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Neck Motion Analysis Using a Virtual Environment

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1. Introduction

Neck pain is common and constitutes a major cause of disability in the western world with significant ramifications to the injured individuals and to society at large (Hogg-Johnson, S. et al. 2008). A need exists for an objective evaluation of the impairments and disabilities associated with this disorder for both diagnostic and prognostic purposes. An objective assessment is needed in the subgroup of whiplash associated disorders, where secondary gains (e.g., monetary compensation) may have a significant effect on performance.
The overall purpose of our research project was to develop an objective and functional assessment of cervical motion. Using this assessment, it was aimed to investigate the effect of neck pain on cervical motion by kinematic analysis. The future goal is to use the developed system for treatment purposes.
This chapter will review the literature related to neck pain as a significant health problem, existing methods for neck assessment and the use of virtual reality (VR) in rehabilitation. This will be followed by description of the developed VR assessment, outcome measures, testing procedures, and statistical analyses. This chapter will present reliability, range of motion (ROM) and kinematic results. It will review the significance of findings in light of existing research, and will indicate contributions of current results to the understanding of the effect of neck pain on motion. Clinical applications, limitations and future goals will conclude this chapter.

1.1 Neck pain- definition, pathomechanisms and epidemiology

Neck pain as described by the Neck Task Force (Bone and Joint Decade 2000-2010) is pain located anywhere inferior to the superior nuchal line and superior to the line connecting the roots of both scapulae, with or without radiation to the head, and upper limb (Guzman, J. et al. 2008). The aetiology of neck pain may be traumatic, such as in cases of whiplash associated disorders (WAD) (Holm, L.W.D. et al. 2008) or may be non-traumatic i.e., of insidious onset (Hogg-Johnson, S. et al. 2008).
The pathological mechanism causing the symptoms associated with neck pain is mainly unknown (Childs, J.D. et al. 2008). Imaging is frequently used for primary screening of traumatic damage in the cervical spine, however the majority of cases of neck pain complaints are non-traumatic, with no structural damage identified in imaging as the cause of pain (Stiell, I.G. et al. 2003). Similarly to low back pain research, cervical imaging studies have been unable to provide answers as to which tissue is responsible for neck pain (Childs,

J.D. et al. 2008). The main limitation of imaging research is that it cannot correlate structural changes such as degenerative changes with symptoms associated with neck pain (Stiell, I.G. et al. 2003). Therefore, the patho-anatomical cause of neck pain is not identifiable and clinical assessment of disability and impairment of body function has remained the accepted approach for evaluation of patients complaining of neck pain (Childs, J.D. et al. 2008).

The incidence rate of neck pain ranges widely between studies with estimates that 22%- 70% of the western world population will experience neck pain sometime during their lives (Childs, J.D. et al. 2008; Cote, P. et al. 2001; Hogg-Johnson, S. et al. 2008). The incidence of neck pain has been constantly growing, and is now second after low back pain in annual worker’s compensation (Cote, P.D.C.P. et al. 2008). Epidemiologic evidence showed that incidence of neck pain increases with age, however it peaks in middle age (45-54 years of age) and declines afterwards (Cote, P.D.C.P. et al. 2008; Hogg-Johnson, S. et al. 2008).

An important subgroup of neck pain complaints consist of WAD resulting from motor vehicle collisions (Holm, L.W.D. et al. 2008; Spitzer, W.O. et al. 1995). In spite of this relatively small proportion of WAD out of general cases of neck pain, it is the subject of much study due to the economic ramifications involved with WAD claims (Holm, L.W.D. et al. 2008). Moreover, a 10-fold increase in the number of patients complaining of neck pain attending an emergency department due to whiplash injuries was reported over the past 20 years (Holm, L.W.D. et al. 2008). A recent epidemiologic study by European insurance associations emphasised the need for an objective assessment of the cervical spine (Chappuis, G. and Soltermann, B. 2008). Similar conclusion as to the severity of the problem were reported based on collected data from the U.S.A, Australia, New Zealand and Switzerland (Barnsley, L. et al. 1994; Brison, R.J. et al. 2000).

The economic ramifications of these injuries are severe with the total costs related to whiplash injuries in the U.S.A being $29 billion per year (Spitzer, W.O. et al. 1995). The average cost for a whiplash injury in Europe was €35,000 (Chappuis, G. and Soltermann, B. 2008).

In spite of the difference in aetiology between traumatic WAD and non-traumatic cases with neck pain, both groups share similar impairments that are of similar severity (Woodhouse, A. and Vasseljen, O. 2008).

1.2 Impairments due to neck pain

Recognised impairments due to neck pain include range of motion (Childs, J.D. et al. 2008; Hogg-Johnson, S. et al. 2008), repositioning ability (Heikkila, H.V. and Wenngren, B.I. 1998; Treleaven, J. et al. 2003), isometric strength (Dvir, Z. and Prushansky, T. 2008), and endurance of the cervical flexor muscles (Jull, G.A. et al. 2008). The following section will critically review existing studies in the field of ROM and repositioning impairments due to neck pain, most relevant to our research topic.

1.2.1 Cervical range of motion

Limitation in cervical ROM is the one impairment most frequently studied and clinically observed (Chiu, T.T.W. and Lo, S.K. 2002; Dall'Alba, P.T. et al. 2001; Dvir, Z. et al. 2006; Heikkila, H.V. and Wenngren, B.I. 1998; Youdas, J.W. et al. 1991). In spite of cervical ROM being such a frequently studied impairment, the accuracy of this measure as a diagnostic tool has been controversial due to conflicting evidence concerning its specificity and sensitivity (Dall'Alba, P.T. et al. 2001; De Hertogh, W.J. et al. 2007). ROM assessment methods include eye-balling, (Chen, J. et al. 1999) radiographs, (Lind, B. et al. 1989; Penning, L. and Wilmink, J.T. 1987) goniometers and inclinometers, (Rix, G.D. and Bagust, J. 2001; Youdas, J.W. et al. 1991) potentiometer-based tools, (Feipel, V. et al. 1999) as well as more advanced technologies such as ultrasonic (Dvir, Z. et al. 2006; Dvir, Z. and Prushansky, T. 2000), optic (Marcotte, J. et al. 2002), and electromagnetic (Day, J.S. et al. 2000; Koerhuis, C.L. et al. 2003) three dimensional (3D) motion tracking devices. While goniometers and inclinometers are used extensively for clinical purposes, these devices only measure two dimensional (2D), static ROM (Rix, G.D. and Bagust, J. 2001; Youdas, J.W. et al. 1991). In contrast, motion tracking devices (Day, J.S. et al. 2000; Dvir, Z. et al. 2006; Dvir, Z. and Prushansky, T. 2000; Koerhuis, C.L. et al. 2003) measure 3D dynamic ROM, but their use is limited primarily to research due to cost and technical complexity.

Among the advanced 3D motion tracking devices, the FASTRAK electromagnetic tracking system (FASTRAK, Polhemus, http://www.polhemus.com/FASTRAK) was selected for this study. It was investigated for its reliability in evaluating 3D cervical motion (Amiri, M. et al. 2003; Jordan, K. et al. 2000) in asymptomatic individuals. Inter-tester reliability was shown to be greater than intra-tester reliability for most measures, suggesting variability of ROM in asymptomatic individuals over a period of a few days was greater than variability between repeated measures on the same day by two testers. These findings may indicate that there are normal physiological or biological changes in the human body which lead to changes in cervical ROM, representing the normal variability in population. Jordan et al. (Jordan, K. et al. 2000) additionally found that full-cycle measurements (i.e., flexion (F)+extension (E), right rotation (RR)+left rotation (LR)) were more reliable than half-cycle ones (i.e., F, E, RR, LR), recommending the use of full-cycle measures.

1.2.2 Cervical repositioning ability

Cervical repositioning ability, also known as kinaesthetic ability, is commonly measured by the difference in displacement between an original position and a reproduced position (Treleaven, J. 2008). Revel et al. (Revel, M. et al. 1991; Revel, M. et al. 1994) in the early 1990's led this field with 2D distance measurements between points on a cardboard. Participants wore helmets with a laser pointer attached to it, by which they pointed at a designated sign on a board in front of them (Revel, M. et al. 1991; Revel, M. et al. 1994). Using this simple set up, Revel et al.(Revel, M. et al. 1991; Revel, M. et al. 1994) showed that patients with neck pain presented with increased repositioning error as compared to control individuals without symptoms.

Three dimensional tracking, which emerged later, enabled measuring angular displacement of the cervical spine rather than the linear distance between visual targets, and therefore became more commonly used for cervical motion analysis (Heikkila, H.V. and Wenngren, B.-I. 1998; Treleaven, J. et al. 2003). Reported increased repositioning error (Heikkila, H.V. and Wenngren, B.-I. 1998; Revel, M. et al. 1991; Treleaven, J. et al. 2003) may indicated a deficit in kinaesthetic and/or vestibular sensibility, possibly affected by neck pain. However, this evidence is controversial for several reasons. First, the reported repositioning error is small (2°-5°) (Heikkila, H.V. and Wenngren, B.-I. 1998; Revel, M. et al. 1991; Treleaven, J. et al. 2003). Second, a group difference in repositioning error was found significant only for one subgroup (moderately-severely disabled patients with neck pain) (Sterling, M. et al. 2003). Third, repositioning ability was insufficient for differentiating patients with neck pain from non-symptomatic individuals due to its low sensitivity and specificity (Treleaven, J. et al. 2006). Forth, contrasting findings by four other studies (Edmondston, S.J. et al. 2007; Grip, H. et al. 2007; Rix, G.D. and Bagust, J. 2001; Woodhouse, A. and Vasseljen, O. 2008) showed no significant group difference in repositioning error between patients with non-traumatic chronic neck pain and non-symptomatic individuals. Therefore, the value of repositioning error measurement for evaluation of impairment due to neck pain remains uncertain. Lastly, repositioning assessments, as well as ROM measurement, are static measurements.

A more dynamic approach to kinaesthesia assessment was attempted in "the fly" (Kristjansson, E. et al. 2001; Kristjansson, E. et al. 2004) project, where the main task was to follow a displayed movement pattern with head motion, controlled by a tracking system. Three movement patterns, represented by closed curved line patterns, were projected on a computer screen, to be followed by head motion using tracking data (Kristjansson, E. et al. 2001; Kristjansson, E. et al. 2004). The error between the performed trajectory of head motion and the displayed movement pattern was increased in patients with WAD as compared to non-symptomatic individuals (Kristjansson, E. et al. 2001; Kristjansson, E. et al. 2004). The main advantage of the "Fly" is in measuring dynamic cervical motion. However, a limitation of this study should be noted. The use of a flat screen in front of the participant restricted the ROM stimulated in this method, and therefore could not assess maximal cervical ROM.

1.3 Cervical kinematics analysis

Patients presenting with neck pain often report difficulty in performing neck movements, especially fast movements, in their daily life. As the above literature review demonstrated, most existing methodologies analyse measures of a static position. Although part of our daily function is static, we much more frequently move our neck dynamically in response to multiple stimuli. Very few studies have analysed the dynamic kinematics of neck motion, (Gregori, B. et al. 2008; LoPresti, E.F. et al. 2003) and specifically in relation to neck pain (Dvir, Zeevi and Prushansky, Tamara 2000), (Sjolander, P. et al. 2008). The methods and results of studies that investigated cervical kinematics are presented in Table 1.

Dvir and Prushansky, (Dvir, Zeevi and Prushansky, Tamara 2000) in their reproducibility study, reported that mean velocity of voluntary neck motion ranged from 200/s to 300/s in 25 individuals without symptoms. A recent pilot study (Sjolander, P. et al. 2008) evaluated kinematic features of fast cervical motion. Electromagnetic tracking was used for assessment of 16 individuals with chronic neck pain and 16 control individuals (Sjolander, P. et al. 2008). The results did not demonstrate a significant difference in ROM or in velocity between the groups, but did show a significant group difference in smoothness of motion (Sjolander, P. et al. 2008). The lack of group difference in cervical ROM found by Sjolander et al. (Sjolander, P. et al. 2008) contrasts strong existing evidence for ROM restriction in patients suffering with neck pain as described above (Chiu, T.T.W. and Lo, S.K. 2002; Dall'Alba, P.T. et al. 2001; Dvir, Z. et al. 2006; Heikkila, H.V. and Wenngren, B.I. 1998; Youdas, J.W. et al. 1991).

LoPresti et al. (LoPresti, E.F. et al. 2003) used a head mounted display (HMD) to characterize how individuals with severe neurological disorders such as multiple sclerosis (without neck pain) control a computer mouse via cervical motion; the requested task was to select computer icons. The performance of this task and its kinematic characteristics were analysed and compared between the group of individuals with severe disabilities and a control

Study	Sjolander et al. (2008)	Gregori et al. (2008)	Lopresti et al. (2003)	Dvir & Prushansky (2000)	Present study
Population	16 patients with chronic neck pain; 16 control individuals	15 patients with cervical dystonia; 13 control individuals	10 subjects with severe neurological disorders; 15 control individuals	25 individuals without symptoms	25 patients with chronic neck pain; 42 control individuals
Motion analysed	Rotation	Rotation; Flexion-Extension	Rotation; Flexion-Extension	Rotation; Flexion-Extension; Lateral Flexion	Rotation; Flexion-Extension
Outcome measures	ROM, Vpeak, smoothness (jerk index)	ROM, MT, Vpeak	ROM, MT, RT, Vpeak, accuracy, smoothness (NVP)	ROM, Vmean	ROM, MT, RT, Vmean, Vpeak, TTP%, smoothness (NVP)
Movement initiation cut off	5% of Vpeak	10% of Vpeak	50% of Vpeak, or 3.68 cm/s	Not described	2.5% of Vpeak
Type of instruction	Verbal request for cervical motion	Verbal request for cervical motion	Computer icons selection task	Verbal request for cervical motion	Obtaining a virtual target, interactive task.
Requested motion	Fast	Fast	Naturally-paced	Naturally-paced	Fast
Tracking system	Electro-magnetic	Optic	Ultrasonic	Ultrasonic	Electro-magnetic
Mean Velocity (deg/s)	120-130	Not reported	Not reported	Flexion-extension ~ 19 Rotation ~ 30 Lateral flexion ~ 20	Flexion-extension ~ 30 Rotation ~50
Peak Velocity (deg/s)	Not reported	Flexion-extension ~ 300 Rotation~600	529.2 pixels/s*	Not reported	Flexion-extension ~ 120-130 Rotation~160
Significant group differences	Smoothness	ROM, MT, Vpeak	ROM, MT, Vpeak, accuracy, smoothness	No group comparison was performed	ROM, Vmean, Vpeak, MT, smoothness

Table 1. Characteristics of studies of cervical motion kinematic analysis. ROM- range of motion, MT- movement time, RT- response time, Vpeak- peak velocity, Vmean- mean velocity, TTP%- time to peak percentage out of movement time, NVP- number of velocity peaks. * Velocity units were non comparable to deg/s, and were not presented by direction.

group. Significant differences were shown in all kinematic features, indicating that the patient group presented with severe kinematic impairments, as expected in such severe disorders (LoPresti, E.F. et al. 2003). Gregori et al. (Gregori, B. et al. 2008) investigated cervical motion kinematics for the purpose of studying the effect of therapy with botulinum toxin type-A (BTX-A) in patients with dystonia. The values of cervical velocity reported in non-symptomatic individuals were very high compared to the other reports; no explanation for this was given. Unlike LoPresti et al. (LoPresti, E.F. et al. 2003), Gregori et al. (Gregori, B. et al. 2008) did not stimulate task-oriented motion, but simply requested participants to move their heads as fast as they could.

As indicated in Table 1, cervical motion was most commonly elicited using verbal instructions for neck motion, (Dvir, Zeevi and Prushansky, Tamara 2000; Gregori, B. et al. 2008; Sjolander, P. et al. 2008) with the exception of LoPresti et al. (LoPresti, E.F. et al. 2003) who used computer icon selection. Fast cervical motion was requested in two studies, (Gregori, B. et al. 2008; Sjolander, P. et al. 2008) and naturally-paced motion was recorded in two others (Dvir, Zeevi and Prushansky, Tamara 2000; LoPresti, E.F. et al. 2003).

The cervical velocity values reported in these studies were inconsistent, possibly due to the differences in types of populations and methodologies.

The above evidence leaves the issue of neck pain's effect on cervical velocity and smoothness of motion unresolved and consequently led to the investigation of this subject in present work, utilizing virtual reality (VR) for this purpose.

1.4 Virtual reality

Virtual reality entails the use of computers and multimedia peripherals, to produce a simulated environment comparable with real world scenario. VR users interact with images and sounds that stimulate responses while providing feedback concerning their performance (Rizzo, A. and Kim, G.J. 2005). Over the past decade, VR technologies have emerged as valuable tools for clinical assessment and intervention (Riva, G. et al. 1999; Rizzo, A.A. et al. 2006; Weiss, P.L. et al. 2003). Some of these applications include VR use for pain distraction, (Hoffman, H.G. et al. 2001) evaluation of cognitive function, (Grealy, M.A. et al. 1999; Wilson, P.N. et al. 1996) investigation of postural control, (Keshner, E.A. and Kenyon, R.V. 2000; Keshner, E.A. and Kenyon, R.V. 2004; Keshner, E.A. et al. 2004) and assessment of attention deficits (Rizzo, A.A. et al. 2006). The latter VR application for attention deficits assessment is the "virtual classroom" by Rizzo et al. (Rizzo, A.A. et al. 2006). This VR application monitored cervical motion in children with attention deficit hyperactive disorder, simulating a classroom scenario (Rizzo, A.A. et al. 2006). Auditory and visual distractive stimuli were programmed to appear unexpectedly, and the response of the child to the distraction, and his return to focus on the blackboard was monitored via head motion tracking (Rizzo, A.A. et al. 2006). Results showed significant differences in several parameters of performance and attention ability in children with ADHD, compared to children without ADHD (Rizzo, A.A. et al. 2006). The "virtual classroom" (Rizzo, A.A. et al. 2006) is the closest identified VR application to the present work in its set up as it involved head motion analysis, however the objectives, developed environment and population are completely different.

The important assets of using virtual reality for clinical application include interaction, motivation, and pain distraction. Active interaction within a VR environment has been previously demonstrated to enhance the effectiveness of exercise interventions in various applications (Holden, M.K. 2005; Mirelman, A. et al. 2009). Bryanton et al. (Bryanton, C. et al. 2006) compared compliance to lower limb VR exercises with compliance to conventional exercises in children with cerebral palsy, and found increased dorsiflexion ROM and higher motivation during the VR session. High motivation to participation in VR was also reported by Harris and Reid (Harris, K. and Reid, D. 2005) who used VR for exercise purposes, although they did not compare the VR methodology to other methods. Lee et al (Lee, J.H. et al. 2003) showed that VR was more effective than conventional methods for cognitive training purpose, with longer a duration of participation, increased motivation and prolonged attention as compared with the conventional method.

Clinical applications of virtual reality appear to be effective in reducing pain and anxiety (Hoffman, H.G. et al. 2001; Sharar, S.R. et al. 2008). A VR application for pain control was used during burn wound debridement in a hydrotherapy tank for 11 burn unit patients (Hoffman, H.G. et al. 2008). The use of VR for this purpose was found to be effective in reducing the reported pain level, and therefore offered a non-pharmacological pain reduction technique during wound care (Hoffman, H.G. et al. 2008). Recent evidence from functional magnetic resonance study showed VR distraction to have significant analgesic efficacy as represented by reductions in pain-related brain activity in the insula, thalamus, and secondary somatosensory cortex (Hoffman, H.G. et al. 2007).

1.5 Rationale

Most existing methodologies (Chen, J. et al. 1999; Nordin, M. et al. 2008; Sjolander, P. et al. 2008) for cervical assessment evaluated voluntary motion, elicited by instruction. This common methodology will be referred to as "conventional" throughout this dissertation. However, in day-to-day life, head movement is generally an involuntary response to multiple visual, auditory, tactile and/or olfactory stimuli. Therefore, measures obtained via conventional assessment may not truly represent functional ability. To achieve a more functional approach to objective cervical motion assessment, the current study aimed to develop a specialized VR system.

The rationale was that participants would be involved in a simple, yet engaging VR game, in which head motion is monitored via electromagnetic tracking. Such cervical assessment that is programmed to enhance performance, would potentially distract the participant from sensations of pain, and provide dynamic kinematic data. In doing so, such developed cervical assessment may help in improving screening processes, in evaluating effectiveness of interventions, in differentiating patients from healthy individuals, and consequently in improving health care of patients with neck pain, and in reducing financial burden due to neck pain.

Neck pain has become the focus of increased global attention by various health, research, and insurance bodies (Chappuis, G. and Soltermann, B. 2008; Childs, J.D. et al. 2008). These have emphasized the need for objective, reliable and valid method (Lidgren, L. 2008). This chapter presents an advanced and functional solution to neck assessment.

The overall objective of this research project was to develop an innovative assessment method for neck disorders, and to utilize it for the investigation of cervical kinematics in patients with chronic neck pain compared to individuals without symptoms. The new method took advantage of the unique characteristics of virtual reality to quantify, measure, and analyse cervical spine mobility. Furthermore, the virtual environment elicits neck motion in a fashion that is closer to real neck function than existing assessments, and is gradable and motivating.

2. Materials and methods

Upon completion of development of the VR system for cervical motion assessment, the reliability study commenced. Inter- and intra-tester reliability of range of motion (ROM) measures taken with the newly developed VR system and by the conventional assessment method were evaluated. Once the reliability of the new VR assessment was supported, the VR system was used for assessment of cervical motion in patients with chronic neck pain and in individuals without neck symptoms.

The first part of the comparative study investigated cervical ROM in the two groups of participants, by the VR and conventional methods of cervical ROM assessment, and will be referred to henceforth as the comparative ROM study. In addition to investigation of group differences, the comparative ROM study explored the differences between the VR and conventional methods of assessment, and between horizontal and sagittal cervical motion. The diagnostic ability of ROM measures was evaluated by logistic regression analysis for both VR and conventional methods of assessment.

The second part of the comparative study investigated kinematic measures representing the dynamic characteristics of cervical motion, and will be referred to as the comparative kinematics study. Kinematic outcome measures were assessed only by the developed VR method. In addition to the investigation of group differences, the comparative kinematic study explored differences between the four motion directions, as well as differences between horizontal and sagittal cervical motion.

This study was approved by the University of Haifa Institutional Review Board, and by the Helsinki Ethical Committee of the Rambam Medical Centre, Haifa. Each participant signed an informed consent form prior to testing.

2.1 Participants

The research sample included 30 participants without symptoms in the reliability study (22 females and 8 males, mean age ± SD =28.6 ± 7.5), and 67 participants in the comparative study. The comparative study population included two groups, 42 individuals without symptoms in the control group (31 females, 11 males, mean age ± SD =35.3±12.4 years), and 25 patients with chronic neck pain in the patient group (16 females, 9 males, mean age ± SD =39.0±12.7 years).

<u>Inclusion criteria of participants with neck pain:</u>

1. Complaint of neck pain for 6 weeks or more, with or without referral to the upper limb.
2. Etiology of either WAD or insidious onset of symptoms without trauma.

<u>Exclusion criteria of participants with neck pain:</u>

1. Neck pain caused by other pathological entities such as diffuse connective tissue diseases, rheumatic syndromes, metabolic and endocrine diseases, neoplasm, fractures or dislocations.
2. Regular intake of medication which may affect pain or motor performance, such as analgesics, relaxants, steroids, and non-steroidal anti inflammatory drugs.

<u>Exclusion criteria for asymptomatic participants:</u>

1. Current or past history of neck pain or WAD within the past 10 years.
2. Current history of vertigo, dizziness, or other vestibular disorder.
3. Visual impairment (uncorrected by optical devices).
4. Complaints of altered sensation (e.g., pins and needles), or weakness of the upper limbs, which can be caused by disorders such as multiple sclerosis, spinal stenosis, spinal cord injuries, neuropathies.

5. Cognitive impairment that could affect ability to follow instructions.

Participants were recruited from a local physiotherapy clinic and from the University of Haifa, respectively. Exclusion criteria for the control group were identical those presented above.

2.2 The developed VR cervical assessment system

A customized video game-like virtual environment was developed in order to encourage and motivate participants to achieve maximal cervical ROM (ROM analysis), and to stimulate fast cervical mobility (kinematics analysis). The VR system was constructed from off-the-shelf hardware and was operated using customized software.

Hardware consisted of two main components: an electromagnetic tracker (Fastrak, Polhemus, http://www.polhemus.com/FASTRAK) and a Head Mounted Display (HMD) (I-glasses HRV Pro, Virtual Realities, http://www.vrealities.com). The tracker sampled motion via two sensors at 60 Hz each. Sensors were placed at the back of the HMD, adjacent to the occipital protuberance, and on the sternal notch in order to differentiate trunk motion from that of the neck and remove it from the data.

A virtual environment was developed using Game Maker software (http://www.gamemaker.nl), and tracking data were analysed using Matlab software (version 12b, http://www.mathworks.com). We have used this system to study cervical motion charecteristics and compared conventional and VR methods (Sarig-Bahat, H. et al. 2009; Sarig-Bahat, H. et al. 2010). In the conventional method participants were orally instructed to move their head into flexion, extension, rotation, and lateral flexion. In the VR method, cervical motion was elicited by interaction with images in a video game that were displayed on the two monitors embedded in the HMD (Sarig-Bahat, H. et al. 2009; Sarig-Bahat, H. et al. 2010). The HMD and sensors are shown in Figure 1.

The VR gaming environment developed for this study enabled us to elicit cervical motion by the participants and to assess its dynamic characteristics. During the game, fly targets were displayed on the HMD monitors and the participant's task was to "spray" the flies. This was achieved by aligning each fly with a virtual target sign attached to a virtual spray canister. The position of the spray canister was controlled by the participant's head motion. The participant was instructed to spray the flies as fast as possible. In the ROM game the participant moved from one target to the other, and in the velocity game he had to return to mid-position after hitting each target. Directions of the targets were randomly ordered, eliciting fast cervical flexion (F), extension (E), right rotation (RR), and left rotation (LR). Two targets were placed at 100% of ROM and an additional two targets at 80% of ROM, as measured conventionally at the beginning of the experiment. An example of a fly target appearing on the left side of the screen to stimulate LR is shown in Figure 2.

The ROM game challenged participants with constantly increasing ROM required to hit target flies. Flies continued to appear at increasing distances from the central resting position until the participant failed to point the spray can nozzle at the fly in a given direction during three consecutive trials. However, in the velocity game there was a set number of trials at 80% and 100% conventional ROM.

2.3 Procedure

The experimental session commenced with an interview regarding possible exclusion criteria, and the completion of VAS, NDI, and TSK questionnaires by the participants with neck pain. A short warm up followed with two repeated cervical movements in all directions.

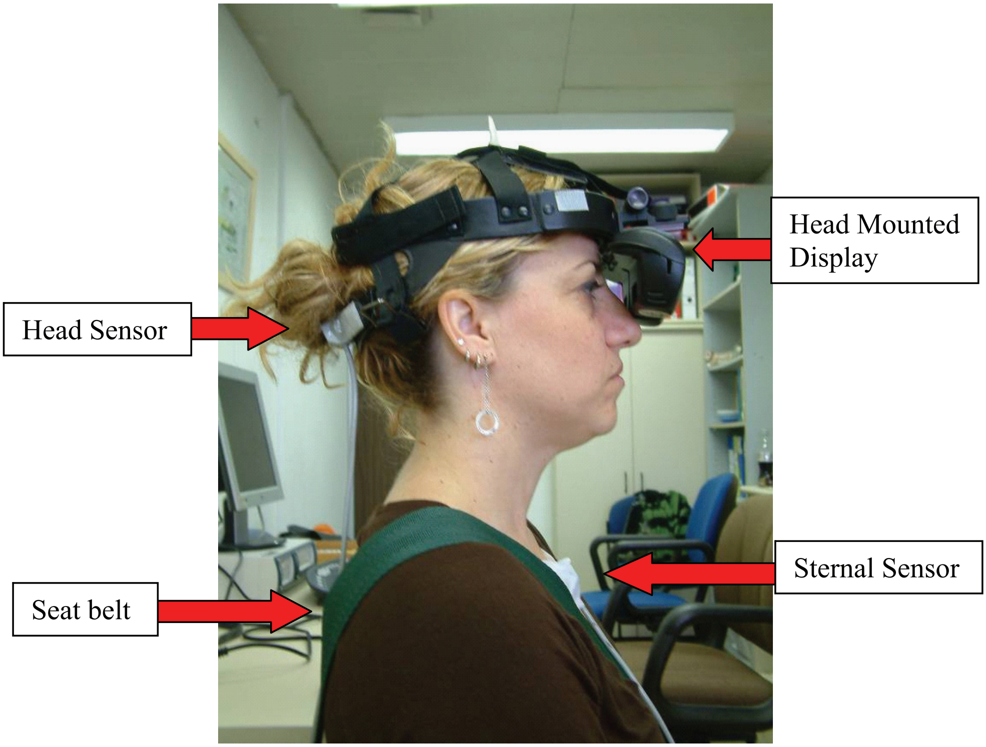

Fig. 1. Head Mounted Display with tracking sensors attached.

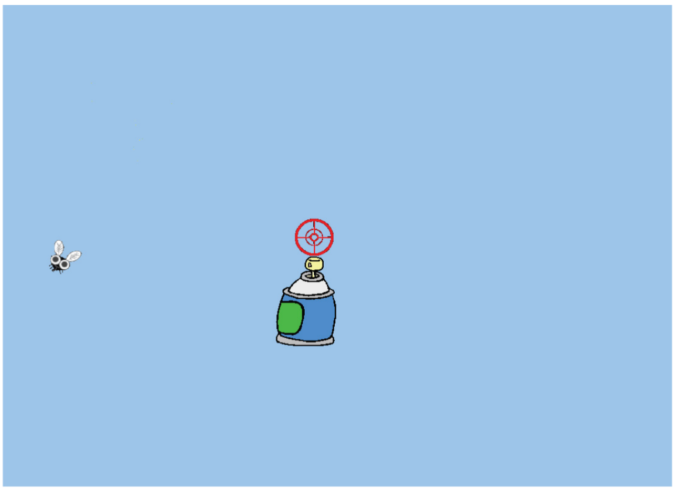

Fig. 2. A screen capture as viewed via the HMD, during the VR game. The Fly is the target; the task is to point the target sign (in the top of the spray canister) at the fly via movements of the head.

At the beginning of each assessment, participants were requested to place their head in what they perceived as mid-position, and this location was recorded and used for data analysis. Each assessment included the following stages: a conventional ROM assessment (Conv1), a VR assessment, including the ROM game and the velocity game, and a repeated conventional ROM assessment (Conv2).
During the reliability study each participant was assessed twice during the first session by two different testers, randomly ordered. The assessment was repeated by one of the testers 3-7 days later.
In the following comparative kinematic study, each participant was assessed once, and all by the same tester. Assessments were performed by a musculoskeletal physiotherapist.

2.4 Subjective outcome measures

Participants with neck pain completed three questionnaires, reflecting different aspects of their disorder:
Visual Analogue Scale (VAS) (Breivik, E.K. et al. 2000; Langley, G.B. and Sheppeard, H. 1985; Ogon, M. et al. 1996; Wainner, R.S. et al. 2003) is a 10 cm line representing pain intensity. Patients were requested to indicate on the line the point that best represented their level of neck pain at the beginning of the assessment. The VAS has been recognized as a valid and sensitive pain intensity instrument (Breivik, E.K. et al. 2000; Wainner, R.S. et al. 2003) and is reported to be the most cited pain intensity measure in studies of neck pain (Nordin, M. et al. 2008).
Neck Disability Index (NDI) is a self-rated instrument assessing disability due to neck pain (Vernon, H. 2008; Vernon, H. and Mior, S. 1991). It consists of 10 items related to daily living activities, such as working, reading, and sleeping, with each item rated on a six-point scale (0-5). The NDI has been widely used and has been shown to have good validity and reliability (Pietrobon, R. et al. 2002; Vernon, H. 2008).
Tampa Scale of Kinesiophobia (TSK) (Sullivan, M.J. et al. 2002) is a 17-item questionnaire used to assess fear of movement or re-injury, in which patients are asked to rate their level of agreement with each item on a four-point scale (1-4). The TSK has been shown to have adequate internal consistency and reliability (Cleland, J.A. et al. 2008) and to be associated with measures of behavioral avoidance and disability (Sullivan, M.J. et al. 2002).

2.5 Objective outcome measures

Objective measures included two main categories, ROM measures and kinematic measures. ROM measures were analysed in the reliability study and in the comparative ROM analysis. Kinematic measures were analysed in the comparative kinematic analysis.
Conventional ROM measures included half-cycle (F, E, RR, LR, RLF, LLF) and full-cycle (F+E, RR+LR, RLF+LLF) cervical ROM. Three repeated measurements were performed for each direction in the reliability study, and two, in the comparative ROM study. This change in number of repetitions was due to software adaptation following four cases of side effects in the reliability study, due to high total number of repetitions in high rate.
VR ROM measures collected included only full cycle measures as there was continuous motion between targets during the game with no return to a stationary central resting position between successive trials. The VR game elicited movements in F, E, RR, and LR, but not lateral flexion. The three greatest scores were collected from the VR assessment for statistic analysis.

Kinematic measures were analyzed from the data collected by the tracker for each of the 16 assessment trials throughout the virtual game. Each trial period was defined as the time from target appearance to target hit. Data were low pass filtered (Butterworth, 10 Hz, order = 10), and an angular velocity profile was computed for each trial from angular rotations (i.e., roll, pitch, and yaw). Mean values of the kinematic outcome measures were calculated for each of the four directions (flexion, extension, right rotation, and left rotation). The following variables were analyzed:

Response time extends from target appearance to motion initiation. Motion initiation towards the target was defined as the point where velocity passes a threshold value set at 2.5% of peak velocity. Compared to reported thresholds of 10% and more, (LoPresti, E.F. et al. 2003; Michaelsen, S.M. et al. 2001) 2.5% was preferred in order to prevent significant data loss during the analysis.

Peak velocity (Vpeak) refers to the maximal velocity value recorded throughout a trial.

Mean velocity (Vmean) refers to the mean value of velocity from motion initiation to target hit.

Time to peak percentage (TTP%) refers to the time from motion initiation to the peak velocity moment, as a percent of total movement time.

Number of velocity peaks (NVP) refers to the number of velocity peaks from motion initiation to target hit, indicating motion smoothness. NVP was defined by counting the number of times that the acceleration curve changed sign, i.e., crossed the zero line.

Impairment percentages were calculated for each kinematic measure in each direction by the following formula, where "value" refers to each kinematic measure:

(Mean value for patients – Mean value for controls) / Mean value for controls

2.6 Statistical analysis

The following section will discourse statistics methods performed in each part of the study. Significance was determined at $p \leq 0.05$. JMP® statistics software was used (S.A.S Institute, www.jmp.com), as well as SAS® software (Statistical Analysis Software, www.sas.com).

2.6.1 Reliability study

The mean value of three largest ROM results to each direction was used for statistical analysis. Repeatability was assessed based on methods developed by Bland and Altman (Bland, J.M. and Altman, D.G. 1986; Bland, J.M. and Altman, D.G. 2007). Repeatability coefficient r95% was calculated as 1.96 times the standard deviations of the differences between the two measurements (tester1 and tester2, or day1 and day2) (Bland, J.M. and Altman, D.G. 1986; Bland, J.M. and Altman, D.G. 2007). The r95% measure, with units of degrees in our study, represents the value below which the absolute difference between two repeated test results may be expected to lie with a probability of 95%.

In addition, Bland & Altman's analysis (Bland, J.M. and Altman, D.G. 1986; Bland, J.M. and Altman, D.G. 2007) was used to evaluate differences between assessment methods, comparing results from Conv1 and VR. In order to compare between the VR and the conventional methods, differences between the results of both assessment methods during each of the three experimental stages (Conv1, VR, and Conv2) were assessed by a mixed-model ANOVA, with stage as the fixed factor and participant as the random factor. When the ANOVA indicated significant overall differences between stages, pairwise differences were assessed by the Tukey-Kramer test.

2.6.2 ROM analysis

The mean value of the three largest ROM results in each direction was used for statistical analysis. Full cycle and half cycle measures were analysed by the conventional method, and full cycle measures alone were analysed by the VR method. Differences between the results of the two groups (patients vs. control), the two planes of motion (sagittal vs. horizontal), and the three experimental stages (Conv1, VR, and Conv2) were assessed by a mixed-model ANOVA, with group, plane of motion, and experimental stage as the fixed factors and participant as the random factor. When the ANOVA indicated significant overall differences between stages, pairwise differences were assessed by the Tukey-Kramer test.
Univariate and multivariate logistic regression analyses and receiver operating characteristic (ROC) curves were used to examine the predictive relationship between test parameters and status (patients vs. control groups). In addition to tests of model significance and ROC area under the curve, these analyses included determination of odds ratios and their confidence intervals, and sensitivity and specificity of different model cut-off thresholds.

2.6.3 Kinematic analysis

The mean value of four trials for each kinematic measure to each motion direction (F, E, RR, and LR) was calculated. Failure-to-hit trials were less than 1% of trials in both groups and were excluded. Differences between the two groups (patient vs. control), and between the four motion directions (F, E, RR, and LR) were assessed by a two-way repeated measures ANOVA (group x direction of motion). When the ANOVA indicated significant interactions (group x direction of motion), pairwise differences were assessed by the Tukey-Kramer test, and contrasts were analysed to evaluate differences between the sagittal (combination of F with E results) and horizontal (combination of RR with RR results) planes of motion.

3. Results

This part will cover results in four main categories: (a) reliability; (b) group differences; (c) VR vs. conventional methods of ROM assessment differences, and (d) dynamic kinematics differences.

3.1 Reliability

The inter- and intra-tester repeatability analysis using Bland and Altman's method4 resulted in no bias ($p>0.1$) in all full cycle measures for both conventional and VR assessments. r95% of full cycle results ranged from 19.90 to 29.20 by conventional method and from 15.00 to 22.60 by VR method. These results showed an advantage for the VR method compared to the conventional method, with smaller repeatability coefficient (r95%) values. Inter tester reliability was found to be higher as compared with intra tester reliability, with smaller repeatability coefficient (r95%) values.
Half-cycle reliability results (conventional method) were found to be non-biased, with the exception of RLL and LLF in the inter-tester analysis which demonstrated a trend ($0.05<P<0.1$). The r95% of half cycle conventional results ranged between 9.90 and 27.30. In summary, full-cycle measures were found more reliable than half-cycle measures, and VR measures were found more reliable than conventional ones, although both methods resulted no bias. Additional analysis in the reliability study compared between the conventional and VR methods of assessment with advantage found to the VR method for full-cycle measures (Sarig-Bahat, H. et al. 2009).

3.2 Comparative ROM study results

Following the reliability evaluation, the VR assessment was utilised for assessment of cervical ROM in patients with neck pain and in control participants without neck symptoms.

Cervical assessments were performed on all 67 participants. Comparable demographic baseline values for control and patient groups were found with no significant differences in age or in gender ($p=0.12$). Demographic characteristics of both groups are listed in Table 2. In addition, Table 2 presents the symptoms, function and fear of motion associated with neck pain as reported by the patients using the VAS, NDI and TSK.

Characteristic	Patient group (n=25)	Control group (n=42)
Age in years (Mean (SD), Range)	39.0 (12.7), 22 - 65	35.3 (12.4), 23 - 64
No. of females / males	16 / 9	31 / 11
Duration in months (Mean, SD, Range)	43.40 (53), 1.5 - 240	N/A
No. of cases with right / left / bilateral symptoms	12 / 6 / 7	N/A
No. of cases with / without whiplash injury	7 / 18	N/A
Neck Disability Index (Mean (SD), Range)	11.60 (4.88), 3 - 23	N/A
Tampa Scale of Kinesiophobia (Mean (SD), Range)	35.74 (5.71), 25 - 53	N/A
Visual Analogue Scale (Mean (SD), Range)	3.30 (2.05), 0 - 9	N/A

N/A- not applicable, SD- standard deviation.

Table 2. Characteristics of experimental groups.

Results of mixed-model three-way ANOVA indicated significant overall differences (a) between groups ($F(1,65.3)=15.2$, $p=0.0002$), (b) between experimental stages ($F(2,296)=121$, $p<0.0001$), and (c) between sagittal and horizontal planes of motion ($F(1,294)= 487.6$, $p<0.0001$). All interactions were non-significant ($p>0.1$) with one trend found in the interaction between plane and group ($p=0.06$).

The complementary Tukey-Kramer test for full cycle ROM measures showed significant differences ($p<0.05$) for every possible between-experimental stages pairwise comparison. Figure 3 shows the group difference in ROM, with patient group demonstrating reduced values. In addition, Figure 3 shows that Conv2 ROMs were significantly greater than Conv1 ROMs and VR-ROMs were significantly greater than both pre- and post VR assessments. In other words, a single VR session showed a significant motion enhancement effect in both groups, as demonstrated by greater ROM during the VR game, as compared with conventional ROM collected before and after the VR game (see Figure 3).

Horizontal plane measures of motion (right and left rotation) presented with greater ROM, compared to sagittal plane measures of cervical motion (flexion and extension).

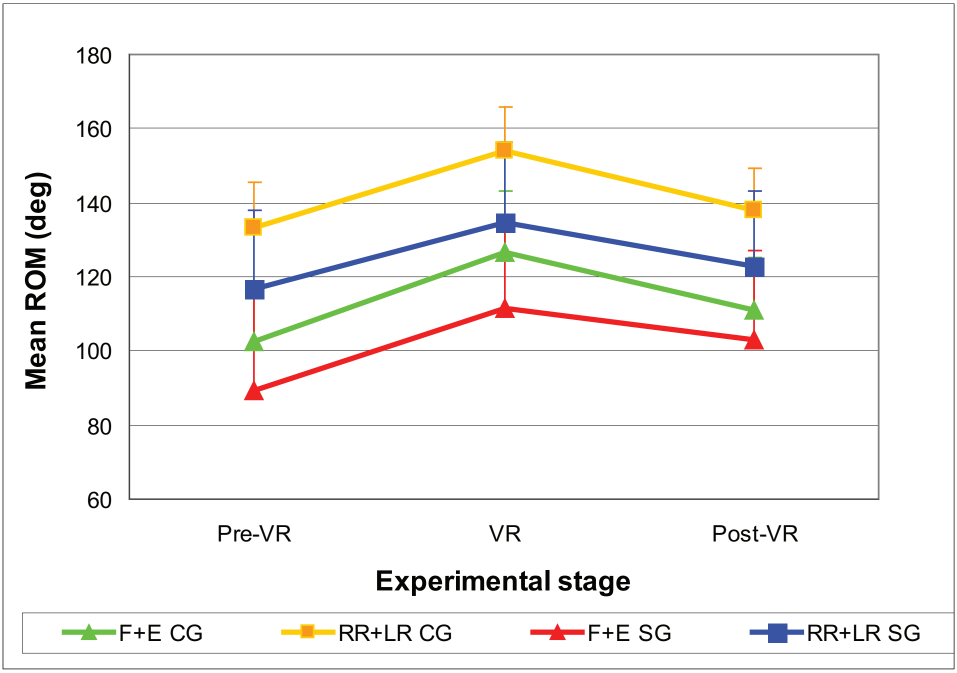

Fig. 3. Mean ± SD of cervical range of motion, as maintained in the three experimental stages.

Conv1- first conventional assessment; VR- virtual reality assessment; Conv2- second conventional assessment; F+E- flexion and extension, RR+LR- right rotation and left rotation; CG- control group; PG- patient group; ROM- range of motion.
ROM impairment percentage by the conventional method was 13.15% in FE, and 12.32% in rotation, and by the VR method, 12.15% and 12.60%, respectively.

3.3 Logistic regression results

Results of the logistic regression analysis performed for full cycle measures were found to be statistically significant diagnostic factors. The diagnostic values in Table 3 are sorted by sensitivity, from highest to lowest. For each outcome measure the actual predictor value is given, i.e., the optimal cut-off value based on the best overall accuracy (a trade-off between sensitivity and specificity). For example, for F+E ROM during VR (first row in Table 7), every 10 increase above 133.3 reduces the odds of being a true patient by a factor of 0.96. Thus, the larger the ROM, the more likely it is that the participant is well.
Two very important values reported in Table 3 are sensitivity and specificity. The sensitivity of VR F+E was found to be 88%, such that 22 out of the 25 patients were identified as true positive cases (i.e., they were diagnosed correctly). Specificity of VR F+E, however, was low, 43%; that is, only 18 out of the 42 control participants were identified as true negative cases

by this single measure. The results of high sensitivity and low specificity of VR F+E are consistent with the common trade-off between sensitivity and specificity. Good sensitivity (72%) was found for VR RR+LR, which also showed good specificity of 79%. Henceforth, VR RR+LR was found to be the most accurate measure. In contrast to the VR measures, conventional ROM measures demonstrated low sensitivity (<60%) however their specificity values were higher than those of the VR measures, 88% for conventional R+LR and F+E; i.e., 37 out of 42 control participants were identified correctly using conventional measures.

Outcome measures	F+E VR	RR+LR VR	RR+LR Conv.	F+E Conv.
Model significance	0.002	<0.0001	0.0002	0.009
Predictor significance	0.006	0.001	0.001	0.015
Optimal predictor value	133.3	146	119.3	81.8
Unit Odds Ratio	0.96	0.92	0.94	0.97
Odds Ratio 95% CL	0.93 - 0.99	0.88 - 0.97	0.90 - 0.98	0.94 - 0.99
Sensitivity	0.88	0.72	0.56	0.4
Specificity	0.43	0.79	0.88	0.88
Accuracy	0.31	0.51	0.44	0.28
Area Under Curve	0.7	0.79	0.74	0.66

Sig.- significance; CL-confidence limits, lower limit- higher limit; F- flexion; E- extension; VR- virtual reality; RR- right rotation; LR- left rotation; Conv- conventional.

Table 3. Diagnostic value of significant outcome measures

3.4 Comparative kinematic study results

VR assessments and kinematic analysis were performed on all 67 participants (25 patients and 42 controls) in the comparative part of the study.

Results of the mixed model ANOVA indicated significant group differences for (a) movement time ($F(1,65)=16.23$, $p=0.0001$); (b) Vpeak ($F(1,65)=22.3$, $p<0.0001$); (c) Vmean ($F(1,65)=23.91$, $p<0.0001$); and (d) NVP ($F(1,65)=9.11$, $p=0.0036$). Results showed that participants with neck pain performed with lower peak and mean velocities when they moved towards the virtual fly target, compared to control participants. The velocity curves of patients with neck pain also showed a greater number of peaks (maxima), indicating impaired motion smoothness. No significant group differences were found for response time and for TTP%. There was no significant interaction found between group and motion direction for most of the measures, except for Vmean and Vpeak where a significant interaction was found. Tukey-Kramer test and contrast analysis were performed only for the measures with significant interactions, i.e., Vmean and Vpeak. Group and direction differences are illustrated for peak velocity, and mean velocity in Figure 4 and Figure 5, respectively. Contrast results indicated significantly higher mean and peak velocities in the horizontal plane versus the sagittal plane (Figures 4 and 5).

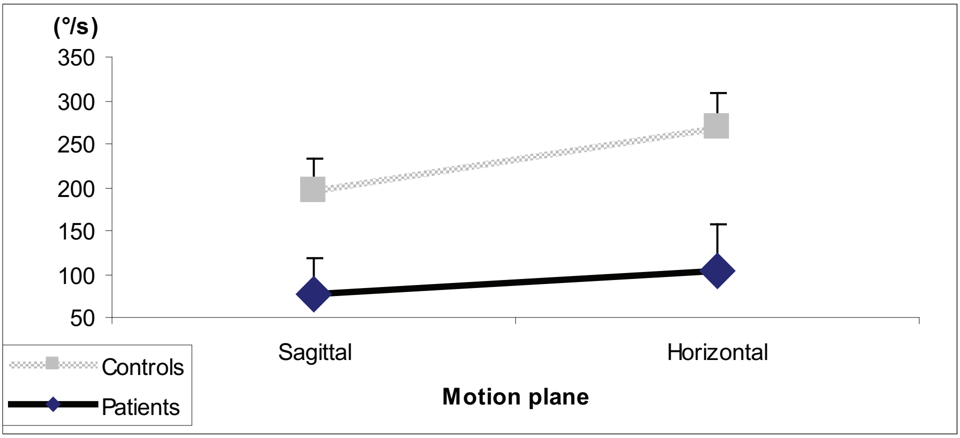

Fig. 4. Mean ± SD of peak velocity for control and patient groups, in sagittal and horizontal plane of motion. Higher peak velocity is demonstrated in horizontal motion as compared with sagittal motion, for both patient and control group. The difference between motion planes was greater in the patient group, as indicated by the interaction effect found.

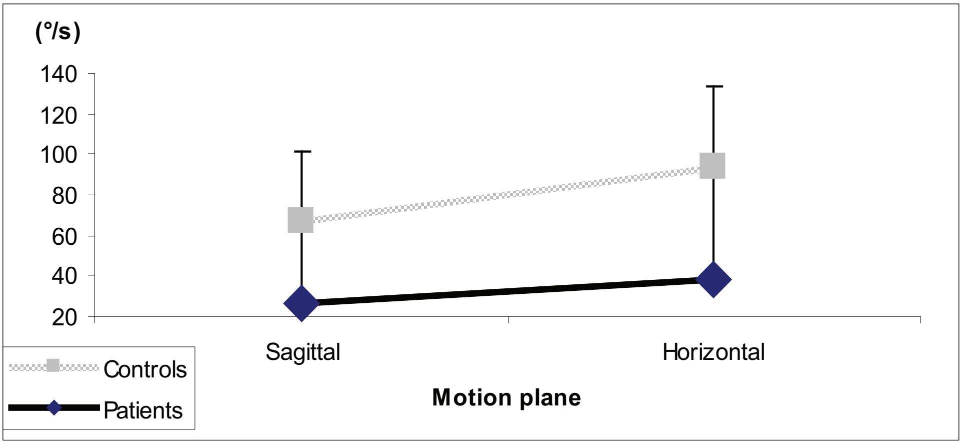

Fig. 5. Mean ± SD of mean velocity for control and patient groups, in sagittal and horizontal plane of motion. Higher mean velocity is demonstrated in horizontal motion as compared with sagittal motion, for both patient and control group. The difference between motion planes was greater in the patient group, as indicated by the interaction effect found.

The presented results showed that the developed VR system for cervical motion assessment is reliable, is capable of demonstrating ROM and kinematic differences between participants with neck pain and control participants, with good sensitivity and specificity. Furthermore, the VR system demonstrated a motion enhancement effect within a single session in both patient and control groups.

4. Discussion

Neck pain is a common and growing health problem in the western world, causing a heavy burden on society (Hogg-Johnson, S. et al. 2008). The scope of the problem, the high expenditure associated with it, as well as the limitations of existing methods for its assessment emphasise the need for an objective and reliable assessment of impairments due to neck pain (Chappuis, G. and Soltermann, B. 2008; Nordin, M. et al. 2008).

This chapter introduced a novel method developed to analyze cervical motion, which provides a more functional, task-oriented method, compared to existing conventional methodologies. It presented the development of the VR system for cervical assessment, evaluation of its reliability, and results of cervical motion analysis in patients with neck pain and in healthy individuals.

Reliability findings demonstrated non biased inter- and intra-tester reliability of the VR- and the conventional ROM assessments; inter-tester reliability was greater than intra-tester reliability, and horizontal motion measures were more stable than sagittal motion measures.

The VR assessment was used to investigate cervical motion impairment in patients with neck pain compared to healthy control individuals. The findings demonstrated significantly reduced cervical ROM, motion velocity, and movement smoothness in patients with chronic neck pain. The findings of impaired velocity and smoothness of cervical motion, in particular, contribute new knowledge to the understanding of the impairments associated with neck pain, and establish a reference for future kinematic research in the cervical spine.

The diagnostic ability of the VR system was evaluated by logistic regression analysis with findings of good sensitivity and specificity for many of the studied outcome measures. This demonstrated their ability to identify correctly patients suffering from neck pain and individuals without neck pain. In addition to its ecologic validity, reliability and diagnostic ability, the VR cervical motion assessment was found advantageous as compared to conventional assessment in its ability to enhance cervical mobility, in both groups of the study. This enhancement suggests its therapeutic potential.

4.1 Reliability

The non-biased inter- and intra-tester results determined here support the reliability of both the VR-based and conventional assessment methods tested in this study. Values of repeatability coefficients (r95%) ranged from 150 to 29.20, which may be considered fairly large. However, these values are similar to those reported by Assink et al., (Assink, N. et al. 2005) who also used electromagnetic tracking system, evaluated active ROM reliability using similar statistical method. Assink et al.(Assink, N. et al. 2005) reported repeatability coefficients ranged from 14.5° to 27°. From a clinical point of view, both previous and current findings show that substantial differences should be expected when measuring cervical ROM, despite accurate measuring equipment and a rigid measurement protocol.

In agreement with previous studies, (Chen, J. et al. 1999; Jordan, K. et al. 2000; Lantz, C.A. et al. 1999) the current analysis within the conventional assessment demonstrated that half cycle measures are less stable than full cycle measures.

The results of the reliability analysis indicate that maximal ROM results obtained via VR were more stable than those obtained via conventional assessments. VR appears to act as an engaging and motivating modality (Rizzo, A. and Kim, G.J. 2005), directing attention to an external stimulus rather than to the body motion itself (Wulf, G. et al. 1998; Wulf, G. et al. 2007), resulting in better performance. These unique features of the VR-based assessment may be responsible for the smaller repeatability coefficients obtained with this methodology.

4.2 ROM findings

Various measuring instruments and protocols have been used to characterize cervical ROM (Chen, J. et al. 1999; Nordin, M. et al. 2008). All reviewed studies reported using conventional protocols similar to the one used in the current study (Chen, J. et al. 1999). A very wide variability of ROM results in healthy subjects was documented with largest differences in between technologies up to 55° in full cycle rotation, 78° in full cycle lateral flexion, and 64° in full cycle flexion-extension (Chen, J. et al. 1999). Nevertheless, we note that the results of the present study fell within the ranges reported in the literature using electromagnetic tracking technology.

4.3 Motion enhancement effect by VR

Results of the comparison between the three experimental stages (Conv1, VR, and Conv2) demonstrated a significant motion enhancement effect by the developed VR assessment. ROM of both rotation and flexion-extension movements attained while the participants were engaged in a task in the virtual environment were significantly higher than those recorded conventionally, prior to, and post- the VR-based assessment. The phenomenon of motion enhancement by VR was demonstrated first in the reliability study in participants without symptoms, and second, in the comparative ROM study, in both patient and control groups. Future investigation of changes in ROM across trials could help explain the large intra-rater reliability.

Motion enhancement may be partially explained by the increased motivation obtained while the participants were involved in an engaging and challenging game. Motivation benefits of VR have been reported in numerous studies involving subjects with various disabilities (Bryanton, C. et al. 2006; Harris, K. and Reid, D. 2005; Holden, M.K. 2005; Mirelman, A. et al. 2009). It is likely that the participants with neck pain in the present study also benefited from pain-distraction induced by involvement in VR (Hoffman, H.G. et al. 2001; Hoffman, H.G. et al. 2008; Hoffman, H.G. et al. 2007). VR distraction has been shown to have a significant analgesic effect (Hoffman, H.G. et al. 2001; Hoffman, H.G. et al. 2008) as demonstrated by significant reductions in pain-related brain activity in the insula, thalamus, and secondary somatosensory cortex(Hoffman, H.G. et al. 2007).

The difference between VR and conventional results may be further explained by the difference in focus of attention between the two methods of cervical motion assessment. Multiple studies have shown the advantage of an external focus of attention over an internal focus of attention on motor performance and motor learning (McNevin, N.H. et al. 2003; Wulf, G. 2008; Wulf, G. et al. 1998; Wulf, G. et al. 1999; Wulf, G. and McNevin, N.H. 2001; Wulf, G. and Su, J. 2007; Zachry, T. et al. 2005). The fact that motion enhancement by VR was shown in both groups with no interaction effect strengthens the suggestion that the noted improvements may be due to a changed focus of attention and not to pain distraction. The shift in focus of attention may have contributed to the enhanced motion during VR game. The VR game seems to have therapeutic potential in improving motor performance and movement economy of the cervical region.

4.4 Kinematics analysis and neck pain

In the comparative kinematic study, the dynamic characteristics of neck motion, in patients with neck pain and in control subjects were examined. A dynamic assessment of cervical motion was needed due to (a) its functional value; (b) lack of existing evidence regarding kinematics of cervical motion, and (c) clinical experience with patients suffering from neck pain who often report difficulty in performance of fast neck movements.

In day to day living we normally move our heads in response to multiple sensory stimuli, such as turning our head when hearing a loud sound or smelling an attractive scent. The location and timing of these environmental stimuli is unknown and changing, often requiring head motion that is both fast and accurate. Most existing assessments of impairment due to neck pain collect measures of a static nature, such as ROM measurements, (Chen, J. et al. 1999) repositioning ability, (Treleaven, J. 2008) and isometric muscle strength (Dvir, Z. and Prushansky, T. 2008) evaluation. The VR based methodology developed in the present study elicited fast cervical motion in response to visual stimuli.

The effect of neck pain on cervical motion control via kinematic analysis has been seldom studied. Identified studies (Gregori, B. et al. 2008; LoPresti, E.F. et al. 2003) that have investigated cervical kinematics (described in Table 1, page 11) studied populations with neurological disorders and severe disabilities very different to neck pain.

Sjolander et al. (Sjolander, P. et al. 2008) was the sole study to have investigated kinematics of cervical motion in relation to neck pain. Sjolander et al. (Sjolander, P. et al. 2008) reported higher velocity values than ones reported here (see Table 1). They found that cervical motion smoothness was impaired in patients suffering from neck pain, whereas ROM and cervical motion velocity were not. In contrast, current results demonstrated that individuals suffering from neck pain moved more slowly and less smoothly towards virtual targets. The lack of ROM restriction in their patient group, no description of severity or disability, and investigation of rotation alone, are all methodological weaknesses that should be considered when referring to the study by Sjolander et al. (2008).

The present results play an important role in providing a reference for future research in cervical kinematics.

The overall impairment percentage in velocity and smoothness of cervical motion in patients with neck pain ranged from an impairment of 22% to 44%, compared to control participants. The overall ROM impairment percentage found in the comparative ROM analysis for the same population with the same VR technology, ranged from an impairment of 12.15% to 13.5%, compared to control participants. Therefore it seems that in the examined mildly disabled chronic population, velocity and smoothness of cervical motion were restricted by a relatively greater proportion to cervical ROM. This may be explained by the greater degree of difficulty in performance of fast motion compared to naturally-paced motion. Velocity and smoothness, unlike ROM measurement, reflect dynamic cervical motion, and therefore may reveal more of the impairment than ROM assessment.

Since the ability to move quickly in response to external stimuli is a necessary function, this deficit in cervical motion velocity and smoothness is probably meaningful and needs to be addressed. Further research should investigate if this finding of greater impairment in cervical velocity and smoothness as compared to ROM exists in more severely affected individuals.

4.5 Limitations and further research

Several limitations were identified in this study, and reflect on future research requirements. The VR game facilitated motion in F, E, RR, and LR directions; however it was not programmed to elicit lateral flexion, unless when coupled with rotation. In order to elicit isolated LF, a separate task or game is needed. From a clinical and functional point of view, it seemed that isolated LF is of least value compared to other directions of motion.

Reliability was evaluated only in non-symptomatic individuals, and should be evaluated on patients with neck pain in the future. The patient group assessed in this study was characterized by mild chronic disability, and a moderate level of kinesiophobia. Therefore furthere research should investigate a more heterogenic population.

Subjective and objective measures were not correlated in present study. Future research should assess the correlations between subjective and objective measures. The effect of subjective measures such as pain intensity and fear of motion on objective kinematic measures should be evaluated. This would help identify which subjective characteristics restrict performance. This finding may guide treatment. In addition, prognostic analyses should be evaluated using a prospective methodology, exploring risk factors for prolonged disability and poor treatment outcome, and positive predictive factors, for successful treatment outcomes.

The current findings of impaired motion velocity and smoothness in individuals suffering from chronic neck pain have clinical implications for both the assessment and management of neck pain.

Investigation of a patient's ability to perform fast and sudden neck movements should be included in any clinical examination. Subjective examination should include questioning relating to the ability to perform fast cervical motion.

Present ROM analysis showed a significant cervical motion enhancement effect by a single VR session. Future study should evaluate the therapeutic effectiveness of VR-training for cervical rehabilitation, using a randomized controlled trial methodology. Future development of VR-based management strategies may include training regime that challenge fast, task-oriented exercising, using visual/auditory stimuli, directed at external focus of attention. Further development is needed for treatment purposes to create a variety of games and tasks that will maintain motivation and interest in the VR game during several sessions.

The use of VR may play an additional role in overcoming fear of motion via pain distraction, and therefore VR training should be further studied for its effectiveness in reducing kinesiophobia and preventing chronicity.

5. Summary

Neck pain has recently drawn international attention as a growing health problem in western society (Lidgren, L. 2008; Rydevik, B. 2008). Consequently, a need for a reliable, objective and functional assessment was stressed in existing literature (Chappuis, G. and Soltermann, B. 2008; Nordin, M. et al. 2008). Qualities of VR technology were utilised in order to provide a solution for this need.

Our research included development of a novel VR assessment of cervical motion, reliability evaluation of the developed VR, and comparison of cervical motion kinematics between patients with chronic neck pain and control individuals without symptoms.

The described advantages of the VR assessment over existing conventional assessments include the interactive use of external visual stimuli; the VR motion enhancement effect demonstrated in ROM analysis; and the greater sensitivity found for VR ROM and kinematic measures compared to existing outcome measures.

The validation of the VR assessment was supported by two analyses, first by demonstrating group differences in range, velocity and smoothness of cervical motion, and second by showing good diagnostic value for outcome measures used.
As part of the investigation, and in agreement with previous literature, advantageous findings and better performance were shown for horizontal motion as compared with sagittal motion. This included differences in reliability, range and velocity of cervical motion.
The developed VR system may serve a platform for future therapeutic modalities, for training in rehabilitation of patients suffering from neck pain.

6. Acknowledgement

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