with 9 years of experience in musculoskeletal assessment and treatment. At all times, the physical therapist as well as the patients remained blinded to the ENT diagnosis. The physical examination consisted of a set of clinical tests of the cervical spine and the Neck Bournemouth Questionnaire (NBQ).

First, the left and right passive rotation movement of the cervical spine was investigated using the manual rotation test. Using this test, the quality of the passive rotation movement, on C0-C2 and C2-C7 levels, is rated based on three parameters: range of motion (hyper-/normal/hypomobility), end feel (hard/normal/soft/empty) and pain provocation (visual analogue scale VAS > 2 cm). The test was found positive, when for at least one movement, two out of three parameters are aberrant. Normal mobility at the C0-C2 segments was set at an estimated 45° rotation for subjects under 40 years of age, and an estimated 35° rotation for those older than 40 years. At the C2-C7 segments, normal rotation was set at an estimated 25–30° rotation.

Second, the adapted Spurling test (AST), a segmental provocation test using a combination of cervical extension, lateral flexion and rotation, was used. This test was positive when at least on one level, pain was provoked with a VAS > 2 cm. Both tests have shown high sensitivity (77.8) and specificity (77.3) in discriminating patients with neck dysfunction from asymptomatic controls.

Figure 5.1: Adapted Spurling test
Third, the strength and endurance of the deep neck flexor muscles (DNF) were measured using the craniocervical flexion test (CCFT)\textsuperscript{93}. The CCFT is performed with the patient in supine crook lying with the neck in a neutral position such that the line of the face is horizontal and a line bisecting the neck longitudinally is horizontal to the testing surface. An uninflated pressure sensor is placed behind the neck so that it abuts the occiput and is inflated to a baseline pressure of 20 mm Hg. The craniocervical flexion movement is performed gently and slowly as a head nodding action (as if saying “yes”). The CCFT tests the activation and endurance of the deep cervical flexors in progressive inner range positions as the patient attempts to sequentially target five, 2-mm Hg progressive pressure increases from the baseline of 20 mm Hg to a maximum of 30 mm Hg as well as to maintain a isometric contraction at the progressive pressures as an endurance task \textsuperscript{93}. The strength of the DNF was scored as aberrant when the patient could not maintain the isometric contraction at all five pressures for 2-3 seconds without compensations or abnormal movement patterns. For the endurance test a minimal isometric contraction of 10 seconds at all five pressures was used as a cut-off point. This cut-off point was not determined using a receiver operating characteristic curve.

Finally, the tenderness of sixteen myofascial trigger points was tested by applying manual pressure. A trigger point was identified as positive when the patient scored more than 2 cm on a VAS for pain. The test was positive when at least one trigger point was found positive. The locations of the trigger points were determined according to the findings of Teachey et al. \textsuperscript{3} and are displayed in figure 5.2 and 5.3.

\textbf{Figure 5.2: Locations of trigger points in M. Levator scapulae (left) and M Splenius Capitis (right) (figures adjusted from Travell and Simons \textsuperscript{107})}
Figure 5.3: Locations of trigger points in Upper Trapezius (left) and M. Sternocleidomastoideus (right) (figures adjusted from Travell and Simons) 

In addition to these clinical tests, the NBQ was used to assess self-reported pain intensity, limitations in activities of daily living, depression and self-control. The NBQ has shown high sensitivity (83.3) and specificity (90.9) in identifying patients with neck disorders. The NBQ was found positive when a patient scored > 14/70.

All tests were performed in the sequence as mentioned above, starting with the manual rotation test and ending with the trigger point tests. All of the tests were scored dichotomously as negative or positive, based on the thresholds mentioned above. Additionally, the provocation of changes in tinnitus loudness was queried after each test.

5.3.4 Statistics

The data were analysed using 2x2 contingency tables. From the 2x2 contingency tables, sensitivity, specificity, likelihood ratios (LR), pre- and post-test probability, to discriminate CST from non-CST patients were calculated. The pre-test probability is calculated for each test, as due to missing data, this probability can vary slightly. The pre-test probability is the probability of the CST diagnosis without the extra information of the cervical spine tests. The post-test probability is the probability of the CST diagnosis taking into account a positive or negative result of a test.

IBM SPSS Statistics for Windows (version 22.0, IBM Corporation) was used for obtaining the contingency tables. The sensitivity, specificity, LR and pre- and post-test probability were calculated using Microsoft Excel for Windows.
5.4 RESULTS

In total, 87 adult tinnitus patients, with a mean age of 50 years old (SD 14), were included in the study between August 2012 and January 2013. No significant differences in gender (p=0.729) or age distribution (p=0.07) were found between the CST and non-CST group. However, a tendency of the CST patients to be slightly older (53 years (SD 13)) than the non-CST patients (47 years (SD 15), can be noted. The demographic features are shown in table 5.1.

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>CST</th>
<th>Non-CST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Subjects</td>
<td>87</td>
<td>37 (43%)</td>
<td>50 (57%)</td>
</tr>
<tr>
<td>% male/female</td>
<td>68/32</td>
<td>70/30</td>
<td>66/34</td>
</tr>
<tr>
<td>Age (mean (SD))</td>
<td>49.70 (14.44)</td>
<td>46.38 (15.41)</td>
<td>52.16 (13.30)</td>
</tr>
</tbody>
</table>

Table 5.1: Demographic features

SD: Standard Deviation; CST: cervicogenic somatic tinnitus

In our population, 43% was diagnosed with CST and 46% of the patients complained of a certain degree of neck pain. The average tinnitus loudness was 51mm (SD 25mm) on a VAS, the average tinnitus questionnaire score (TQ-score) was 41 out of 82 points (SD 14) and the average score on the hyperacusis questionnaire was 18 points (SD 8). Tinnitus was unilateral in 36%, bilateral in 48% and central in 3% of the patients. Tinnitus had a high frequency (> 2000Hz) in 86%, hyperacusis was reported in 56%, difficulties concentrating in 78% and 60% complained of sleeping problems. No significant differences between CST and non-CST patients were found regarding the tinnitus characteristics.

<table>
<thead>
<tr>
<th>Test</th>
<th>Total population</th>
<th>CST</th>
<th>Non-CST</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAS-loudness</td>
<td>51 (25)</td>
<td>51 (25)</td>
<td>50 (25)</td>
<td>0.815</td>
</tr>
<tr>
<td>Tinnitus Questionnaire</td>
<td>41 (17)</td>
<td>44 (19)</td>
<td>38 (16)</td>
<td>0.122</td>
</tr>
<tr>
<td>Hyperacusis</td>
<td>18 (8)</td>
<td>19 (8)</td>
<td>17 (8)</td>
<td>0.208</td>
</tr>
<tr>
<td>PTA (R)</td>
<td>15 (11)</td>
<td>15 (10)</td>
<td>15 (12)</td>
<td>0.995</td>
</tr>
<tr>
<td>PTA (L)</td>
<td>18 (18)</td>
<td>16 (10)</td>
<td>19 (22)</td>
<td>0.439</td>
</tr>
</tbody>
</table>

Table 5.2: Tinnitus characteristics (average and (SD))

PTA: pure tone average; R: right ear; L: left ear

To quantify the diagnostic value of the clinical cervical spine tests and the NBQ, sensitivity, specificity, LR and pre- and post-test probability (PTP) were calculated. An overview of the clinimetric properties of the tests can be found in table 5.3. The relevant items are mentioned below.
Table 5.3: Clinimetric properties

<table>
<thead>
<tr>
<th>Test</th>
<th>Sens</th>
<th>Spec</th>
<th>LR+</th>
<th>LR-</th>
<th>Pre-test prob.</th>
<th>Post-test prob.+</th>
<th>Post-test prob.-</th>
</tr>
</thead>
<tbody>
<tr>
<td>AST</td>
<td>48</td>
<td>84</td>
<td>3</td>
<td>0.6</td>
<td>42</td>
<td>65</td>
<td>32</td>
</tr>
<tr>
<td>Manual rotation</td>
<td>69</td>
<td>65</td>
<td>2</td>
<td>0.3</td>
<td>43</td>
<td>58</td>
<td>27</td>
</tr>
<tr>
<td>Manual rotation + AST</td>
<td>47</td>
<td>90</td>
<td>5</td>
<td>0.6</td>
<td>43</td>
<td>78</td>
<td>29</td>
</tr>
<tr>
<td>CCFT Strenght</td>
<td>38</td>
<td>74</td>
<td>1</td>
<td>0.8</td>
<td>43</td>
<td>52</td>
<td>39</td>
</tr>
<tr>
<td>CCFT Endurance</td>
<td>60</td>
<td>32</td>
<td>0.9</td>
<td>1</td>
<td>43</td>
<td>39</td>
<td>50</td>
</tr>
<tr>
<td>Trigger points</td>
<td>82</td>
<td>53</td>
<td>2</td>
<td>0.3</td>
<td>43</td>
<td>55</td>
<td>22</td>
</tr>
<tr>
<td>Provocation of tinnitus NBQ</td>
<td>16</td>
<td>90</td>
<td>2</td>
<td>1</td>
<td>43</td>
<td>64</td>
<td>40</td>
</tr>
<tr>
<td>NBQ</td>
<td>80</td>
<td>62</td>
<td>2</td>
<td>0.3</td>
<td>41</td>
<td>59</td>
<td>19</td>
</tr>
</tbody>
</table>

LR+: positive likelihood ratio; LR-: negative likelihood ratio; Sens: sensitivity; Spec: specificity; Pre-test prob: pre-test probability; Post-test prob+: positive post-test probability; Post-test prob-: negative post-test probability; NBQ: Neck Bournemouth Questionnaire; AST: Adapted Spurling test; CCFT: craniocervical flexion test

In case of a negative NBQ result (<14/70), the probability of diagnosing a patient with CST decreases from 41% to 19% (negative LR: 0.3). Moreover, the sensitivity of the NBQ for diagnosing CST was high (80%), indicating a low risk of false negative results. On the other hand, the specificity of the NBQ for diagnosing CST was only moderate (62%), indicating a high risk of false positive results.

Likewise, the absence of trigger points reduces the probability of the CST diagnosis from 43% to 22% (negative LR: 0.3). A high sensitivity (82%) was also found for this test.

A positive manual rotation test in combination with a positive AST increases the probability of diagnosing a patient with CST from 43% to 78% (positive LR: 5). In addition, the specificity of the combination of manual rotation and AST tests was high (90%), indicating a low risk of false positive results.

A positive AST, without positive manual rotation test, still increases the probability of a CST diagnosis to 65% (positive LR:3) with a specificity of 84%.

In case one of the clinical tests is able to provoke the tinnitus, the probability of a CST diagnosis increases from 43% to 64%, with a specificity of 90%.

The CCFT strength test showed an acceptable specificity of 74%, but the positive as well as the negative LR’s were too close to 1 for the test to be helpful for diagnosing
CST. The CCFT endurance test showed overall low sensitivity, specificity and LR’s and PTP’s.

5.5 DISCUSSION

The aim of this study was to assess the diagnostic value of clinical cervical spine tests in CST.

We found that several tests can be useful in the diagnostic process of CST. In patients with suspected CST, the NBQ can be administered first. In case of an NBQ score <14 points, the diagnosis of CST becomes less likely, as is shown in the negative PTP, sensitivity and negative LR. Similar results were found for using the NBQ to diagnose patients suffering from neck pain. The co-occurrence of tinnitus and cervical spine dysfunction can easily lead to suspected causality. In this case, a substantial cervical spine dysfunction is needed. The NBQ allows to objectify the cervical spine complaint. As described in previous studies, an NBQ of >14 points is needed for a substantial cervical spine complaint. In case of an NBQ <14 points the cervical spine dysfunction is not substantial enough and causality can be excluded.

The trigger point test can be added to the NBQ in the diagnostic evaluation of patients with suspected CST. The absence of trigger points will reduce the probability of CST, as is shown in the negative PTP, sensitivity and negative LR figures.

In case of a positive NBQ, the risk of false positives is too high, so a highly specific test, as the combination of manual rotation and AST tests, is necessary to decrease the risk of false positives. In case both tests are positive, the diagnosis of CST becomes more likely, as is shown in the positive PTP, specificity and positive LR. In case of a positive AST, without positive manual rotation test, the probability of CST still increases, as is confirmed in the positive PTP, specificity and positive LR. Similar results were previously found for using the manual rotation and AST to diagnose patients with neck pain and cervical facet joint pain. Using a combination of tests will increase the diagnostic value as is demonstrated in a study of Schneider et al. investigating cluster diagnostics in patients with cervical facet joint pain.

The CCFT was not useful in diagnosing patients with CST. This is in accordance with the findings of a recent study that found no differences in CCFT comparing neck related symptoms in CST and non-CST patients. No information is available on differences in CCFT between CST patients and asymptomatic controls, which could be interesting, because in other neck related populations such as cervicogenic headache patients, a significant difference in CCFT could be found between patients and asymptomatic controls. Previous research has shown that impairments in
patients with neck pain are mainly observed at the lower levels of the test (22, 24 and 26 mmHg)\textsuperscript{22}, while we also used the higher levels. This might have caused the absence of differences between CST and non-CST patients. In future research, 26 mmHg should be used as a cut off for normal.

To date, no clinical tests have been described in literature for diagnosing CST. Therefore, the clinical diagnosis of CST is currently based on the medical history.

As several clinical tests have proven to be useful in the diagnostic process of CST, the authors advise to add the NBQ to the anamnesis. In case of an NBQ score <14 points, the CST diagnosis becomes very unlikely and further cervical spine tests will not be necessary. In case of an NBQ score >14 points the ENT can refer the patient to the physical therapist which can perform the manual rotation test and AST to rule out false positive CST diagnoses. In this way, the physical therapist can cooperate with the ENT during the diagnostic process.

The study population was recruited in a tertiary referral centre for tinnitus patients, where all patients underwent a thorough ENT examination for diagnosing the tinnitus subtype.

The diagnosis of CST was made when the predominant feature was the temporal coincidence of onset or increase of both neck pain and tinnitus. This diagnosis is more limited than the original criteria for somatic tinnitus by Sanchez et al.\textsuperscript{22}, where the diagnosis is made when at least one of the following occurrences prior to the onset of tinnitus is present: (1) evident history of head or neck trauma, (2) tinnitus association with some manipulation of the teeth, jaw or cervical spine, (3) recurrent pain episodes in head, neck or shoulder girdle, (4) temporal coincidence of appearance or increase of both pain and tinnitus, (5) increase of tinnitus during inadequate postures during rest, walking, working or sleeping and (6) intense bruxism periods during the day or night.

In our study we decided to exclude patients suffering from whiplash trauma because of the complexity of the pathology and the heterogeneity of the clinical presentation. We also excluded patients suffering from temporomandibular disorders, as the population of interest in this study was the CST population.

For the abovementioned reasons, criteria 1, 6 and part of 2 were not used for the diagnosis of CST in this study. As we wanted to minimize the risk of including patients with tinnitus and cervical spine disorders, but without any relation between the tinnitus and the neck complaints in the CST group, we decided to primarily use criterion 4 for the diagnosis of CST. The authors however recognize the possibility that in our non-CST population some of the patients with significant neck dysfunction actually are CST patients that did not notice or comment on a coincidental onset of neck pain and tinnitus symptoms.
In our study, the diagnosis of CST was made in 43% of the patients. This number corresponds with the percentages reported by Abel et al. They found that 36.7% complained of neck, jaw or facial pain. This was recently also confirmed by Ostermann et al.\textsuperscript{94} and Fabijanska et al.\textsuperscript{95}. This implies that our patient sample was representative for the entire population. The pre-test probability to diagnose a patient suffering from CST was generally 43%, but small differences can be noted due to missing data for some of the clinical tests.

No significant differences were found in tinnitus loudness, TQ, hyperacusis and hearing impairment between the CST and non-CST group. These results correspond to the findings of Vielsmeier et al.\textsuperscript{96} in patients with or without temporomandibular joint related tinnitus and outline the necessity for cervical spine investigation, as the tinnitus characteristics alone cannot differentiate between both populations.

A limited number of clinical tests was used in this study. The manual rotation and AST were included, because they have proven to have good sensitivity and specificity in the diagnosis of non-specific neck pain. The CCFT was included because it has proven good reliability\textsuperscript{110} for measuring deep neck flexor endurance testing. Additionally, differences in CCFT were found comparing cervicogenic headache patients and healthy controls\textsuperscript{109}. The trigger points test was added, because this test has proven to be positive in tinnitus patients\textsuperscript{3}. The reliability of this test can however be questioned. To eliminate the risk of inter-rater pressure differences in this study, all tests were performed by the same therapist who has 9 years of experience in clinical examination of the cervical spine. The use of pressure algometry would however increase the reliability of this measure, but then the resemblance to daily clinical practice would reduce.

In future research, other highly reliable clinical cervical spine tests should be tested for validity in diagnosing CST and the effect of cervical spine treatment is to be investigated.

5.6 CONCLUSION

Clinical tests of the cervical spine can support the diagnostic process of patients with CST. An NBQ score <14 points and the absence of trigger points can help to exclude CST. In contrast, a positive manual rotation test and AST can help to include CST. We advise to include these test in a multidisciplinary assessment of patients with suspected CST.
Cervical sensorimotor control (cSMC) can be seen as a part of the system providing functional stability of the cervical spine. This system incorporates the afferent information from cervical structures (especially muscle spindles in the suboccipital muscles), visual and vestibular system, together with the efferent information from the central nervous system and the central integration and processing.

CSMC is generally measured using repositioning tasks (measuring joint position errors) or trajectory registrations (monitoring the entire movement). The head repositioning accuracy (HRA) to the neutral head position is the most commonly used repositioning task. The entire movement can be objectified using a continuous linear movement test (CLMT), developed by Sjölander et al.

Both HRA and CLMT tests have proven to provide reliable measurements. For the HRA, the reliability varies from very bad to excellent, depending on the referred study. The CLMT has shown very bad to almost perfect agreement, depending on the used outcome measure. Regarding discriminant validity, the HRA can overall differ between patients with cervical spine problems and asymptomatic controls. The construct validity of this test can however be questioned, as the HRA only measures position sense. Regarding construct validity, the CLMT seems to meet the concept of cSMC more completely. The CLMT takes into account the proprioceptive input from the cervical spine as well as the efferent output from the central nervous system after central integration and processing. Instead of position sense, the CLMT measures the entire movement using kinematic parameters. The CLMT has also proven to be able to discriminate between patients with chronic idiopathic neck pain and asymptomatic controls using range of motion (ROM) and Jerk Index (Cj) parameters.

CSMC has become important in the assessment of patients with neck pain. Since the first publication describing the head repositioning test by Revel et al., several authors have found altered cSMC in patients with neck complaints compared to asymptomatic controls.

Another population where cSMC might be impaired is a subgroup of chronic subjective tinnitus patients. In this subgroup of tinnitus patients, tinnitus has been...
related to the somatosensory system of the cervical spine. This type of tinnitus is named cervicogenic somatic tinnitus (CST).

The underlying mechanism of CST is explained by animal studies, which have found connections between the cervical somatosensory system and the cochlear nuclei (CN). Cervical somatosensory information is conveyed to the brain by afferent fibres, the cell bodies of which are located in the dorsal root ganglia or the trigeminal ganglion. These afferent fibres also project to the central auditory system. This makes the somatosensory system able to influence the auditory system by altering the spontaneous rates (i.e. not driven by auditory stimuli) or the synchrony of firing among neurons in the CN, inferior colliculus or auditory cortex. As a result, the somatosensory system might be able to alter the intensity and the character of the tinnitus.

As cervical somatosensory afference might be altered in patients with CST, cSMC could be affected in these patients. Therefore, the aim of this study is to investigate cSMC in patients with CST, using the CLMT test to compare patients with CST and asymptomatic controls.

6.2 METHODS

6.2.1 Subjects

Patients were recruited from the Antwerp University Hospital at the tertiary tinnitus clinic. During consult, patients were thoroughly examined to exclude any objective causes of tinnitus. Patients were included in the study when suffering from severe chronic non-fluctuating subjective tinnitus, which had been stable for at least three months, combined with neck complaints. The severity of the tinnitus was evaluated using the Tinnitus Functional Index (TFI). Severe tinnitus is defined as a score between 25 and 90 on the TFI. The presence of a significant neck complaint was objectified using the 14 points cut of point of the Neck Bournemouth Questionnaire. Patients were excluded when suffering from vertigo, objective tinnitus, subjective tinnitus with etiologies such as hearing loss or Meniere’s disease, severe depression (diagnosed by a psychologist), progressive middle ear pathology, intracranial pathology, traumatic cervical spine injury, tumors or cervical spine surgery. Patients were also excluded if they received physical therapy treatment directed to the cervical spine in the past 2 months.

A control group was recruited amongst students and staff of the University of Antwerp and the Antwerp University Hospital and friends and relatives of the investigators. The inclusion criteria for the control group were the absence of current or previous (past 6 months) neck complaints, traumatic cervical spine injury,
cervical spine surgery, known systemic inflammatory, neurological or metabolic disorders.

Ethical approval was obtained from the local ethics committee (reference number: B300201421113). Informed consent was obtained for all subjects. The study was registered at ClinicalTrials.gov (NCT02016313).

6.2.2 Procedure

The movements of the cervical spine were investigated in the three cardinal planes using a VICON® measuring device. This device uses the reflection of near infrared light on applied markers to perform a 3D movement analysis. The mean absolute error for this measuring device in dynamic conditions is 0.48° (SD 0.05°). In our setting, eight cameras were used to provide 3D images of nine reflective markers with a frequency of 100 Hz.

Five of the markers were mounted to a helmet that was placed on the subject’s head and four were mounted to a rhombic plate that was attached to the sternum, just below the jugular notch (Figure 6.1).

![Measuring setup Vicon®-markers](image)

**Figure 6.1: Measuring setup Vicon®-markers**

The CLMT was conducted in the M²OCEAN laboratory, in the Antwerp University Hospital. Cervical spine movements were performed with eyes closed, in a sitting position with backrest. Patients were asked to sit up straight, with both hips and knees in approximately 90° flexion. The same examiner performed all tests. The instructions given to the subjects were standardized, since these were written down. Subjects were asked to move smoothly, which means at a comfortable pace without causing discomfort to the subject. Regarding the ROM, the instruction was given to move as far as possible without causing any discomfort.
During the CLMT, subjects were required to perform three series of 10 repetitions of movements in a fixed order: flexion-extension, both rotations and lateral flexions.

6.2.3 Data analysis

The captured data of the Vicon® markers were first reconstructed and labeled using Nexus® software. Afterwards, a BodyBuilder® model was used to calculate angle positions for each captured frame. These data were then processed, using a custom made MATLAB® code (version R2014a, MathWorks Inc., USA).

The data were processed separately for each movement series. This resulted in six manageable categories of outcome measures per movement series (i.e. flexion-extension): mean cycle time (t), variation in cycle time (var-t), range of motion (ROM), velocity (v), acceleration (acc) and Jerk index (Cj). The outcome measures are defined as follows:

The ‘mean cycle time’ is the average time needed to perform one movement cycle (e.g. maximal flexion to maximal extension). The ‘variation in cycle time’ is the average ‘cycle time’-deviation of the different movement cycles. The ‘range of motion’ is the average range of motion per movement direction. The ‘velocity’ is the average velocity and the ‘acceleration’ the average acceleration during the movement trial. The ‘Jerk Index’ is a measurement of the smoothness of the movement which is calculated using the algorithms described by Kitazawa et al.\textsuperscript{84}. These algorithms calculate the sum of the different vectors of Jerk values over the movement (the size and direction of the deviation from the average movement trajectory), with respect to the average movement time and distance. The ‘Jerk Index’ was calculated as:

$$
C_j = \sqrt[\frac{1}{2}]\frac{1}{n} \sum_{l=1}^{n} J_l^2 \frac{t^5}{D}
$$

where the J is the vector of the jerk values over the movement (calculated from the kinematic data, as described above), n the number of samples of the vector, l the vector index, t the movement time and D the movement distance\textsuperscript{42,90}.
6.2.4 Statistics

After processing, the obtained outcome parameters were investigated as follows: first, the normality of the data’s distribution was investigated using the Kolmogorov-Smirnov test, combined with a visual interpretation of the normality curves. Second, differences between patients and controls were calculated using an independent-samples t-test for the normally distributed data and a Mann-Whitney-U test for the non-normally distributed data. Post-hoc Bonferroni tests were performed to decrease the risk of type I errors. The corrected p-values are reported in the results-section as: $p_{corr}$.

6.3 RESULTS

In total, 85 subjects participated in this study. In the patient group 44 adults, suffering from CST, were included. The control group consisted of 41 asymptomatic adults. No significant differences in age or gender were found between patients and controls. An overview of the demographics can be found in table 6.1. The data regarding the severity of the tinnitus and neck complaints in the patient group are presented in table 6.2.

<table>
<thead>
<tr>
<th>CST patients</th>
<th>Control subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of subjects</td>
<td>44</td>
</tr>
<tr>
<td>Females</td>
<td>16</td>
</tr>
<tr>
<td>Males</td>
<td>28</td>
</tr>
<tr>
<td>Age (mean ± SD)</td>
<td>48.7 ± 13.9</td>
</tr>
</tbody>
</table>

Table 6.1: Demographic features

<table>
<thead>
<tr>
<th>CST patients</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tinnitus Functional Index (mean ± SD)</td>
<td>53.64 ± 19.72</td>
</tr>
<tr>
<td>Neck Bournemouth Questionnaire (mean ± SD)</td>
<td>33.26 ± 13.08</td>
</tr>
</tbody>
</table>

Table 6.2: Tinnitus and neck complaints

6.3.1 Time

Significant differences in mean cycle time were found between both groups for each movement direction (flexion-extension: $p < 0.001$ and $p_{corr} < 0.006$, lateral flexion: $p = 0.002$ and $p_{corr} = 0.012$, rotation: $p < 0.001$ and $p_{corr} < 0.006$). In all directions, the patients needed more time to perform one movement cycle than the control subjects. The variation in cycle time was only significantly different for
the flexion-extension movement ($p = 0.022, \ p_{\text{corr}} = 0.132$). The patients showed less variation in cycle time than the control subjects.

### 6.3.2 Range of motion

The tinnitus patients showed a significantly smaller flexion-extension ROM ($p = 0.005, \ p_{\text{corr}} = 0.03$) than the control subjects. Although rotation and lateral flexion ROM were also systematically smaller in the patient group, these differences were not statistically significant. The coupled movements during flexion-extension, lateral flexion and rotation were systematically larger in the patient group compared to the controls. None of these differences however, were statistically significant.

### 6.3.3 Velocity and acceleration

No significant differences in velocity were found between patients with CST and controls. The acceleration figures of the control subjects showed significantly more acceleration than the patients ($p = 0.030, \ p_{\text{corr}} = 0.18$) during lateral flexion. In the other movement directions, no significant differences were found.

### 6.3.4 Jerk Index

The Jerk index figures showed significant differences between patients and controls for the lateral flexion ($p = 0.003, \ p_{\text{corr}} = 0.018$) and rotation ($p = 0.012, \ p_{\text{corr}} = 0.072$) movements. During lateral flexion, the patients show smaller Jerk Indexes than the controls. During rotation on the other hand, patients show larger Jerk Indexes.
<table>
<thead>
<tr>
<th>Outcome</th>
<th>Mean (SD)</th>
<th>Asymptomatic</th>
<th>t-test/ Wilcoxon</th>
<th>p</th>
<th>pcorr</th>
</tr>
</thead>
<tbody>
<tr>
<td>t-FE (s)</td>
<td>1.23 (0.49)</td>
<td>1.89 (0.87)</td>
<td>&lt; 0.001</td>
<td>&lt; 0.006</td>
<td></td>
</tr>
<tr>
<td>t-LF (s)</td>
<td>1.12 (0.47)</td>
<td>1.68 (0.89)</td>
<td>0.002</td>
<td>0.012</td>
<td></td>
</tr>
<tr>
<td>t-R (s)</td>
<td>1.37 (0.58)</td>
<td>2.21 (1.08)</td>
<td>&lt; 0.001</td>
<td>&lt; 0.006</td>
<td></td>
</tr>
<tr>
<td>var-t-FE (s)</td>
<td>1.01 (0.42)</td>
<td>1.32 (0.64)</td>
<td>0.022</td>
<td>0.132</td>
<td></td>
</tr>
<tr>
<td>var-t-LF (s)</td>
<td>0.95 (0.43)</td>
<td>1.09 (0.53)</td>
<td>0.400</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>var-t-R (s)</td>
<td>1.11 (0.53)</td>
<td>1.35 (0.78)</td>
<td>0.100</td>
<td>0.600</td>
<td></td>
</tr>
<tr>
<td>ROM-FE (deg)</td>
<td>98.52 (33.48)</td>
<td>109.75 (23.83)</td>
<td>0.005</td>
<td>0.030</td>
<td></td>
</tr>
<tr>
<td>ROM-LF (deg)</td>
<td>57.59 (25.18)</td>
<td>62.24 (25.43)</td>
<td>0.400</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>ROM-R (deg)</td>
<td>135.77 (43.86)</td>
<td>128.84 (27.89)</td>
<td>0.390</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Mean-v-FE (deg/s)</td>
<td>0.84 (3.31)</td>
<td>0.34 (1.40)</td>
<td>0.370</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Mean-v-LF (deg/s)</td>
<td>0.46 (2.36)</td>
<td>0.05 (2.37)</td>
<td>0.320</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Mean-v-R (deg/s)</td>
<td>0.63 (4.11)</td>
<td>0.18 (1.69)</td>
<td>0.240</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Mean-acc-FE (deg/s)</td>
<td>13.97 (88.69)</td>
<td>0.05 (0.79)</td>
<td>0.320</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Mean-acc-LF (deg/s)</td>
<td>0.06 (1.11)</td>
<td>13.56 (101.34)</td>
<td>0.030</td>
<td>0.180</td>
<td></td>
</tr>
<tr>
<td>Mean-acc-R (deg/s)</td>
<td>0.98 (7.54)</td>
<td>0.02 (1.30)</td>
<td>0.410</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Cj-FE</td>
<td>30956.36 (93448.13)</td>
<td>96195.87 (325690.40)</td>
<td>0.210</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Cj-LF</td>
<td>5631.56 (11258.48)</td>
<td>16521.24 (28391.29)</td>
<td>0.003</td>
<td>0.018</td>
<td></td>
</tr>
<tr>
<td>Cj-R</td>
<td>119059.70 (439264.00)</td>
<td>77741.38 (167701.80)</td>
<td>0.012</td>
<td>0.072</td>
<td></td>
</tr>
</tbody>
</table>

Table 6.3: Mean CLMT values in patients with tinnitus and asymptomatic controls (using the specific test-setup)

SD: standard deviation from the mean; Mean: mean value; t: average time; var-t: variation in time; Mean-v: mean velocity; Mean-acc: mean acceleration; ROM: range of motion; Cj: Jerk index; FE: flexion and extension movement; LF: lateral flexion; R: rotation; p: significance level; s: seconds; deg: degrees

### 6.4 Discussion

The aim of this study was to investigate cSMC in patients with CST, using the CLMT to compare patients with CST and asymptomatic controls.

The tinnitus patients needed significantly more time to perform one movement cycle than the asymptomatic controls. This is in line with the expected based on measurements of movement time during a cervical circumduction movement comparing neck pain patients and asymptomatic controls \(^{113}\). Slower movements can be associated with neck pain, making the patients move more carefully.
The flexion-extension ROM is significantly smaller in the patient group. In the other movement directions, this difference, however present, was not statistically significant. These results are similar to the findings of Sjolander et al. who found no significant differences in ROM between patients with insidious neck pain and asymptomatic controls, although a smaller ROM was noted in the patient group. The smaller rotation ROM is also in line with our findings using the manual rotation test in patients with CST and with the rotation deficit in patients with tinnitus shown in the study of Reisshauer et al. Based on these studies however, a significant difference between patients with tinnitus and asymptomatic subjects would be expected.

The limited significance of the differences in ROM in our study as well as in the study of Sjolander et al., might be caused by a lack of standardization of the movement speed. In our study, the subjects were instructed to move at a comfortable pace, but “comfortable” can differ within a group of patients or control subjects. Since Bonnechère et al. have found a significant difference in ROM depending on the movement speed, large within-group differences may have caused the limited differences between patients and controls. Additionally, it must be noted that when a subject moves faster than 2.1° per second, cervical input decreases and vestibular input increases. In cSMC measurement we are especially interested in the cervical input and less in the vestibular input. Using a standardized movement speed, for instance 0.5° per second, might solve the problem of differences in ROM and would ensure us to mainly measure cervical input instead of vestibular input. The 0.5° per second is the average cycle time reached by the patients in our study and should therefore be achievable in patients suffering from neck pain as well as in control subjects. To make sure patients move at the required pace a metronome can be used as an indication for the movement speed in future research.

Another reason for the limited difference in ROM might be the motivation of the subject to move as far as possible. In the patient group, subjects might have been more motivated to perform a maximal ROM, while the control subjects might have moved more naturally, without using the maximal ROM possibility.

Regarding the v and acc figures, very little differences were found between patients and controls. Especially when taking into account the post-hoc tests. These results are comparable to the lack of significant differences in peak velocity in studies of Sjolander et al. and Yang et al., but they are in contrast to the significantly larger velocity figures in neck pain patients compared to controls in a study of Meisingset et al.
Larger Jerk indexes were found during rotation movement in the patient group compared to the controls. These results are similar to the results of Sjolander et al.\textsuperscript{42}. After post-hoc testing, this difference was however, not statistically significant in our study. The Jerk index was also calculated during flexion-extension and lateral flexion. No differences between patients and controls were recorded during flexion-extension, but during lateral flexion significantly smaller Jerk indexes were found in the patient group.

Previous research has shown that Jerk Index measurements are most reliable during rotation movements\textsuperscript{90}. The test-retest reliability during flexion-extension and lateral flexion is very limited\textsuperscript{90}. Therefore, we advise to primarily use the rotation movement for obtaining Jerk indexes in future research.

To decrease the risk of type I errors, we performed post-hoc Bonferroni tests. Using these stricter conditions, initial significant differences in variation in time, acceleration and Jerk Index were no longer statistically significant. Nevertheless, since this is a first exploratory study, we suggest to investigate the Jerk Index more thoroughly in future research, although no statistically significant differences were found in this study. Rejecting the Jerk Index at this stage would decrease the risk of type I errors, but on the other hand it could increase the risk of introducing type II errors.

The measuring protocol, used in this study, turned out to be very time consuming. This disadvantage, together with the expensive measuring equipment, makes the protocol not suitable for everyday practice. But the outcome parameters can translated to outcome for clinical practice. A laser pointer can for instance be attached to the patient’s head by means of a headband. The patient can then be asked to follow a horizontal line on the wall with the laser light by rotating his head. In this way, large Jerk indexes can be seen as Jerky movements (velocity changes) of the laser light. The same test can also show rotation ROM deficits, however it must be noted that, as mentioned above, no significant differences were found regarding ROM between patients with CST and asymptomatic controls. In individual patients this difference can however be present.

6.5 Conclusion

Generally, cSMC in patients with CST is altered in terms of increased time needed to perform one movement cycle. A trend of increase in Jerk Index during rotation was found as well. Further investigation of the Jerk Index and the ROM in conditions of standardized movement speed is however necessary.
7 PHYSICAL THERAPY TREATMENT IN PATIENTS SUFFERING FROM CERVICOGENIC SOMATIC TINNITUS: STUDY PROTOCOL

7.1 ABSTRACT

**Background:** Tinnitus occurs in a large part of the general population with prevalences ranging from 10 to 15% in an adult population. One subtype is cervicogenic somatic tinnitus, arising from cervical spine dysfunctions, justifying cervical spine assessment and treatment. This study aims to investigate the effect of a standardized physical therapy treatment, directed to the cervical spine, on tinnitus. Additionally, a second aim is to identify a subgroup within the tinnitus population that benefits from physical therapy treatment.

**Methods and design:** This study is designed as a randomized controlled trial with delayed treatment design. Patients with severe subjective tinnitus (Tinnitus Functional Index (TFI) between 25 and 90 points), in combination with neck complaints (Neck Bournemouth Questionnaire (NBQ) > 14 points) will be recruited from the University Hospital of Antwerp.

Patients suffering from tinnitus with clear otological etiologies, severe depression, traumatic cervical spine injury, tumors, cervical spine surgery or conditions in which physical therapy is contra-indicated, will be excluded.

After screening for eligibility, baseline data such as TFI, NBQ and a set of cervical biomechanical and sensorimotor tests will be collected.

Patients are randomized in an immediate therapy group and in a group with a delayed start of therapy by 6 weeks.

Patients will receive physical therapy with a maximum of 12 sessions of 30 minutes for a six weeks program. Data from the TFI and NBQ will be collected at baseline (week0), at the start of therapy (week0 or 6), at the end of therapy (week6 or 12), 6 weeks after therapy (week12 or 18) and 3 months after therapy (week18 or 24). Secondary outcome measures will be collected at baseline and 6 weeks after the therapy (week12 or 18), as the maximal therapy effect on the cervical spine dysfunctions is expected at that moment.

**Discussion:** This study is the first to investigate the effect of a standardized physical therapy treatment protocol on somatic tinnitus with a prospective comparative
delayed design and with blinded evaluator for baseline, end of the therapy and 6 and 12 weeks after therapy.

7.2 BACKGROUND

Tinnitus is the phantom sensation of sound, in the absence of overt acoustic stimulation \(^91\). It occurs in 10 to 15% of the adult population \(^{117}\).

Tinnitus can be related to many different aetiologies such as hearing loss, a noise trauma or the tinnitus may be related to the somatic system of the cervical spine or the temporomandibular area \(^{117}\).

This study will focus on physical therapy treatment for patients suffering from chronic non-fluctuating subjective cervicogenic somatic tinnitus (CST).

The existence of a link between the cervical spine and tinnitus can be assumed based on several prior studies. Connections between the dorsal column of the spinal cord and the cochlear nuclei (CN) have been found in several animal studies \(^{118,17}\). These axons of the dorsal column originate from the C1-C8 dorsal roots of the spinal cord. Especially stimulation of the C2 dorsal root ganglion generates responses from cells in the CN \(^{102}\). Additionally, Matsushima et al. \(^{103}\) demonstrated that tinnitus improved in 52% of the patients after an occipital nerve block. Other recent studies in humans, found that in some patients, tinnitus could be evoked or modulated by input from the somatic system, for instance: by forceful muscle contractions of the head, neck and limbs and pressure on myofacial trigger points \(^{20,104,30,105}\). These findings might explain the ability of some tinnitus patients to modulate their tinnitus by certain head or neck movements. For example: some patients indicate that their tinnitus worsens when performing a combined cervical spine extension and rotation.

Several research groups have investigated the effect of cervical spine treatments on CST \(^{22,23}\). Regarding physical therapy treatments, little scientific data are available. Sanchez et al. \(^{22}\) reviewed five case reports in which cervical spine mobilizations and stretching of suboccipital muscles could decrease the intensity of the tinnitus in five patients. Latifpour et al. \(^{23}\) showed in an RCT of 13 tinnitus patients and 11 controls, a greater improvement in tinnitus loudness after application of stretching, posture exercises and acupuncture compared to controls \((p > 0.001)\).

Although only case reports and one RCT are reported, the ability of physical therapy treatment directed to the cervical spine to reduce the tinnitus seems promising.
Consequently, the aim of this study is to investigate the effect of a standardized physical therapy treatment program directed to the cervical spine, on several tinnitus and neck related parameters. Additionally, a second aim is to identify a subgroup within the tinnitus population that benefits from the physical therapy treatment.

7.3 METHODS

7.3.1 Patients

Patients will be recruited from the University Hospital of Antwerp by otolaryngologists at their tertiary tinnitus clinic. During this consult, patients will be thoroughly tested to exclude any objective causes of the tinnitus. Patients will be included when suffering from severe chronic non-fluctuating subjective CST, which has been stable for at least three months, combined with neck complaints. The severity of the tinnitus will be evaluated using the ‘Tinnitus Functional Index’ (TFI) \(^{111}\). Severe tinnitus is defined as a score between 25 and 90 on the TFI \(^{111}\). The presence of a significant neck complaint will be objectified using the 14 points cut of point of the ‘Neck Bournemouth Questionnaire’ (NBQ) \(^{112, 92}\). Patients will be excluded when suffering from objective tinnitus, subjective tinnitus with etiologies, such as hearing loss or Meniere’s disease, severe depression (diagnosed by a psychologist), progressive middle ear pathology, intracranial pathology, traumatic cervical spine injury, tumors, cervical spine surgery or any cervical spine condition in which physical therapy treatment is contra-indicated. Given the treatment that is studied, patients will also be excluded if they received physical therapy treatment directed to the cervical spine in the past 2 months.

7.3.2 Study design

This study is designed as a randomized controlled trial to evaluate the effectiveness of a standardized cervical spine treatment on tinnitus and neck related parameters in patients suffering from CST. A delayed treatment design (figure 7.1) will be used to create a waiting list to obtain the data for the control group \(^{119}\). At baseline, patients are randomly assigned by the responsible researcher to receive immediate treatment or to the waiting list. In part 1, the immediate treatment group receives the cervical spine treatment for six weeks. In part 2, the patients on the waiting list receive cervical spine treatment for the next six weeks. The immediate treatment group now enters a six weeks follow up period. In part 3 all patients enter a follow up period which ends twelve weeks after the last treatment session.
A pilot study was used for calculating the sample size needed and to optimize the inclusion as well as the follow up measuring procedure.

The results of the trial will be reported according to the CONSORT guidelines.

### 7.3.3 Randomization procedure

After the baseline measurements, the patients are randomized into the immediate treatment group or into the waiting list in a 1:1 ratio based on a block-randomization with variable block lengths. The responsible researcher generated a randomization list with Microsoft Excel® software (version 14.3.5, 2010 © Microsoft corporation). The randomization list is only accessible for the responsible researcher.

### 7.3.4 Ethical approval and consent

Ethical approval was obtained from the ethics committee of the University Hospital of Antwerp (reference number: B300201421113). The names of all ethical bodies that approved the study can be found in the additional file. Informed consent is obtained for all patients. The trial is currently in the recruitment phase.

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In this pilot study, 14 patients were included and randomly assigned to one of the groups (7 in each group). All patients were assessed as described in the protocol and received the described treatment. No adjustments to the inclusion criteria or measuring procedure were needed based on this pilot study.
7.3.5 Outcome measures

The primary outcome measures are the TFI and NBQ.

The TFI focuses on eight different domains: the unpleasantness of the tinnitus, reduced sense of control, cognitive interference, sleep disturbance, auditory difficulties attributed to the tinnitus, interference with relaxation, reduction in quality of life and emotional distress. The test-retest reliability of the TFI is good (r: 0.78). The convergent validity with the Tinnitus Handicap Inventory (r: 0.86) and Visual Analogue Scale (r: 0.75) is good, as well as the discriminant validity with the Beck Depression Inventory-Primary Care (r: 0.56). The clinically relevant reduction was a 13-point reduction.

The pilot study showed that the studied treatment had most influence on the ‘reduced sense of control’ and ‘interference with relaxation’ subscales. Consequently, special attention to these subscales will be paid.

The secondary outcome measures will be the NBQ, a set of different biomechanical and sensorimotor neck parameters and the tinnitus loudness.

The NBQ consists of 7 questions on the severity of the neck complaint and its interference with the patient’s wellbeing and professional and daily activities. The test-retest reliability of the NBQ is moderate (ICC: 0.65). The construct validity was acceptable with both the Neck Disability Index (r: 0.50) and the Copenhagen Neck Functional Index (r: 0.44). The effect size was found to be high (Cohen’s d: 1.67), which indicates that the NBQ is highly responsive to changes in cervical spine complaints.

For measuring the biomechanical and sensorimotor neck parameters, first, the cervical spine mobility will be investigated in the three cardinal planes.

The range of motion (ROM) is registered using a VICON measuring device. This device uses the reflection of near infrared light on applied markers to perform a 3D movement analysis. The mean absolute error of this measuring device in dynamic conditions is 0.48° (SD 0.05°).

Second, the sensorimotor control of the cervical spine will be measured using the head repositioning accuracy (HRA) to the neutral head position and the continuous linear movement test (CLMT). The HRA measurement will be executed as described by Revel et al. in 1991. The VICON® will be used to register the joint position errors.

The continuous linear movement test (CLMT), as described by Sjolander et al., will be used to objectify the movement speed, acceleration and Jerk index using the
VICON® data. Special attention will be paid to the movement speed and acceleration, as these parameters have proven to have good test-retest reliability.

Third, a set of tests will be executed to objectify the impairments in cervical spine mobility and muscle function. This set of tests includes a manual investigation of the cervical spine, tenderness of trigger points and a strength and endurance test of the deep neck flexor muscles. The manual investigation consists of a manual rotation test and adapted Spurling test, and a flexion rotation test evaluating the upper cervical spine rotation mobility. The tenderness of 16 trigger points, is investigated by applying manual pressure. The strength and endurance of the deep neck flexor muscles is objectified using the craniocervical flexion test.

All outcome measures will be documented at baseline and at 12 weeks. The primary outcome measures will additionally be documented at 6 and 18 weeks.

7.3.6 Intervention

The intervention, a physical therapy treatment directed to the cervical spine, consists of a multimodal care containing manual mobilizations, exercise therapy and home exercises. This multimodal physical therapy treatment is based on recent insights of cervical spine therapy. Additionally, patients are instructed to perform exercises at home. For these exercises, a booklet established by Castien et al., was adjusted for the tinnitus patients, implementing exercises for the deep neck flexor muscles (figure 7.2 and 7.3) and self-mobilizing exercises.

Figure 7.2.a: Craniocervical flexion exercise in supine position (starting position)
Treatment will be applied by a selected group of physical therapists that all obtained a master’s degree in physical therapy and an additional master’s degree in manual therapy. Moreover, they all participated in a training session organized by the research group. During this training session, the treatment protocol was discussed and trained. Patients included in the trial will be referred for treatment to one of the selected therapists (guided referral). The treatment protocol provides a maximum of 12 standardized physical therapy treatment sessions. The therapists are free to adapt the mobilization techniques and exercises to the current situation of the patient. The therapist registers all performed techniques and exercises.
7.4 **SAMPLE SIZE AND POWER**

The sample size\(^h\) was calculated using Medcalc (Medcalc Software bvba.). This calculation was based on data of the primary outcome measure, obtained in a pilot study of 14 patients. Sample size calculation was performed for the clinically relevant change of 13 points in TFI score. The sample size was calculated for the study to have 80% power to reject the null hypothesis (H\(_0\)). The type I error probability, associated with this test, is 0.05. To achieve the 80% power, 17 patients are needed in each group.

The primary analysis population is the intention-to-treat population. This population includes all randomized patients who provided baseline data, regardless whether or not they adhere to the complete protocol.

7.5 **STATISTICS**

The primary statistical hypotheses are:

\[ H_0: \text{Change in TFI-baseline to TFI-6 weeks (treated)} = \text{Change in TFI-baseline to TFI-6 weeks (waiting list)} \]

\[ \text{Change in NBQ-baseline to NBQ-6 weeks (treated)} = \text{Change in NBQ-baseline to NBQ-6 weeks (waiting list)} \]

The primary outcome is a change in the scores on the TFI and NBQ after 6 weeks. The mean change in TFI and NBQ-baseline and TFI and NBQ-6 weeks follow up scores will be calculated.

This mean change in TFI and NBQ scores of the treated group will be compared to the mean change in TFI and NBQ scores of the waiting list group.

A repeated measures ANOVA and post hoc tests will be used to compare the mean changes of the treatment and waiting list population at 6 weeks and secondary at baseline, 12 and 18 weeks follow up.

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\(^{h}\) Sample size calculation was based on a two-sided test using the data of a pilot study group of 14 patients with a global TFI mean of 45.37 points (SD: 17.90).
7.6 Discussion

The aim of this study is to investigate the effect of a standardized physical therapy treatment protocol on several tinnitus and neck related parameters. Currently, only five case studies and one RCT have studied the effect of physical therapy on somatic tinnitus. Additional RCT’s of good quality are therefore needed to verify the effect of physical therapy on somatic tinnitus.

Studies investigating the effect of physical therapy treatment on somatic tinnitus mainly focus on a limited number of treatment modalities. For example, Alcantara et al. 27 and Kessinger et al. 99 focus on manipulations of the cervical spine in individual case studies. Recent studies concerning physical therapy treatment programs directed to the cervical spine however indicate that a multimodal treatment, combining mobilization or manipulation and exercise therapy has better results than a treatment that merely focusses on mobilizations or manipulations 45,46,121,125.

In this rationale, we decided to use a multimodal treatment in the current study, especially since a prior study from our research group showed a combination of dysfunctions in several structures of the cervical spine in cervicogenic somatic tinnitus patients. These results add to the prospect of a positive effect of a multimodal treatment, since this is directed to multiple dysfunctions at once.

In the current study, all therapists will adjust the treatment modalities to the needs of the individual patient. This pragmatic aspect was chosen to investigate the physical therapy treatment in the full spectrum of everyday clinical settings in order to maximize the applicability and generalizability 126.

This study will need 40 patients with severe tinnitus, also complaining from cervical spine problems. This amount seems feasible, considering the fact that 100 tinnitus patients could be recruited in 6 months in the same setting last year.

The somatic tinnitus population is frequently described as tinnitus that can be modulated by forceful muscle contractions of the head, neck or limbs 20, or pressure on myofascial trigger points 105. Based on the previous research of Levine et al. 20 and Rocha et al. 105, the inclusion should be limited to the patients who can modulate their tinnitus. As, before inclusion, all objective causes of tinnitus are excluded, we chose to include all patients with a combination of severe subjective tinnitus and neck complaints in order to include all patients who can potentially benefit from our treatment. The patient’s ability to modulate the tinnitus is registered and will be taken into account in the post treatment analysis.
A control group, receiving no treatment at all, cannot be used in our tertiary referral center due to ethical considerations. Instead, we will use a delayed treatment design to collect the data for the control group. In this type of design, one group of patients will be treated immediately, while the other group will be on the waiting list for 6 weeks and will be treated afterwards.

The pilot study showed that physical therapy treatment has an effect on the TFI scores. Changes in total TFI score however are small. When looking at the different subscales, the largest effect can be noted in the ‘reduced sense of control’ and ‘interference with relaxation’ subscales. To a lesser extent, a change could be noted in the ‘cognitive interference’ subscale. The physical therapy treatment appeared to have little effect on the ‘unpleasantness of the tinnitus’, ‘sleep disturbance’, ‘auditory difficulties attributed to the tinnitus’, ‘reduction in quality of life’ and ‘emotional distress’. Taking into account the content and goals of a physical therapy treatment, the lack of effect on the ‘auditory difficulties attributed to the tinnitus’ seems expectable. Likewise, for a larger effect on the coping related subscales, such as ‘reduction in quality of life’, ‘emotional distress’ and ‘unpleasantness of the tinnitus’, a more psychosocial treatment approach would be necessary.

This study is the first to investigate the effect of a standardized physical therapy treatment protocol on somatic tinnitus with a prospective comparative delayed design and with blinded evaluator for baseline, end of the therapy and 6 and 12 weeks after therapy.
8 CERVICAL PHYSICAL THERAPY IN PATIENTS WITH CERVICOGENIC SOMATIC TINNITUS: A RANDOMIZED CONTROLLED TRIAL ASSESSING PROGNOSTIC INDICATORS.

8.1 ABSTRACT

Objective: Tinnitus can be related to the somatic system of the cervical spine, called cervicogenic somatic tinnitus. Cervicogenic somatic tinnitus patients may benefit from cervical spine treatment, but it is hard to predict the treatment outcome. Therefore, we aimed to identify prognostic indicators that are likely to decrease tinnitus after cervical physical therapy.

Methods: Patients with severe subjective tinnitus (Tinnitus Functional Index: 25–90 points) and neck complaints (Neck Bournemouth Questionnaire > 14 points) received cervical physical therapy for 6 weeks (12 sessions). Patients were randomized in an immediate-start therapy group (n = 19) and a 6-week delayed-start therapy group (n = 19). Tinnitus Functional Index and Neck Bournemouth Questionnaire scores were collected at baseline, immediately after treatment and after a 6-week follow-up period.

Results: Tinnitus Functional Index and Neck Bournemouth Questionnaire scores decreased significantly after treatment (p = 0.04 and p < 0.001). Neck Bournemouth Questionnaire scores remained significantly lower after follow-up (p = 0.001). Patients with low-pitched tinnitus benefited more from treatment than patients with high-pitched tinnitus (87% versus 48%, p = 0.04). Patients with covarying (increasing or decreasing simultaneously) tinnitus and neck complaints (49%) had significantly lower Tinnitus Functional Index scores after treatment (p = 0.001) and follow-up (p = 0.03). The presence of this covariation and a combination of low-pitched tinnitus and increasing tinnitus during inadequate cervical spine postures are prognostic indicators of a decrease of Tinnitus Functional Index scores after cervical physical therapy (adjusted R² = 0.357).

Interpretation: Patients who experience a tinnitus decrease from cervical physical therapy are those with covarying tinnitus and neck complaints and those with a combination of low-pitched tinnitus and increasing tinnitus during inadequate cervical spine postures.
8.2 INTRODUCTION

Tinnitus is the phantom sensation of sound in the absence of overt acoustic stimulation\(^91\). It occurs in 10 to 15% of adults and is experienced as severely annoying by 1.6%\(^1\). The degree of severity can be expressed in terms of health-related quality of life (Tinnitus Functional Index (TFI)) and in terms of tinnitus loudness, graded with the visual analogue scale (VAS), as there is no objective way to measure tinnitus\(^127\).

Tinnitus is mostly subjective, as only the patient experiences the tinnitus, and it is generally described as hissing, sizzling or ringing\(^1\). In some patients, tinnitus has a pulsatile nature that, when synchronous with the heartbeat, is likely to be of vascular origin\(^1\). Additionally, tinnitus can be constant or intermittent, located in one or both ears or centrally located in the head.

Typically, tinnitus is related to hearing loss or a noise trauma, where cochlear abnormalities are the initial source and neural changes in the central auditory system maintain the tinnitus\(^1\). It has been suggested that tinnitus only reaches conscious awareness or annoyance levels when aberrant neuronal activity in the primary sensory cortex is connected to a wider cortical network involving frontal, parietal and limbic brain regions\(^8,9\).

One subtype of tinnitus is related to the somatic system of the cervical spine, called cervicogenic somatic tinnitus (CST). Several animal studies that have found connections between the cervical somatosensory system and cochlear nuclei (CN) offer a physiological explanation for CST\(^17,18\). Cervical somatosensory information is conveyed to the brain by afferent fibres, the cell bodies of which are located in the dorsal root ganglia or the trigeminal ganglion. Some of these fibres also project to the central auditory system. This enables the somatosensory system to influence the auditory system by altering spontaneous rates or synchrony of firing among neurons in the CN, inferior colliculus or auditory cortex. In this way, the somatosensory system is able to alter the intensity and character of tinnitus\(^19\).

Previous research has shown that CST is present in 36 to 43% of the overall tinnitus population\(^16,94,95,106\). CST patients mainly suffer from restricted cervical spine rotation\(^98,106\), pain provocation during combined extension, lateral flexion and rotation\(^106\) of the cervical spine or sensitive trigger points\(^98,106\) in the presence of a positive score (\(>14/70\)) on the Neck Bournemouth Questionnaire (NBQ)\(^106\).

Several studies have found positive effects of cervical spine treatments on CST\(^22,23\) but these studies often lack scientific quality due to very limited numbers of patients and lack of control groups and randomization. Therefore, the use of cervical spine treatment in tinnitus patients is still under dispute. Moreover, CST
diagnosis is mainly based on medical history, and no information is available on the tinnitus subtype that benefits most from cervical spine treatment.

Consequently, the primary aim of this study was to identify prognostic indicators that are highly likely to decrease tinnitus complaints after cervical physical therapy. The secondary aim was to investigate the effect of a standardized cervical physical therapy program on several tinnitus and neck-related parameters.

8.3 METHODS

8.3.1 Study design

This study was designed as a delayed-start randomized controlled trial to evaluate the effectiveness of a standardized cervical physical therapy treatment on tinnitus and neck-related parameters in patients suffering from CST. The delayed-start design (Fig 1) allowed us to obtain data for a control group by creating a waiting list.

Figure 8.1: Delayed-start design

A: immediate-start group; B: delayed-start group; Q: questionnaires; Exam.: cervical spine examination

At baseline, patients were randomly assigned to receive immediate treatment (immediate-start group) or to be placed on the waiting list (delayed-start group). In phase 1 (weeks 0 to 6), the immediate-start group received cervical physical therapy for 6 weeks; the delayed-start group received no cervical physical therapy during this phase. In phase 2 (weeks 6 to 12), the patients in the delayed-start group received cervical physical therapy for the next 6 weeks. The immediate-start group
then entered a 6-week follow-up period. In phase 3 (weeks 12 to 18), the delayed-start group entered a 6-week follow-up period. The immediate-start group ended their participation in the study at the end of week 12.

8.3.2 Patients

Patients were recruited from Antwerp University Hospital at the tertiary tinnitus clinic. During consult, patients were thoroughly examined to exclude any objective causes of tinnitus. Included in the study were patients suffering from severe chronic non-fluctuating subjective tinnitus that had been stable for at least three months combined with neck complaints. The severity of the tinnitus was evaluated using the TFI. Severe tinnitus is defined as a score between 25 and 90 on the TFI. Neck complaints were considered to be significant with a score of > 14 on the NBQ. Patients suffering from vertigo, objective tinnitus, subjective tinnitus with etiologies (such as hearing loss or Meniere’s disease), severe depression (diagnosed by a psychologist), progressive middle ear pathology, intracranial pathology, traumatic cervical spine injury, tumors, cervical spine surgery or any cervical spine condition in which physical therapy treatment is contraindicated were excluded from the study. Patients were also excluded if they had received physical therapy treatment for the cervical spine in the past two months.

8.3.3 Intervention

The intervention, a physical therapy treatment for the cervical spine, consisted of multimodal care containing manual mobilizations, exercise therapy and home exercises. This multimodal physical therapy treatment was based on recent insights of cervical spine therapy. For the home exercises, a booklet established by Castien et al. was adjusted for tinnitus patients, implementing exercises for the deep neck flexor muscles and self-mobilizing exercises. Treatment was applied by a selected group of physical therapists, all of whom had obtained a master’s degree in physical therapy and an additional master’s degree in manual therapy. Prior to the start of the study, all therapists participated in a training session about the treatment protocol, which was organized by the research group. Patients included in the trial were referred for treatment to one of the selected therapists (guided referral). The treatment protocol provided 12 standardized cervical physical therapy sessions during a 6-week treatment program. The therapists were free to adapt the mobilization techniques and exercises to the current situation of the patient.

No changes were made to the patients’ drug use during the study, but no additional treatments, such as neuromodulation or transcutaneous electrical nerve stimulation (TENS), were allowed.
### 8.3.4 Outcome measures

The primary outcome measure, the TFI\(^{111}\), assesses tinnitus annoyance in eight different domains: the unpleasantness of the tinnitus, reduced sense of control, cognitive interference, sleep disturbance, auditory difficulties attributed to the tinnitus, interference with relaxation, reduction in quality of life and emotional distress. The test-retest reliability of the TFI is good (r: 0.78). The convergent validity with the Tinnitus Handicap Inventory (r: 0.86) and visual analogue scale (VAS) (r: 0.75) is good, as well as the discriminant validity with the Beck Depression Inventory-Primary Care (r: 0.56)\(^{111}\). A reduction of 13 points is considered to be clinically relevant\(^{111}\).

The secondary outcome measures are the NBQ\(^{112}\), global perceived effect (GPE) and a set of different biomechanical and sensorimotor neck parameters.

The NBQ\(^{112}\) consists of seven questions on the severity of the neck complaints and its interference with the patient’s wellbeing and professional and daily activities. The test-retest reliability of the NBQ is moderate (ICC: 0.65). The construct validity is acceptable with both the Neck Disability Index (r: 0.50) and the Copenhagen Neck Functional Index (r: 0.44). The effect size was high (Cohen’s d: 1.67), which indicates that the NBQ is highly responsive to changes in cervical spine complaints.

The GPE consists of the patient’s subjective opinion on changes in his or her tinnitus complaints. Figures for the GPE were obtained by asking whether or not (dichotomous) the patient experienced a substantial improvement of their tinnitus complaints compared to baseline. The test-retest reliability of the GPE was excellent (ICC: 0.90-0.99) in patients with musculoskeletal disorders, but the patients’ current status strongly influenced the rating\(^{129}\). Therefore, in our study we only compared the current status to baseline.

Cervical spine mobility is investigated in the three cardinal planes using a VICON® measuring device. This device uses the reflection of near infrared light on applied markers to perform a 3D movement analysis.

The sensorimotor control of the cervical spine is measured using head repositioning accuracy (HRA)\(^{35}\) to the neutral head position and the continuous linear movement test\(^{42,90}\).

Impairments in cervical spine mobility and muscle function were identified using manual investigation of the cervical spine, tenderness of trigger points and a strength and endurance test of the deep neck flexor muscles\(^{93}\).

First, the passive rotation movement of the cervical spine was investigated using the manual rotation test\(^{92}\). This test rates the quality of passive rotation movement...
on C0-C2 and C2-C7 levels based on three parameters: range of motion (hyper-normal/hypomobility), end feel (hard/normal/soft/empty) and pain provocation (VAS > 2 cm) 92.

Second, the adapted Spurling test, a segmental pain provocation test using a combination of cervical extension, lateral flexion and rotation, was used92. Both the manual rotation and adapted Spurling test have shown high sensitivity (77.8) and specificity (77.3) in discriminating patients with neck dysfunction from asymptomatic controls 92.

Third, the strength and endurance of the deep neck flexor muscles were measured using the craniocervical flexion test 93.

Finally, the tenderness of sixteen myofascial trigger points was tested by applying manual pressure. A trigger point was identified as positive when the patient scored more than 2 cm on a VAS for pain. The test was positive when at least one trigger point was found to be positive. The locations of the trigger points were determined according to the findings of Teachey et al. 3.

All outcome measures were documented at baseline and 6 weeks after the last treatment session (follow-up). The TFI, NBQ and GPE were also documented after the 6-week wait-and-see period in the delayed-start group and immediately after the last treatment session in both groups (post-treatment).

8.3.5 Randomization procedure and blinding

After baseline measurements were recorded, patients were randomized into the immediate-start group or delayed-start group in a 1:1 ratio based on block-randomization with variable block lengths. A concealed randomization list was generated using random numbers in Microsoft Excel® software (version 14.3.5, 2010 © Microsoft Corporation). All questionnaires were filled out in the presence of a blinded investigator. The therapists were blinded at all times to whether a patient was included in the immediate-start or delayed-start group.

8.3.6 Ethical approval and consent

Ethical approval was obtained from the local ethics committee (reference number: B300201421113). Informed consent was obtained for all patients. The study was registered at ClinicalTrials.gov (NCT02016313).
8.4 Statistics

An intention-to-treat analysis was performed on the study cohort. Baseline comparability (p > 0.05) of both groups was analyzed using descriptive statistics, independent samples t-tests and chi-square tests.

The difference in evolution in time of the primary outcome measures between both groups was analyzed using a two-way repeated measures ANOVA. Afterwards, for all patients, the evolution in time of the primary outcome measures was calculated using a one-way repeated measures ANOVA, and differences between baseline, post-treatment and follow-up were calculated using paired samples t-tests.

Differences in primary and secondary outcome measures between the improved and not improved patients at baseline were calculated using an independent samples t-test or chi-square test. The same analysis was performed for differences between patients with covarying (increasing or decreasing simultaneously) tinnitus and neck complaints and patients without this covariation.

The relationship between TFI decrease after treatment and potential prognostic indicators was individually evaluated using linear regression analysis. Adjusted regression coefficients and 95% confidence intervals were calculated. Additionally, standardized regression coefficients were reported to compare the strength of the influence of the different prognostic indicators.

A multivariate model for the prediction of TFI decrease was created using a multiple linear regression analysis retaining only the strongest predictors from the individual linear regression analysis.
8.5 RESULTS

8.5.1 Patients

In total, 40 patients\(^1\) were randomly assigned to the immediate-start or delayed-start groups. Two patients decided not to receive physical therapy after the randomization. An overview of the enrollment, allocation and follow-up can be found in Figure 8.2.

\[^1\] Taking into account a 15% drop-out rate
No significant differences in primary or secondary outcome measures were found at baseline between the immediate-start and delayed-start groups (Table 8.1), except for the presence of both a positive manual rotation and adapted Spurling test ($p = 0.05$).

<table>
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<th>Characteristic</th>
<th>Immediate-start group</th>
<th>Delayed-start group</th>
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<th>$p$</th>
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<tr>
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<td>19</td>
<td>38</td>
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</tr>
<tr>
<td>Age (SD)</td>
<td>46(14)</td>
<td>52(12)</td>
<td>50(13)</td>
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<tr>
<td>TFI (SD)</td>
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<td>51(18)</td>
<td>49(21)</td>
<td>0.91</td>
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<td>NBQ (SD)</td>
<td>37(10)</td>
<td>32(12)</td>
<td>32(12)</td>
<td>0.15</td>
</tr>
<tr>
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<td>5(2)</td>
<td>5(2)</td>
<td>0.55</td>
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<td>19(9)</td>
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<td>53%</td>
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<td>AST</td>
<td>74%</td>
<td>53%</td>
<td>63%</td>
<td>0.18</td>
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<tr>
<td>Trigger points</td>
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</tr>
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<td>Provocation of tinnitus</td>
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<td>11%</td>
<td>1.00</td>
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</tbody>
</table>

* Significant difference between both groups

SD: standard deviation; TFI: Tinnitus Functional Index; NBQ: Neck Bournemouth Questionnaire; VAS: Visual analogue scale; AST: adapted Spurling test

**8.5.2 TFI responses to treatment**

All patients suffered from severe tinnitus at baseline with an average TFI score of 49 (SD: 21). Immediately after treatment, the average TFI score decreased significantly to 44 points (SD: 22, $p = 0.04$) and increased to 47 points (SD: 22) 6 weeks after the last treatment session.
Figure 8.3 shows the difference in evolution between the immediate-start and delayed-start group. This difference, however, was not statistically significant.

![Chart showing Tinnitus Functional Index (TFI) evolution](image)

**Figure 8.3: Evolution of the Tinnitus Functional Index (TFI) in the immediate-start and delayed-start group**

### 8.5.3 NBQ responses to treatment

The average NBQ score at baseline was 33 points (SD: 12). Immediately after treatment, the NBQ score decreased significantly to 16 points (SD: 12, p < 0.001). This significant decrease was maintained 6 weeks after the last treatment session (p = 0.001), although the average NBQ score slightly increased to 21 points (SD: 15).

Figure 8.4 shows the evolution of NBQ scores over time between the immediate-start and delayed-start group. A significant difference between both groups was found 6 weeks after the baseline measurements (p = 0.001).

![Chart showing Neck Bournemouth Questionnaire (NBQ) evolution](image)

**Figure 8.4: Evolution of the Neck Bournemouth Questionnaire (NBQ) in the immediate-start and delayed-start group**

* significant difference between both groups
8.5.4 Global perceived effect

Six weeks after the baseline measurements, 58% of the patients in the immediate-start group (11 out of 19) experienced improvement of the tinnitus compared to no improvement in the delayed-start group that had ended the wait-and-see period.

Immediately after treatment, 53% of the entire study population (20 out of 38) experienced substantial improvement of tinnitus compared to baseline. This effect was maintained 6 weeks after the last treatment session in 24% of the patients (9 out of 38).

8.5.5 Characteristics of improved patients

At baseline, no significant differences were documented in TFI, NBQ or VAS for tinnitus, hyperacusis or impairments in the cervical spine between the improved and not improved patients.

Immediately after treatment, the subjectively improved patients reported an average decrease in TFI of 11.9 points (SD: 21.4), while the not improved patients reported an average increase of 0.7 points (SD: 4.8). After the follow-up period, the average TFI score decreased by 16.9 points (SD: 26.6) in the improved patients and increased by 2.4 points (SD: 8.3) in the not improved patients when compared to baseline. No significant differences in the decrease of NBQ scores were found between subjectively improved and not improved patients. The changes in TFI and NBQ scores are presented in Table 8.2. Additionally, no significant differences in neck parameters were found between the subjectively improved and not improved patients.

<table>
<thead>
<tr>
<th>Change in</th>
<th>Post Treatment</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>TFI</td>
<td>Not improved</td>
<td>Improved</td>
</tr>
<tr>
<td></td>
<td>+0.67 (4.78)</td>
<td>-11.89 (21.43)</td>
</tr>
<tr>
<td>NBQ</td>
<td>-15.19 (17.17)</td>
<td>-18.32 (15.03)</td>
</tr>
</tbody>
</table>

Table 8.2: Changes in TFI and NBQ in subjectively improved and not improved patients

* Significantly different between improved and not improved patients.

TFI: Tinnitus Functional Index; NBQ: Neck Bournemouth Questionnaire

When exploring the tinnitus characteristics, it can be noted that patients suffering from low-pitched tinnitus are significantly more likely to benefit from the applied treatment than patients suffering from high-pitched tinnitus (87% of the patients versus 48%) (p = 0.04). No differences were found regarding the quality (noise or
pure tone), the continuous or pulsatile nature or the location (unilateral, bilateral or central) of the tinnitus.

Differences in the presence of one or more of the diagnostic criteria for CST were also investigated. Differences between the improved and not improved patients were found for the criterion of ‘increase of tinnitus during inadequate postures while resting, walking, working or sleeping’ (e.g., anteroposition of the head during computer work; rotated position of the head during sleeping). Only 17% of the patients who did not meet this criterion benefited from the treatment compared to 43% of the patients who did meet the criterion (p = 0.03).

When combining low-pitched tinnitus with the ‘increase of tinnitus during inadequate postures while resting, walking, working or sleeping’ criterion, a group of patients could be identified that all experienced substantial improvement of their tinnitus directly after treatment and after the 6-week follow-up period. All of these patients had lower TFI values post-treatment (28.00 points; SD: 8.49) versus 43.65 points (SD: 22.81; p = 0.16) and after the 6-week follow-up period (34.00;SD: 4.02) versus 47.53 (SD: 23.43; p = 0.002) than patients who did not meet both criteria.

8.5.6 Covariation between tinnitus and neck complaints

Covariation between TFI and NBQ scores—meaning that tinnitus and neck complaints decrease or increase together—could be noted in 49% of the study population. At baseline, no significant differences between the covarying and non-covarying groups were present. Directly after treatment and after the 6 week follow-up period, significantly lower TFI values could be noted in the covarying group (p = 0.001 and p = 0.03 respectively). Directly after treatment, the TFI scores were 23.45 points (SD: 6.50) lower in the covarying group. At the 6-week follow-up, the TFI score was an average of 16.64 points (SD: 7.23) lower in the covarying group. No significant differences were found for the NBQ scores.

8.5.7 Prognostic indicators for treatment effect

Table 8.3 shows the prognostic indicators for decrease in TFI score after treatment, their regression coefficients and 95% confidence intervals. A statistically significant association was found for the covariation of tinnitus and neck complaints and for the presence of a low-pitched tinnitus in combination with an ‘increase of tinnitus during inadequate postures while resting, walking, working or sleeping.’ The multiple regression analysis showed that the combination of these variables explained 35% of the TFI decrease after cervical physical therapy.
**Table 8.3: Prognostic indicators of TFI decrease post-treatment: adjusted regression coefficients**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Regression analysis individual</th>
<th>Multiple regression model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>95%CI</td>
</tr>
<tr>
<td>Co-varying</td>
<td>-17.38</td>
<td>-38.83 – (-6.94)</td>
</tr>
<tr>
<td>Low-pitch + Postures</td>
<td>-26.62</td>
<td>-50.88 – (-2.37)</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

B: regression coefficient; β: standardized regression coefficient; CI: confidence interval

### 8.6 Discussion

The primary aim of this study was to identify prognostic indicators that are highly likely to decrease tinnitus complaints after cervical physical therapy. The secondary aim was to investigate the effect of a standardized cervical physical therapy program on several tinnitus and neck related parameters. The applied physical therapy treatment was a noninvasive, approachable and easily available treatment option.

In our study, 53% of the patients experienced substantial improvement of tinnitus immediately after a 6-week treatment period. This effect was maintained after the follow-up period in 24% of the patients. This success rate is high, given the chronicity and the therapy resistance of the tinnitus complaints in our tertiary referral center population. Despite the difference in outcome measures, our results match the results of a study performed by Bakker\(^{130}\) that found a significant decrease of tinnitus after 12 sessions of physical therapy in 62.9% of the patients. This effect was not maintained in any of the patients after follow-up.

Despite the relatively high success rate, our study could not prove a significant difference in TFI scores between the immediate-start and delayed-start groups at week 6 of the study. At this point, we expected the patients in the immediate-start group to experience the effects of the treatment while the delayed-start group had not received treatment yet. Small differences in TFI scores between both groups were found, but due to large standard deviations, these differences were not statistically significant.

It is possible that the TFI is not responsive enough to identify changes in tinnitus at 6 weeks. Meikle et al.\(^{111}\) used a time interval of 3 months to identify the effect sizes of the TFI. In our study, the average TFI decrease in the improved group was 11.9 points, which is similar to the 13-point reduction Meikle et al.\(^{111}\) suggested to be clinically important. The standard deviations, however, were very large in our study.
as well as in that of Meikle et al.\textsuperscript{111}, making it hard to identify statistically significant differences between groups.

The NBQ scores showed significant improvement on the cervical spine complaints immediately after treatment as well as after follow-up. Despite the significant decrease of NBQ scores between baseline and follow-up, a slight increase of NBQ scores can be seen during the follow-up period. In cervical spine treatment studies of other populations, the effect of the treatment on the VAS for pain remained about the same post-treatment and after a 6-week follow-up period\textsuperscript{124,131}.

Various factors may have caused the increase of neck complaints in our study. First, the treatment period of 6 weeks might have been too short for a population with a chronic disorder. In this case, the cervical spine dysfunction may not have disappeared completely, causing a quick reoccurrence after the treatment period. Second, patients might have stopped the home exercises after the last treatment session. These exercises are meant to prevent the reoccurrence of cervical spine dysfunction and need to be continued on a regular basis. Therefore, we suggest the use of more physical therapy sessions over a longer treatment period. For example, 18 sessions spread out over a 12-week treatment period.

Patients were included in this study based on the diagnostic criteria for CST\textsuperscript{22}. After exclusion of other causes of tinnitus, the criterion ‘recurrent pain episodes in head, neck or shoulder girdle’ was used as the main criterion for inclusion, as patients without recurrent pain episodes are not likely to benefit from a cervical spine treatment. The other criteria were also questioned during the anamnesis.

The presence of both an ‘increase of tinnitus during inadequate postures while resting, walking, working or sleeping’ and covariation of tinnitus and neck complaints combined with low-pitched tinnitus resulted in a multivariate model predicting 35\% of the decrease in TFI score.

All patients meeting these criteria experienced substantial improvement of tinnitus directly after treatment and after the 6 week follow-up period. Although these conclusions are based on small numbers, the covariation and low-pitched tinnitus with an ‘increase of tinnitus during inadequate postures while resting, walking, working or sleeping’ seem to be suitable criteria for referring patients for cervical spine treatment. Larger studies, specifically including patients who meet these criteria, are needed.

The predictive power of the presented multivariate model is rather weak, which indicates the need for further examination of other factors that can influence tinnitus decrease.
Low-pitched tinnitus as a prognostic indicator for therapy effect, as mentioned above, is in accordance with a study of Won et al.\textsuperscript{132} that investigated tinnitus modulation. Won et al.\textsuperscript{132} described a unilateral buzzing and low-pitched tinnitus as the most optimal criteria for treatment. Our study could not confirm the influence of a unilateral or buzzing nature of tinnitus on the treatment outcome.

In TFI and NBQ scores, a similar decrease after treatment and increase after follow-up can be noted, and patients with covariation of tinnitus and neck complaints benefited significantly more from cervical spine treatment than patients without this covariation. These findings can be considered proof of the somatosensory influence on the intensity and the character of tinnitus. Complementary, this can contribute to the discussion on a causal relation between tinnitus and neck complaints. This causal relation can be presumed in the specific group of patients with low-pitched tinnitus, covarying with neck complaints and increasing during inadequate cervical spine postures, who all experienced a decrease of their tinnitus both after treatment and after follow-up.

The delayed-start design used in this study has been used previously in slowly progressive debilitating diseases such as Parkinson’s disease. We chose this study design because using a control group that receives no treatment at all would not be advisable or ethical in a tertiary referral center study population.

One of the known difficulties of the delayed-start design is defining the duration of the treatment and the wait-and-see periods\textsuperscript{119}. The treatment period should be long enough for the effect of the therapy in the immediate-start group to become stable\textsuperscript{119}. In the absence of previous studies using the same treatment modalities in tinnitus patients, a period of 6 weeks was chosen based on previous studies treating cervical spine related diseases\textsuperscript{124}. As previously mentioned, 6 weeks might have been too short in a population suffering from chronic tinnitus.

A second difficulty of this study design as mentioned by d’Agostino et al.\textsuperscript{119}, is missing data during the follow-up period. In our study, all patients had an appointment in the tinnitus clinic after the follow-up period and none were lost to follow-up.

In future research, this study should be repeated with only patients suffering from low-pitched tinnitus that covaries with neck complaints and increases during ‘inadequate postures while at rest, walking, working or sleeping’ to investigate the short and long-term effects of cervical physical therapy.
8.7 Conclusion

Prognostic indicators that are highly likely to decrease tinnitus complaints after cervical physical therapy could be identified. The group of patients that benefited most from cervical physical therapy was patients with low-pitched tinnitus covarying with neck complaints and increasing during inadequate cervical spine postures. To prove the efficacy of cervical physical therapy in these patients, the study needs to be repeated to include only the described subgroup.
General Discussion and Conclusions
General discussion

In this chapter the main findings and conclusions of this thesis will be summarized and discussed and the research questions will be answered.

The main goal of this thesis was to investigate the role of cervical spine dysfunctions in patients with chronic subjective tinnitus. To achieve this goal, we divided this thesis into two parts. In general, part 1 deals with the measurement of cervical sensorimotor control (cSMC), one of the outcome parameters we needed in the second part, and part 2 concerns the examination and treatment of cervical spine dysfunctions in patients with tinnitus.

As such, the following research questions are addressed:

1. What is the preferred measuring method for cSMC, taking into account the required task, device and clinimetrics?
2. What is the test-retest reliability of the CLMT?
3. Which cervical dysfunctions are present in patients diagnosed with CST in comparison with patients suffering from other forms of chronic subjective non-pulsatile tinnitus?
   Is cSMC altered in patients suffering from CST compared to asymptomatic controls?
4. What is the diagnostic value of a set of clinical cervical spine tests in diagnosing CST?
5. Which prognostic indicators can predict a positive effect of cervical physical therapy on tinnitus complaints in patients with CST?
6. What is the effect of a standardized cervical physical therapy program on tinnitus and neck related parameters in patients with CST?

CERVICAL SENSORIMOTOR CONTROL

Cervical sensorimotor control includes cervical somatosensory information. This cervical somatosensory afference is assumed to play a role in altered intensity of tinnitus in patients with CST. Therefore, we wanted to investigate cSMC in patients with tinnitus. The first part of this dissertation was needed to find a reliable and valid cSMC-measuring technique.
PREFERRED MEASURING METHOD FOR cSMC

Since various cSMC-measuring methods exist, we performed a systematic review to verify if a preferential method can be identified, taking the required task and the methodological quality of the test into account. We found that the reliability and validity of cSMC-measuring methods can vary, depending on the used method and on the way they are applied.

Currently, HRA-to-NHP measurements are the most widely used and they are considered to be the ‘gold standard’. During the HRA-to-NHP test a subject is asked to return to his or hers neutral head position after, for example, rotating the cervical spine. The average deviation from the actual neutral head position results in the outcome parameter: the joint position error (JPE).

Several studies have investigated the reliability and validity of this test. A fair to excellent reliability has been reported, with ICCs ranging from 0.35 to 0.87\cite{41, 51, 52}. The device used to register the JPE does apparently not affect the reliability of this test. Similar ICCs were found in studies using the laser pointer\cite{41}, the electromagnetic trackers\cite{51} and the ultrasound based trackers\cite{52}. The HRA-to-NHP also has good discriminant validity (table 1.2). Seven authors\cite{36-40, 55, 66} demonstrated differences between WAD patients and controls. In four out of five studies\cite{35, 39, 63, 65} the HRA-to-NHP could also demonstrate a difference between patients with non-traumatic neck pain and controls. On the contrary, no differences could be demonstrated between patients with WAD and patients with non-traumatic neck pain using the HRA-to-NHP. Possibly, JPEs are equally increased in both patient groups and other outcome measures, taking into account the entire movement trajectory, are needed to differentiate between these patient populations\cite{39, 43, 44}.

The Fly™ is such a method that uses kinematic parameters for trajectory registrations. The reliability of The Fly™ can be considered as moderate to excellent (ICC: 0.60 – 0.86)\cite{54, 68} and the discriminant validity seems to be good when comparing patients with WAD to controls and to patients with non-traumatic neck pain (table 1.4). The ability of The Fly™ to detect differences between different patient populations suggests a diagnostic potential. Despite the initial interesting results, a pilot study showed us that the device accompanying The Fly™ software (InterSense InertiaCube™) was too unreliable and the measuring errors too large for further use in our research (addendum)\cite{89}.

Based on the included literature in 2011, two measuring methods were sufficiently reliable and valid to objectify cSMC. The reliability of the HRA-to-NHP was investigated in several studies and the test proved to be able to discriminate between patient populations and control subjects. Questions arise however,
regarding the content validity of this test, as the HRA-to-NHP only measures the position sense\textsuperscript{39,43,44}.

The Fly\textsuperscript{TM} test seemed to have good reliability and good content as well as discriminant validity, shown in studies of good to excellent methodological quality (6 and 7 out of 8 points). The Fly\textsuperscript{TM} is able to discriminate between different patient populations (WAD and non-traumatic neck pain), but these results were based on few studies. Currently, no new information is available on the reliability and validity of the Fly\textsuperscript{TM} test. The one research group that developed the test is still the only one that uses it. Additional studies, using the original setup with the electromagnetic tracking system, performed by independent researchers, should be performed to confirm the reliability and validity of The Fly\textsuperscript{TM}. Therefore, based on literature search, the HRA-to-NHP in the meantime remains the ‘gold standard’ in cSMC assessment.

**RELIABILITY OF THE CLMT**

Based on a systematic review\textsuperscript{88} (chapter 1) we concluded that the CLMT was one of the tests with good discriminant validity and comparable construct as The Fly\textsuperscript{TM}. Its reliability was not investigated yet. To verify the usefulness of this test in a clinical study, the test-retest reliability needed investigation.

The CLMT uses kinematic parameters to objectify the quality of the movement throughout the entire trajectory. Time and variation in time needed to perform one movement cycle are registered, as patients suffering from cervical spine problems are thought to move slower than control subjects. In the same rationale patients with neck pain are expected to have more limited range of motion (ROM) of the cervical spine. Both time and ROM are used to calculate the peak velocity and Jerk Index, which objectifies the smoothness of the movement.

Our reliability study\textsuperscript{90} showed negligible to excellent reliability results (ICC/$k_w$: 0.00 – 0.95), depending on the used outcome measure. The time and variation in time needed to perform one movement cycle seemed to be reliable parameters when studying movement trajectories. The discriminant validity of these parameters has not yet been investigated. Our results also indicate that the ROM can be used as a reliable parameter in objectifying movement trajectories in future research. Since ROM changes with increasing age\textsuperscript{86}, an age representative control group is recommended for studies comparing patients and control subjects. The peak velocity is currently not a recommended outcome parameter due to very limited reliability as well as low discriminant validity\textsuperscript{42}. Replacing the peak velocity by the average velocity should be considered, since this average velocity has shown good validity results in a study of Öhberg et al.\textsuperscript{75}. 

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The Jerk index showed a very weak to weak inter rater reliability ($\kappa_w$: 0.00 to 0.31) and weak to good intra rater reliability ($\kappa_w$: 0.27 to 0.69). The validity study of Sjölander et al.\textsuperscript{42} showed differences in Jerk index values during rotation movements between patients with neck complaints and asymptomatic controls. Due to these contradictory reliability and validity results, this parameter needs further investigation before generalized use can be recommended.

In conclusion, the CLMT has shown good discriminant validity and better construct validity than the HRA-to-NHP, although the reliability of some of the outcome parameters is questionable. Taking into account the validity as well as the reliability results, we recommend using the time (time and variation in time), ROM and Jerk index parameters, preferably during rotation movements, as these are the most reliable.

**Tinnitus and the cervical spine**

The second part of this thesis aimed to investigate cervical spine dysfunction in patients suffering from chronic subjective tinnitus, since a subgroup of these patients has been described where altered cervical somatosensory afference is presumed to alter or cause the tinnitus. Although this subgroup has been described\textsuperscript{22,133} and positive effects of physical therapy on tinnitus complaints have been reported\textsuperscript{22}, very little was known about the type of cervical dysfunction present in these patients. Additionally, no information was available on how to identify those patients that are most likely to benefit from physical therapy treatment, nor was it clear which treatment modalities should be implemented in the physical therapy treatment.

**Cervical spine dysfunction in patients with tinnitus**

At the start of our study it was unclear which cervical spine dysfunctions are present in patients with CST, and no information was available on the presence of cervical spine dysfunction in non-CST patients. Therefore, the prevalence and nature of cervical spine dysfunction in patients suffering from subjective tinnitus was investigated\textsuperscript{134} (chapter 4). In our study, 43% of the included patients were diagnosed with CST. This number corresponds with the percentages reported in literature\textsuperscript{16,94,95}, implying that our patient sample was representative for the entire population.

In response to the publication of these results, our way of diagnosing CST was questioned in a ‘Letter to the editor’\textsuperscript{135}. Unlike what Bhatt et al.\textsuperscript{135} presumed, the diagnosis of CST was not based on one key criterion. As we explained in our
response to this ‘Letter to the editor’, the diagnosis of CST was made after thorough ENT examination (including micro-otoscopy, audiological assessment and brain MRI) to exclude other causes of tinnitus. In case no other cause was found, the CST diagnosis was made based on all diagnostic criteria for CST. The association between onset or exacerbation of tinnitus and neck complaints was an important but not exclusive criterion for the diagnosis. Nevertheless, we have to stress that our study population does not include patients with whiplash associated disorders and therefore does not represent the entire CST population.

Cervical spine complaints (NBQ > 14 points) were present in 56% of the included patients. Significantly more patients in the CST group (79%) had a positive score on the NBQ (> 14 points), although still 40% in the non-CST group had cervical spine complaints. This 40% corresponds to the prevalence of neck pain in the general population. Hence, the presence of cervical spine complaints can be a first indicator for the CST diagnosis, but additional tests are necessary as a substantial part of the non-CST population also complains of cervical spine problems.

The clinical examination of the cervical spine showed significantly higher prevalences in the CST group for the manual rotation, AST, the combination of both manual rotation and AST and the presence of trigger points. No significant differences between both groups were found in strength and endurance of DNF. These results correspond to the findings of Reisshauer et al. who reported a rotation deficit and the presence of sensitive trigger points in the M sternocleidomastoideus, M trapezius and M levator scapulae in patients with CST.

No significant differences were found in tinnitus loudness, Tinnitus Questionnaire, hyperacusis and hearing impairment between the CST and non-CST group. These results correspond to the findings of Vielsmeier et al. in patients with or without temporomandibular joint related somatic tinnitus. These results favor a non-specific reaction pattern, regardless the tinnitus subtype.

In conclusion, we agree with the statement of Langguth et al. that the examination of the cervical spine is essential in the investigation of tinnitus patients. In addition to this statement, we recommend to include cervical spine tests and the NBQ in the diagnostic work-up of chronic subjective tinnitus patients. A positive NBQ (> 14 points) can be used as a first indicator for CST, but a thorough cervical spine examination, performed by a trained investigator, is needed. Additionally, we have to keep in mind that cervical spine complaints are also highly prevalent in non-CST patients.
CERVICAL SENSORIMOTOR CONTROL IN PATIENTS WITH TINNITUS

Apart from the clinical cervical spine tests, we were also interested in potential cSMC problems in patients suffering from CST, as cSMC problems can change the cervical somatosensory afference, which is thought to alter the intensity and character of the tinnitus in patients with CST. Therefore, we investigated the differences in cSMC between patients with CST and asymptomatic controls using the CLMT (chapter 6).

The outcome parameters of the CLMT showed that patients with tinnitus needed significantly more time to perform one movement cycle compared to asymptomatic controls. This is in line with the expected based on measurements of movement time during a cervical circumduction movement comparing neck pain patients and asymptomatic controls\(^{113}\).

The flexion-extension ROM was significantly smaller in the patient group. In the other movement directions, this difference, however present, was not statistically significant. These results are similar to the findings of Sjolander et al.\(^{42}\), who found no significant differences in ROM between patients with insidious neck pain and asymptomatic controls, although a smaller rotation ROM was noted in the patient group. This smaller rotation ROM is also in line with our findings using the manual rotation test\(^{106}\) (chapter 4) and with the rotation deficit in patients with tinnitus shown in the study of Reisshauer et al.\(^{98}\). Based on these studies however, a significant difference between patients with tinnitus and asymptomatic subjects would be expected.

The limited significance of the differences in ROM in our study as well as in the study of Sjolander et al.\(^{42}\), might be caused by a lack of standardization of the movement speed. Since Bonnechère et al.\(^{114}\) have found a significant difference in ROM depending on the movement speed, large within-group differences may have caused the limited differences between patients and controls. Additionally, it must be noted that when a subject moves faster than 2.1° per second, cervical input decreases and vestibular input increases\(^{115}\). In cSMC measurement we are especially interested in the cervical input and less in the vestibular input. Using a standardized movement speed, for instance 0.5° per second, could increase the differences in ROM between patients and controls to a significant level and would ensure us to mainly measure cervical input instead of vestibular input. The 0.5° per second is the average cycle time reached by the patients in our study and should therefore be achievable in patients suffering from neck pain as well as in control subjects. To make sure patients move at the required pace a metronome can be used as an indication for the movement speed in future research.
Larger Jerk indexes were found during rotation movement in the patient group compared to the controls. These results are similar to the results of Sjolander et al.\textsuperscript{42}. Previous research\textsuperscript{90} (chapter 2) has shown that Jerk Index measurements are most reliable during rotation movements as the test-retest reliability during flexion-extension and lateral flexion is very limited\textsuperscript{90}. Therefore, we advise to primarily use the rotation movement for obtaining Jerk indexes in future research.

Generally, cSMC in patients with CST is altered in terms of increased time needed to perform one movement cycle and increased Jerk Index during rotation. This indicates that patients with CST move more carefully and jerkier than asymptomatic controls, which was also seen in patients with other cervical spine related disorders\textsuperscript{42,113}. We recommend investigating both time and Jerk Index parameters and the ROM in patients with CST. Further investigation of the ROM in conditions of standardized movement speed (< 2.1°/s) is however necessary. Additionally, cSMC training should be included in the physical therapy treatment of patients with CST.

**Diagnostic value of clinical cervical spine tests in diagnosing CST**

Currently, the CST diagnosis is solely based on anamnestic data. Hence, additional tests for discriminating between patients with CST and patients with other types of tinnitus would be very useful. Therefore, we investigated the diagnostic value of the cervical spine tests that were used in chapter 4, for diagnosing CST.

We found that several tests can be useful in the diagnostic process of CST. In patients with suspected CST, the NBQ can be administered first. In case of an NBQ score <14 points, the diagnosis of CST becomes less likely. Similar results were found for using the NBQ to diagnose patients suffering from neck pain\textsuperscript{92}. The trigger point test can be added to the NBQ in the diagnostic evaluation of patients with suspected CST. The absence of trigger points will reduce the probability of CST.

In case of a positive NBQ, the risk of false positives needs to be decreased by using a highly specific test, such as the combination of manual rotation and AST tests. In case both manual rotation and AST are positive, the diagnosis of CST becomes more likely. Similar results were previously found for using the manual rotation and AST to diagnose patients with neck pain and cervical facet joint pain\textsuperscript{92,108}. Using a combination of tests will increase the diagnostic value as is demonstrated in a study of Schneider et al.\textsuperscript{108} investigating cluster diagnostics in patients with cervical facet joint pain.

In conclusion, we demonstrated that clinical cervical spine tests can support the diagnostic process of patients with CST. An NBQ score < 14 points and the absence
of trigger points can help to exclude CST and a positive manual rotation and AST can help to include CST. As already stated above, cervical spine complaints are also highly prevalent in non-CST patients. Therefore, we advise to include these tests in a multidisciplinary assessment.

**Prognostic Indicators for Predicting Positive Effect of Physical Therapy on Tinnitus**

Although several case studies and case series\(^ {22,23,27,138}\) have reported positive effects of cervical spine therapy on subjective tinnitus parameters, it was still unknown which patients are most likely to benefit from the treatment. Therefore, this thesis aimed to identify prognostic indicators for a decrease in tinnitus complaints after cervical physical therapy. To achieve this goal, we used a RCT applying a standardized cervical physical therapy treatment in patients with suspected CST.

The RCT showed that the presence of both an ‘increase of tinnitus during inadequate postures’ and covariation of tinnitus and neck complaints combined with low-pitched tinnitus resulted in a multivariate model predicting 35% of the decrease in TFI-score after cervical physical therapy treatment.

All patients meeting these criteria experienced substantial improvement of their tinnitus directly after treatment and after the 6 week follow-up period. Although these conclusions are based on small numbers, the covariation and low-pitched nature of the tinnitus with an ‘increase of tinnitus during inadequate postures’ seem to be suitable criteria for referring patients for cervical spine treatment. Larger studies, specifically including patients who meet these criteria, are needed to confirm our results. The predictive power of the presented multivariate model is rather weak, which indicates the need for further examination of other factors that influence tinnitus decrease in these patients.

Low-pitched tinnitus as a prognostic indicator for therapy effect, as mentioned above, is in accordance with a study of Won et al.\(^ {132}\) that investigated somatic tinnitus patients. Won et al.\(^ {132}\) described a unilateral buzzing and low-pitched tinnitus as the most optimal criteria for treatment. Our study could not confirm the influence of a unilateral or buzzing nature of tinnitus on the treatment outcome.

In TFI and NBQ scores, a similar decrease after treatment and increase after follow-up can be noted, and patients with covariation of tinnitus and neck complaints benefited significantly more from cervical spine treatment (TFI decrease) than patients without this covariation. These findings can be considered proof of the somatosensory influence on the intensity and the character of tinnitus.
Complementary, this can contribute to the discussion on a causal relation between tinnitus and neck complaints. This causal relation can be presumed in the specific group of patients with low-pitched tinnitus, covarying with neck complaints and increasing during inadequate cervical spine postures, who all experienced a significant decrease of their tinnitus both after treatment and after follow-up.

In summary, we recommend to primarily refer patients with low-pitched tinnitus, covarying with neck complaints and increasing during inadequate cervical spine postures for cervical physical therapy, as these patients benefited most from cervical physical therapy in our study. To confirm the efficacy of cervical physical therapy and to identify other factors that influence tinnitus decrease in these patients, the study needs to be repeated including only the described subgroup.

THE EFFECT OF CERVICAL PHYSICAL THERAPY ON TINNITUS AND NECK RELATED PARAMETERS

The use of cervical spine treatment in patients with tinnitus was still under dispute at the start of our study, because the existing studies often showed inconclusive or contradictory results and frequently lacked scientific quality due to very limited numbers of patients or lack of control groups and randomization. Therefore we investigated the effect of a standardized cervical physical therapy treatment program on tinnitus and neck related parameters in patients with suspected CST, using a RCT with delayed treatment design.

Immediately after treatment 53% of the tinnitus patients experienced a substantial improvement of their tinnitus. The TFI-scores decreased significantly (p = 0.04) after treatment compared to baseline, as did the NBQ-scores (p = 0.001). All patients experienced a substantial improvement of their neck complaints, also the 47% that did not experience improvement of their tinnitus complaints.

Despite the relatively high success rate, taking into account the therapy resistance of our tertiary center population, our study could not prove a significant difference in TFI-scores between the immediate-start and delayed-start groups at week 6 of the study. At this point, we expected the patients in the immediate-start group to experience the effects of the treatment while the delayed-start group had not received treatment yet. Small differences in TFI-scores between both groups were found, but due to large standard deviations, these differences were not statistically significant.

It is possible that the TFI is not responsive enough to identify changes in tinnitus at 6 weeks. Meikle et al. used a time interval of 3 months to identify the effect sizes of the TFI. In our study, the average TFI decrease in the improved group was 11.9
points, which is similar to the 13-point reduction Meikle et al.\textsuperscript{111} and Henry et al.\textsuperscript{139} suggest being clinically important. The standard deviations however, were very large in our study as well as in other studies \textsuperscript{111,139}, making it hard to identify statistically significant differences between groups. The use of other, more responsive questionnaires is recommended for identifying differences in tinnitus complaints in future research. It is also advisable to investigate the possibilities of audiological tests such as speech-in-noise tests\textsuperscript{140} to measure changes in tinnitus complaints after treatment.

The NBQ-scores showed significant improvement on the cervical spine complaints immediately after treatment as well as after follow-up. Despite the significant decrease of NBQ-scores between baseline and follow-up, a slight increase of NBQ-scores can be seen during the follow-up period. In physical therapy studies in other cervical spine populations, the effect of the treatment on the VAS for pain remained about the same post-treatment and after a 6-week follow-up period \textsuperscript{124,131}.

Various factors may have caused the increase of neck complaints in our study. Firstly, the treatment period of 6 weeks might have been too short for a population with a chronic disorder. In this case, the cervical spine dysfunction may not have disappeared completely, causing a quick reoccurrence after the treatment period. Secondly, patients might have stopped the home exercises after the last treatment session. These exercises are meant to prevent the reoccurrence of cervical spine dysfunction and need to be continued on a regular basis. Therefore, we suggest the use of more physical therapy sessions over a longer treatment period. For example, 18 sessions spread out over a 12-week treatment period, because doubling the treatment period would decrease the risk of remaining cervical spine complaints at the last session.

In conclusion, further research, only including the patients that are most likely to benefit from cervical physical therapy and extending the treatment period to 12 weeks, is necessary to investigate the short and long-term effects of cervical physical therapy on CST complaints. We also advise to seek a more responsive tinnitus questionnaire and to investigate the possibilities of using audiological tests to measure changes in tinnitus complaints.
RECOMMENDATIONS FOR FUTURE RESEARCH

CERVICAL SENSORIMOTOR CONTROL

CSMC is not only a topic of interest in the population of patients with CST, but altered CSMC has also been reported in patients with nonspecific neck pain\(^\text{39,65}\), cervicogenic dizziness\(^\text{48,60}\) and whiplash patients\(^\text{36-40}\). Although CSMC assessment is investigated in numerous patients with cervical spine related complaints, the assessment itself remains challenging. Currently, based on literature review, the HRA-to-NHP remains the ‘gold standard’, although the content validity of this test is questionable\(^\text{39,43,44}\) and the discriminant validity to differentiate between patient populations is very limited\(^\text{43,44}\). To maximize the reliability of the HRA-to-NHP in future research we recommend sufficient training of the procedure for the examiner, as test-retest reliability can decrease in untrained circumstances. When comparing groups, the homogeneity of groups for e.g. age and gender should be guarded, as CSMC might change with increasing age\(^\text{141}\) and no information is available yet on CSMC differences between men and women.

The Fly™ is a relatively new test that has shown promising reliability and validity results\(^\text{54,68}\). The ability of The Fly™ to detect differences between different patient populations, suggests a diagnostic potential that should be confirmed. Additional studies, using the original setup with the electromagnetic tracking system, performed by independent researchers, should be performed to confirm the reliability and validity of the Fly test.

Another relatively new test is the CLMT. The validity of this test to discriminate between neck pain patients and asymptomatic controls was investigated by Sjolander et al. \(^\text{42}\). In our study the reliability \(^\text{106}\) was investigated and found to be good, especially during rotation movements. Differences were found between patients with CST and asymptomatic controls using this test. The validity of time and variation in time parameters has not yet been investigated, but significant differences between patients with CST and controls were demonstrated using these parameters. The validity of the time and variation in time parameters to discriminate between patients with neck complaints and asymptomatic controls and between different patient populations should be investigated.

The Jerk index showed contradictory reliability and validity results. We advise to primarily use the rotation movement for obtaining Jerk indexes in future research, as the Jerk index showed the highest reliability and discriminant validity during this movement. The Jerk index needs further investigation, taking into account the
effect of movement speed and measuring equipment, before generalized use can be recommended.

As the peak velocity parameter of the CLMT showed limited reliability and validity in both our study and the study of Sjolander et al. 42, we recommend to replace the peak velocity by the average velocity. The average velocity has already shown good validity results in a study of Öhberg et al. 75. The reliability of this parameter is still to be investigated.

Currently, none of the existing cSMC-measuring methods are able to quantify cSMC in real life circumstances, taking into account everyday movements and postures. In an ideal situation, we would be able to record cSMC using daytime analysis (e.g. 12 hour cSMC-assessment) while the patient performs his or her daily activities. A more realistic alternative on short notice, would be the use of virtual reality systems during cSMC assessment, since these systems are already used in sensorimotor training 142.

TINNITUS AND THE CERVICAL SPINE

The studies described in chapters 4, 5 and 6 of this thesis were the first to investigate the nature of cervical spine dysfunction in patients suffering from tinnitus. Several cervical spine dysfunctions were identified in patients with CST, but further research, including other highly reliable clinical cervical spine tests is needed. Especially the strength and endurance of the deep neck flexor muscles should be investigated more thoroughly, as unexpectedly we were unable to find differences between the CST and non-CST groups. When using the CCFT, 26 mmHg 93 should be used as a cut off for normal instead of the 30 mmHg we used in our study. A test, first described by Grimmer et al. 110,143,144, can also be considered for measuring the endurance of the deep neck flexors. This test is far less complicated and time consuming than the CCFT and showed good reliability results (ICC: 0.83 – 0.88).

The trigger point test we used in our study has also been used in other studies investigating tinnitus patients 98,105,138. The test-retest reliability using manual pressure can however be questioned. The use of pressure algometry could increase the reliability of this test in future research, as shown in a recent study of Wytrazek et al. 145. Specific training of health professionals for using pressure algometry in trigger point testing will be necessary in the future.

The RCT, described in chapter 7 and 8, tried to take into account and avoid methodological shortcomings that were identified in previous studies 23. Therefore, we used a delayed treatment design, so blinding of subjects, therapists and raters
was possible. Additionally, we randomly assigned our subjects to the different groups and allocation was concealed. The generalizability of the study results was maximized by clearly describing the inclusion criteria.

Our RCT could identify a group of patients, suffering from low-pitched tinnitus, covarying with neck complaints and increasing during inadequate cervical spine postures, that benefitted significantly more from cervical physical therapy than other patients with CST. To prove the efficacy of cervical physical therapy and to identify other factors that influence tinnitus decrease in these patients, the study needs to be repeated including only the described subgroup. To maximize the therapy effect, we suggest using more physical therapy sessions over a longer period. For example, 18 sessions spread out over a 12-week treatment period. This treatment is more intensive and prolonged than usual in cervical spine related complaints\textsuperscript{124,131}, but the chronic nature of the cervical spine complaints as well as the tinnitus in our study advocates this adaptation.

Additionally, adding other treatment modalities, such as TRT or CBT\textsuperscript{11}, to the cervical physical therapy should be considered, as chronic subjective tinnitus is a complex problem and various factors can influence the decrease or increase of the patient’s tinnitus. Especially central sensitization should be taken into account in this population of chronic subjective tinnitus patients\textsuperscript{146,147}. We therefore suggest a multidisciplinary treatment including, but not limited to cervical physical therapy in patients with CST.

This new RCT should also use different, more responsive, tools for measuring changes in tinnitus complaints. The TQ should be considered, as the sensitivity for change proved to be very good in a study of Zeman et al.\textsuperscript{148}. Future research should also look for possible changes in audiological parameters, such as speech-in-noise\textsuperscript{140}, after cervical physical therapy in patients with CST.
**FINAL CONSIDERATION**

The evaluation and treatment of CST should be a regular feature in the management of every patient suffering from tinnitus. Hence, cervical spine assessment is essential in the investigation of patients with subjective tinnitus. Additionally, in the group of patients with covarying tinnitus and neck complaints, cervical physical therapy treatment should be considered as part of the multidisciplinary treatment of tinnitus. Physical therapists can consequently have a supportive role in the multidisciplinary diagnostic process and treatment of CST, given their specific skills in cervical spine evaluation and treatment. By investigating the presence of cervical spine dysfunctions and the effect of cervical physical therapy in patients with CST, this thesis intended to answer some of the pending questions regarding CST.


Appendix

1 Fleiss, 1986 Classification

<table>
<thead>
<tr>
<th>ICC - value</th>
<th>Verbal descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 0.75</td>
<td>Excellent</td>
</tr>
<tr>
<td>0.40 – 0.75</td>
<td>Fair to good</td>
</tr>
<tr>
<td>&lt; 0.40</td>
<td>Poor</td>
</tr>
</tbody>
</table>

2 Methodological Quality of Articles in Chapter 1

In the table below, we present the methodological quality of the individual articles that were presented in the review in chapter 1.

The checklist we used, was developed by the Dutch institute for healthcare improvement (CBO) and contains 8 questions that are answered with yes or no. Every positive answer results in 1 extra point on the total score of 8 points. In general the checklist questions the patient selection, description of an index test and reference tests. A score < 5 was considered as poor quality, 5-6 as good and 7-8 as excellent quality.
<table>
<thead>
<tr>
<th>Author, Year of publication</th>
<th>Methodological quality score ( / 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heikkilä 1996</td>
<td>5</td>
</tr>
<tr>
<td>Grip 2007</td>
<td>6</td>
</tr>
<tr>
<td>Hill 2009</td>
<td>5</td>
</tr>
<tr>
<td>Kristjansson 2003</td>
<td>7</td>
</tr>
<tr>
<td>Kristjansson 2004</td>
<td>6</td>
</tr>
<tr>
<td>Lee 2006</td>
<td>7</td>
</tr>
<tr>
<td>Lee 2008</td>
<td>7</td>
</tr>
<tr>
<td>Loudon 1997</td>
<td>5</td>
</tr>
<tr>
<td>Pinsault 2009</td>
<td>6</td>
</tr>
<tr>
<td>Pinsault 2008</td>
<td>5</td>
</tr>
<tr>
<td>Revel 1991</td>
<td>6</td>
</tr>
<tr>
<td>Rix 2009</td>
<td>7</td>
</tr>
<tr>
<td>Sjölander 2008</td>
<td>7</td>
</tr>
<tr>
<td>Feipel 2006</td>
<td>6</td>
</tr>
<tr>
<td>Roren 2009</td>
<td>6</td>
</tr>
<tr>
<td>Heikkilä 2000</td>
<td>7</td>
</tr>
<tr>
<td>Heikkilä 1998</td>
<td>8</td>
</tr>
<tr>
<td>Kristjansson 2001</td>
<td>5</td>
</tr>
<tr>
<td>Treleaven 2003</td>
<td>7</td>
</tr>
<tr>
<td>De Hertogh 2008</td>
<td>8</td>
</tr>
<tr>
<td>Kristjansson 2010</td>
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</tr>
<tr>
<td>Strimpakos 2006</td>
<td>6</td>
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<tr>
<td>Palmgren 2009</td>
<td>7</td>
</tr>
<tr>
<td>Woodhouse 2008</td>
<td>7</td>
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<tr>
<td>Kramer 2009</td>
<td>6</td>
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<tr>
<td>Treleaven 2008</td>
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<td>Demaile-Wldyka 2007</td>
<td>6</td>
</tr>
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<td>Rix 2001</td>
<td>7</td>
</tr>
<tr>
<td>Armstrong 2005</td>
<td>5</td>
</tr>
<tr>
<td>Dehner 2008</td>
<td>6</td>
</tr>
<tr>
<td>Hallgren 2008</td>
<td>6</td>
</tr>
<tr>
<td>Lark 2007</td>
<td>7</td>
</tr>
<tr>
<td>Michaelson 2003</td>
<td>6</td>
</tr>
<tr>
<td>Revel 1994</td>
<td>7</td>
</tr>
</tbody>
</table>
3 TINNITUS ASSESSMENT PROCEDURES

3.1 VAS-LOUDNESS

The loudness of the tinnitus is rated using a visual analogue scale (VAS). The patient is asked to indicate the average loudness of his or her tinnitus on a 10 cm horizontal line. On this line, the left end indicates ‘no tinnitus’ and the right end indicates ‘as loud as you can imagine’.

3.2 TINNITUS QUESTIONNAIRE

Tinnitus related distress was measured using the Dutch version of the Tinnitus Questionnaire (TQ) (based on Hallam et al., 1988\textsuperscript{150}), that was validated in 2007\textsuperscript{151}. The TQ consists of 52 questions of which 40 are used for calculating the total score and 2 are counted double (items 5 and 20)\textsuperscript{148}. The questions are answered on a 3-point scale, ranging from ‘true’ (scoring 0), ‘partly true’ (scoring 1) to ‘not true’ (scoring 2). The total score on the TQ ranges from 0 to 84\textsuperscript{148}.

3.3 HYPERACUSIS QUESTIONNAIRE

Hyperacusis was quantified and characterized using the Dutch version of the Hyperacusis questionnaire (HQ)\textsuperscript{152} (based on Khalfa et al., 2002\textsuperscript{153}). This questionnaire consists of 14 questions that are answered on a 4-point scale, ranging from ‘No’ (scoring 0 points), ‘Yes, a little’ (scoring 1 point), ‘Yes, quite a lot’ (scoring 2 points to ‘Yes, a lot’ (scoring 3 points)\textsuperscript{153}. Scores on the HQ consequently range from 0 to 42 and the cut-off value for hyperacusis is 28 points\textsuperscript{153}.

3.4 PURE TONE AVERAGE

Pure-tone audiometry was performed using the British Society of Audiology procedures (British Society of Audiology, 2008) at 0.5kHz, 1kHz, 2kHz. Pure-tone average (PTA) is calculated as the average of hearing sensitivity at 500, 1000, and 2000.
4 RESULTS OF THE VALIDITY STUDY OF THE FLY™

The validity of The Fly™ setup was investigated by comparing the data of range of motion and head repositioning accuracy tests using The Fly™ and VICON®. Both The Fly™ and VICON® markers were mounted on the same headband, so similar results and high correlation coefficients could be hypothesized.

The following tables present the Pearson or Spearman correlation coefficients of a range of motion test and a head repositioning accuracy test, comparing the results of The Fly™ and VICON® setup.

<table>
<thead>
<tr>
<th>HRA</th>
<th>Correlation Coefficient</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pearson</td>
<td>Spearman</td>
</tr>
<tr>
<td>Extension</td>
<td>-0.123</td>
<td>-</td>
</tr>
<tr>
<td>Flexion</td>
<td>0.094</td>
<td>-</td>
</tr>
<tr>
<td>Left rotation</td>
<td>-0.341</td>
<td>-</td>
</tr>
<tr>
<td>Right rotation</td>
<td>-</td>
<td>0.059</td>
</tr>
</tbody>
</table>

Correlation coefficients of the head repositioning accuracy test using The Fly™ and VICON® setup

<table>
<thead>
<tr>
<th>ROM</th>
<th>Correlation Coefficient</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pearson</td>
<td>Spearman</td>
</tr>
<tr>
<td>Extension</td>
<td>0.146</td>
<td></td>
</tr>
<tr>
<td>Flexion</td>
<td>0.025</td>
<td></td>
</tr>
<tr>
<td>Left rotation</td>
<td>0.211</td>
<td></td>
</tr>
<tr>
<td>Right rotation</td>
<td>0.835*</td>
<td></td>
</tr>
<tr>
<td>Left lateralflexion</td>
<td>-0.434</td>
<td></td>
</tr>
<tr>
<td>Right lateralflexion</td>
<td>0.607*</td>
<td></td>
</tr>
</tbody>
</table>

Correlation coefficients of the range of motion test using The Fly™ and VICON® setup (* p<0.05)

This study showed overall very weak correlations between The Fly™ and VICON® setup. Additionally, an average difference of 27.91° was found between The Fly™ and VICON® data.
Curriculum Vitae

PERSONALIA

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EDUCATION

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EMPLOYMENTS

CLINICAL WORK
• Physiotherapist and manual therapist in own private practice, 2008 – present
• Physiotherapist and manual therapist in various private practices, 2005 – 2009

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• Co-supervisor of MSc dissertations (34 completed)

RESEARCH ACTIVITIES
Evaluation and treatment of the cervical spine in tinnitus patients. Supervisors: Prof. dr. P. Van de Heyning, Prof. dr. W. De Hertog, funded by the research council of the University of Antwerp / Artesis Hogeschool Antwerpen.
List of Publications

JOURNAL PAPERS

- Michiels S., De Hertogh W., Truijen S., Van de Heyning P. Physical therapy treatment in patients suffering from cervicogenic somatic tinnitus: study protocol for a randomized controlled trial. Trials 2014; 15: 297
- Michiels S., Van de Heyning P., Truijen S., De Hertogh W., Diagnostic value of clinical cervical spine tests in patients with cervicogenic somatic tinnitus, Physical Therapy 2015 Apr; 95
- Michiels S., Van de Heyning P., Truijen S., Hallemans A., De Hertogh W., Cervical Physical Therapy in Patients with Cervicogenic Somatic Tinnitus: A Randomized Controlled Trial Assessing Prognostic Indicators, under review in Clinical Otolaryngology
CONFERENCE PAPERS


- Michiels S., De Hertogh W., Truijen S., Van de Heyning P. The presence of cervical spine dysfunctions in tinnitus patients. ITS congress, 21-24 May, 2014

- Michiels S., De Hertogh W., Truijen S., Van de Heyning P. The presence of cervical spine dysfunction in tinnitus patients. BBS congress, 29 November, 2014

- Michiels S., De Hertogh W., Truijen S., Van de Heyning P., The effect of physical therapy treatment in patients suffering from cervicogenic somatic tinnitus. TRI conference, Ann Arbor, Michigan, USA, 7-10 June, 2015
Dankwoord

Toen ik 14 jaar geleden aan mijn opleiding kinesitherapie begon, had ik nooit kunnen denken dat ik me zou gaan verdiepen in wetenschappelijk onderzoek, laat staan dat ik ooit een doctoraat zou schrijven. Maar in de loop van mijn opleiding kinesitherapie en later manuele therapie, werd mijn interesse in wetenschappelijk onderzoek gewekt.

Uiteraard had ik dit traject nooit alleen tot een goed einde kunnen brengen. Daarom wil ik in dit dankwoord iedereen bedanken die van ver of kortbij heeft bijgedragen aan mijn doctoraatstraject.

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