MASTER'S THESIS

Comparison of Instantaneous and Cumulative Loads of the Low Back and Neck in Orthodontists

By

THERESA NEWELL

MASTER OF SCIENCE PROGRAMME

Department of Human Work Sciences
Division of Industrial Ergonomics

Comparison of instantaneous and cumulative loads of the low back and neck in orthodontists

By

Theresa Newell, BSc

Luleå University of Technology, Luleå, Sweden

Department of Human Work Sciences

Division of Industrial Ergonomics

February 2003

Abstract

The primary objective of this study was to quantify instantaneous and cumulative spinal loads in orthodontic practice. The study consisted of two parts. The first part of the study included the mailing out of the standardized nordic questionnaire to all orthodontists residing in the province of Alberta, Canada to find out the prevalence of musculoskeletal disorders (MSDs) within the occupation. There was a 56 percent response rate; 32 respondents out of 57 distributed questionnaires. Of the 32 respondents, 19 (59%) reported low back trouble, 18 (56%) neck trouble and 15 (47%) shoulder trouble. The second part of the study included a sample of graduate orthodontic students ($n = 9$) from the University of Alberta. The subjects were videotaped performing their regular duties and the recorded postures were printed for biomechanical analysis of instantaneous compression and shear loads on the low back and neck. Cumulative loads were calculated from the instantaneous loads. A postural discomfort questionnaire was also administered to the subjects to be completed at four different times during the work day. The results showed the average instantaneous lumbosacral compression loads for males and females to be 1,383 N and 936 N respectively. The average daily cumulative lumbosacral compression loads for males and females were 16.2 MNs and 9.9 MNs respectively. The conclusion arises from the results that instantaneous loads are not indicative of cumulative loads, particularly for the occupation of orthodontistry. Furthermore, prolonged static sitting exerts large cumulative loads on the spine, which is compelling evidence to show and confirm that orthodontic practice is of high risk for MSDs.

Table of Contents

Title page	1
Abstract	2
Table of contents	3
List of tables	8
List of figures	11
List of abbreviations	13
General	13
Mathematical	13
1.0 Introduction	16
1.1 Background	16
1.2 Review of literature	17
1.2.1 The economic problem	18
1.2.2 The nature of dental practice	18
1.2.3 MSD research in dental professionals	19
1.2.4 Quantification of loads on the spine	23
1.2.5 Previous instantaneous load research	23
1.2.6 Previous cumulative load research	24
1.3 The research problem	26
1.4 Significance and need	26
1.5 Research questions	27
1.6 The hypothesis	27

1.7 Purpose and objectives	28
1.8 Outline of procedure	28
1.9 Limitations	29
1.10 Definitions	30
2.0 Methodology	33
2.1 Part I	33
2.1.1 Sample	33
2.1.2 Devices and measures	33
2.1.3 Nordic questionnaire administration	34
2.3.4 Nordic questionnaire analysis	35
2.2.5 Statistical analysis	35
2.2 Validation study	36
2.2.1 Validation sample	36
2.2.2 Validation measurement and devices	36
2.2.3 Validation procedure	37
2.2.4 Validation data analysis	38
2.2.5 Validation results	39
2.3 Part II	40
2.3.1 Sample	40
2.3.2 Subject consent	41
2.3.2.1 Group meeting	41
2.3.2.2 Validation subject meeting	41
2.3.3 Task observation and inquiry	42

2.3.4 Devices and measures	42
2.3.4.1 Videotaping	42
2.3.4.2 Postural discomfort questionnaire	43
2.3.5 Procedures	44
2.3.5.1 Videotaping	44
2.3.5.1.1 Retrieving patient consent	44
2.3.5.2 Postural discomfort questionnaire	45
2.3.6 Data analysis	46
2.3.6.1 Video analysis	46
2.3.6.1.1 Posture and timing	46
2.3.6.1.2 Frame measurement	46
2.3.6.1.3 Calculation of instantaneous load	47
2.3.6.1.3.1 Lumbosacral load	48
2.3.6.1.3.2 Cervicothoracic load	57
2.3.6.1.3.3 Limitations	59
2.3.6.1.4 Calculation of cumulative load	59
2.3.6.1.5 Statistical analysis	62
2.3.6.2 Questionnaire analysis	62
3.0 Results	63
3.1 Part I	63
3.1.1 Sample demography	63
3.1.2 Reported symptoms	64
3.1.3 Low back symptoms	67

3.1.4 Neck symptoms	67
3.1.5 Shoulder symptoms	68
3.2 Part II	73
3.2.1 Sample demography	73
3.2.2 Task observation	74
3.2.3 Postures and timing	77
3.2.4 Generalization from students to orthodontists	82
3.2.5 Instantaneous load	84
3.2.5.1 Lumbosacral loads	84
3.2.5.2 Cervicothoracic load	85
3.2.6 Cumulative load	91
3.2.6.1 Lumbosacral load	91
3.2.6.2 Cervicothoracic load	92
3.2.7 Questionnaire	101
4.0 Discussion	107
4.1 Part I	107
4.1.1 Sample demography	107
4.1.2 Reported symptoms	107
4.1.3 Low back, neck and shoulder symptoms	109
4.2 Part II	111
4.2.1 Sample demography	111
4.2.2 Task observation	112
4.2.3 Posture and timing	113

4.2.4 Biomechanical stress in the occupation	114
4.2.4.1 Lumbosacral stress	114
4.2.4.1.1 Instantaneous compression loads	114
4.2.4.1.2 Cumulative compression loads	116
4.2.4.1.3 Shear loads	118
4.2.4.2 Cervicothoracic stress	119
4.2.4.2.1 Instantaneous compression loads	119
4.2.4.2.2 Cumulative loads	120
4.2.4.2.3 Shear loads	121
4.2.5 Questionnaire	121
4.3 Study limitations	123
5.0 Conclusions	124
References	125
Appendix I – Information letter to subject	132
Appendix II – Subject consent form	134
Appendix III – Information letter to patient	135
Appendix IV – Patient consent form	137
Appendix V – Postural discomfort questionnaire	138
Appendix VI – Letter to orthodontists	140
Appendix VII – Standardized nordic questionnaire	141
Appendix VIII – Body segment weights	147
Acknowledgements	148

List of tables

2-1. Demographic details of Validation study sample	36
2-2. Comparison of body joint identification methods	40
3-1. Demographic variables of the responding orthodontists in the nordic questionnaire	64
3-2. Reported symptoms in nordic questionnaire respondents in the last 12 months	65
3-3. Chi-square test results for reported symptoms in nordic questionnaire respondents	66
3-4. Reported low back trouble in nordic questionnaire respondents	70
3-5. Reported neck trouble in nordic questionnaire respondents	71
3-6. Reported shoulder trouble in nordic questionnaire respondents	72
3-7. Demographic details of the graduate orthodontic students who participated in videotaping and postural discomfort questionnaire	73
3-8. Demographic details of the validation subject who participated in videotaping	74
3-9. Description, duration and frequency of orthodontic tasks	76
3-10. Description, duration and frequency of task I postures	78
3-11. Description, duration and frequency of task II postures	79
3-12. Paired t-test p-values for comparison of instantaneous mean values between validation subject and male student sample	84
3-13. Mean instantaneous compression and shear load values for Task I	86
3-14. Mean instantaneous compression and shear load values for Task II	87

3-15. Paired t-test p-values for comparison between postures	90
3-16. Paired t-test p-values for comparison of instantaneous mean values between female and male student sample	90
3-17. Paired t-test p-values for comparison of instantaneous mean values between task I and task II	91
3-18. Mean overall compression and shear load values for Task I	93
3-19. Mean overall compression and shear load values for Task II	94
3-20. Mean daily cumulative compression and shear load values for Task I	97
3-21. Mean daily cumulative compression and shear load values for Task II	98
3-22. Mean daily, weekly, monthly, and yearly cumulative compression and shear load values for Task I	99
3-23. Mean daily, weekly, monthly, and yearly cumulative compression and shear load values for Task II	100
3-24. Mean daily, weekly, monthly, and yearly cumulative compression and shear load values for combined Tasks I and II	100
3-25. Mean and SD postural discomfort questionnaire VAS scores for four time conditions	102
3-26. Paired t-test p-values for postural discomfort questionnaire VAS scores compared between four time conditions	105
3-27. Paired t-test p-values for postural discomfort questionnaire VAS scores compared between body parts	105
3-28. Paired t-test p-values for postural discomfort questionnaire VAS scores compared between male and female responses	106

VIII-1 Segment weights expressed in percentages of body weight (Hall, 1995)	147
VIII-2 Segment lengths expressed in percentages of body height (Hall, 1995)	147
VIII-3 Segmental centre of gravity locations expressed in percentages of segment lengths (Hall, 1995)	147

List of figures

2-1. Two methods of body joint identification	39
2-2. 'Micro-camera' used for videotaping	43
2-3. Variables measured on video frame	47
2-4. Forces on L5/S1 due to gravity	48
2-5. Forces on L5/S1 due to erector spinae muscle (Hall, 1995)	49
2-6. Compression and shear forces (Hall, 1995)	49
2-7. Forces and distances from centre of gravity to L5/S1	52
2-8. Variables used in the calculation of distances t,a,h	52
2-9. Forces acting on C7/T1	57
3-1. Percentage of nordic questionnaire respondents with body part trouble	66
3-2. Task I postures	80
3-3. Task II postures	81
3-4. Comparison of postures between validation subject and student sample	83
3-5. Instantaneous compression loads for each posture in task I on L5/S1	88
3-6. Instantaneous compression loads for each posture in task II on L5/S1	88
3-7. Instantaneous compression loads of each posture of task I on C7/T1	89
3-8. Instantaneous compression loads of each posture of task II on C7/T1	89
3-9. Overall compression loads of each posture in task I on L5/S1	95
3-10. Overall compression loads of each posture in task II on L5/S1	95
3-11. Overall compression loads on each posture of task I on C7/T1	96
3-12. Overall compression loads on each posture of task II on C7/T1	96

3-13. Mean postural discomfort questionnaire VAS scores of orthodontic graduate students during the '8:30am before work' condition	103
3-14. Mean postural discomfort questionnaire VAS scores of orthodontic graduate students during the '12pm before lunch' condition	103
3-15. Mean postural discomfort questionnaire VAS scores of orthodontic graduate students during the '2pm after lunch' condition	104
3-16. Mean postural discomfort questionnaire VAS scores of orthodontic graduate students during the '4:30pm after work' condition	104

List of abbreviations

General

ADAC	The Alberta Dental Association and College
C7/T1	Seventh cervical and first thoracic vertebral joint segment
EMG	Electromyography
ES	The Ergonomics Society
GD	General dentist
IEA	International Ergonomics Association
L5/S1	Fifth lumbar and first sacral vertebral joint segment
MSD	Musculoskeletal disorder or discomfort
OSHA	Occupational Safety and Health Administration
P	Posture (P1, P2, P3, P4, P5) denotes the five postures
r	Correlation coefficient
SD	Standard deviation
SPSS	Statistical Packages for the Social Sciences
SRS	Scoliosis Research Society
VAS	Visual Analogue Scale

Mathematical

a	Distance from arm cofg to L5/S1
---	---------------------------------

ac	Length from arm cofg to C7/T1
ACL%	Length from arm cofg to L5/S1 as a percentage of AL%
al	Arm length
AL%	Arm length as a percentage of TBH
AW%	Arm weight as a percentage of TBW
CDC	Cumulative daily compression load
CDL	Cumulative daily load (shear or compression)
CDS	Cumulative daily shear load
CML	Cumulative monthly load (shear or compression)
CWL	Cumulative weekly load (shear or compression)
CYL	Cumulative yearly load (shear or compression)
cofg	Centre of gravity
f	Frequency of posture per minute
FA	Arm force due to gravity
FC	Total instantaneous compression force
FE	Force exerted on L5/S1 by erector spinae muscle
FH	Head force due to gravity
FN	Force exerted on C7/T1 due to neck extension muscles
FS	Total instantaneous shear force
FT	Trunk force due to gravity
h	Distance from head cofg to L5/S1
hl	Head length
hc	Length from head cofg to C7/T1

HCL%	Length from head cofg to C7/T1 as a percentage of HL%
HL%	Head length as a percentage of TBH
HW%	Head weight as a percentage of TBW
i	Task I
j	Task II
kNs	Kilo newton second
MNs	Mega newton second
N	Newton (unit of force)
Ns	Newton second (force time product)
OL	Overall load (compression or shear)
S%	Average percentage of day spent sitting
t	Distance from trunk cofg to L5/S1
T%	Percentage of task (I or II) that is performed per day
TBH	Total body height
TBW	Total body weight
tc	Length from trunk cofg to L5/S1
TCL%	Length from trunk cofg to L5/S1 as a percentage of TL%
TD	Total duration of sitting assumed by orthodontists
TH	Total number of hours worked per day
tl	Trunk length
TL%	Trunk length as a percentage of TBH
TW%	Trunk weight as a percentage of TBW
Wt	Total force due to upper body weight (trunk, head, and arm)

1.0 Introduction

1.1 Background

Given that work is vital to our existence and our existence vital to our work, it is clear that paramount importance should be given to safe and healthy work environments to make optimal use of our human resources. Ergonomics is the diverse scientific discipline, which endeavours to optimize human factors in the work place. According to the Ergonomics Society (ES) (2002) ‘the job must “fit the person” in all respects, and the work situation should not compromise human capabilities and limitations’. Musculoskeletal disorders (MSDs) may come about when the demands of the job exceed the capabilities of the worker (Occupational Safety and Health Administration [OSHA] 1999). Unfortunately, the nature of work is largely perceived as fixed and seems as though little can be done to change the situation. As a result many people force themselves to endure awkward postures and working practices in order to make a living. In turn this causes unfortunate and unnecessary stress, strain, and injury and further distends into long-term absence, disability, loss of job, depression, etc, winding into an endless and often hopeless cycle of helplessness (Hilderbrandt 1987). Nevertheless, according to Kumar (1999) ‘understanding the mechanism of causation of occupational injuries will place us in a better position to design effective strategies of control and prevention’.

Of particular concern, dental professionals claim a large array of supporting evidence for the precipitation of MSDs, especially involving the low back and neck (Marshall et al. 1997). However, no information regarding orthodontists within the dental profession emerged after a wide literature search. In an effort to gauge and understand the MSDs among orthodontists, the present research will focus on identifying the nature of loads on the low back and neck with which orthodontic professionals are faced with daily.

1.2 Review of literature

In recent years attention and awareness of MSDs in the dental profession has increased noticeably due to the rise in numbers of reported MSDs. Although the numbers vary among the literature, they all support the assumption that dental professionals are at a significantly high risk for developing work-related MSDs. With the increasing numbers of dental professionals developing painful symptoms, changes must be made to the way they practice to allow for longevity in their careers (Graham 2002). Optimistically, Graham (2002) claims that these problems can be avoided by increasing awareness of the postures used during work, redesigning the workstation to promote neutral positions, and following healthier work practices to reduce the stress of dental work on the practitioner's body.

1.2.1 The economic problem

In 1987, Shugars et al. computed that dental professionals lost in excess of \$41 million annually because of musculoskeletal pain and 1.3 million patients had to be cancelled due to dental professionals unable to work owing to pain. In addition to lost income and patient care, musculoskeletal pain causes dental professionals to reduce their daily patient load, take additional breaks, and modify practice procedures (Shugars et al. 1987). Not only do work-related MSDs cause suffering and hardship for the worker and his or her family, but it also adds to the overall cost to society through lost productivity and increased use of medical and welfare services. The cost to society has been estimated at 2-14 percent of the gross national product in different studies in different countries (Mikheev 1994, Murray and Lopez 1997, Leigh et al. 1999).

1.2.2 The nature of dental practice

According to Graham (2002), the current workstation in most dental offices requires the practitioner to lean forward, flex the neck forward and laterally, hold the shoulders abducted with arms flexed, and sustain this position statically for most of the workday. For further burden, practitioners must tightly grip thin, sharp instruments and make a high number of short, forceful movements with the muscles of their wrists and hands. It remains obvious that the human body is not built to handle these kinds of stresses, and the positions in which these professionals must repeatedly put themselves to fulfil their duties places them at great risk for developing MSDs (Graham 2002).

1.2.3 MSD research in dental professionals

Low back pain was the most commonly reported MSD for dental professionals prior to 1985. Since then, there has been a rise in other MSDs from extended workdays, awkward postures, prolonged standing and unsupported sitting, as well as an array of other problems caused by poorly designed workstations, improper work habits, and instruments that are difficult to manipulate (Guay 1998). Hand and wrist disorders are receiving the most attention, although their symptoms are reported less often by dental workers than symptoms of neck and/or back disorders (Guay 1998). According to Rundcrantz et al. (1991), in the fifties pain and discomfort in the low back dominated among dental professionals. The high frequency of pain discomfort in the low back contributed to the introduction of ‘sit-down’ dentistry in the late sixties. It was assumed that back problems would decrease. However, a questionnaire study surveying general dentists (GDs) in 1977 by Thornwall, still showed problems were predominantly localized in the low back, followed by pain and discomfort in the neck and shoulders.

A 1965 Pierre Fauchard Academy poll on dentists’ personal health reported that 33 percent experienced back pain (Fauchard Academy 1968). A study by the British Dental Association reported that 49 percent of a sample of 2,288 dentists noted some form of backache, compared with backache found in only 10 percent of the Royal Air Force education officers in the control group (Fox and Jones 1967). In 1977, Norris stated that one in two US dentists had significant back pain compared to a ratio of one in seven for the general population.

Basset's 1983 study of 465 Canadian dentists found that 62 percent of the respondents had experienced back pain. Responses to a brief questionnaire showed back pain was not related to gender, years of practice, operating style, or frequency of exercise. However, the authors did not conclude or suggest what did relate to the back pain. In addition, 70 percent of those with back pain said they sought professional treatment. Most of these dentists used exercise as the primary means of relief, and 70 percent never missed work because of back pain.

One study in 1987 (Kuorinka et al. 1987) demonstrated that 72 percent of dentists had pain and discomfort either in the neck and/or shoulders or headache. Pain and discomfort were most pronounced among the female dentists. Symptoms in the low back were also frequent (50% of the female dentists and 43% of the male dentists). Only 60 out of 359 dentists had experienced no pain and discomfort in the musculoskeletal system during the previous 12 months (Kuorinka et al. 1990).

A study conducted by Rundcrantz et al. (1991) using the standardized nordic questionnaire to assess work-related MSDs among GDs concluded that reported symptoms in the neck, shoulder and low back appear to have a moderate impact on working ability.

On the other hand a study in 1984, conducted by Diakow and Cassidy, found a 57 percent prevalence of back pain in GDs. The researchers stated that it was well within the

reported range of 50-80 percent for the general population and thus does not show that dentists have a higher occurrence of back pain than the general population. However, there was some indication that attacks of back pain suffered by dentists may be more prolonged. The researchers admitted that no relationship between operating postures and the prevalence of back pain was found, but that it was not really possible to conclude from the study that such a relationship exists. The 30-40 year age group showed the highest frequency of generalised back and low-back pain (Diakow and Cassidy 1984).

Although orthodontists were not discussed specifically, Shugars et al. (1984), indicated in a table of results; out of 32 orthodontists, 41 percent reported general back pain, 22 percent reported upper back pain and 38 percent reported low back pain. The same table showed that out of 347 GDs; 57 percent reported general back pain, 31 percent reported upper back pain and 54 percent reported low back pain. Their report investigated further the data for GDs, and related back pain to factors such as congenital disorders, sports injuries, and traumatic injuries ($r = 0.30$, correlation coefficient). However, poor general posture habits ($r = 0.12$), chair side ($r = 0.15$) posture habits and increasing age ($r = 0.10$) seem only minimally associated with back pain. Years in practice and hours per week spent in practice appear not to be related.

More recently, Lalumandier et al. (2001) conducted a survey gathering general data on the prevalence of MSDs among various dental professionals including GDs, dental hygienists, orthodontists and other dental specialists (i.e. periodontists, oral surgeons, endodontists, prosthodontists, paediatric dentists). Similar to the above study, out of 59

orthodontists, 43 percent reported back pain, 19 percent reported neck pain, 15 percent reported shoulder pain, 15 percent reported leg pain, and 9 percent reported arm pain. In comparison, out of 647 GDs, 35 percent reported back pain, 28 percent reported neck pain, 21 percent reported shoulder pain, 9 percent reported leg pain, and 6 percent reported arm pain. Similar results occurred between the two groups, and back pain as the major source of discomfort was concluded among these groups of dental professionals as well as with most of the other dental professionals surveyed. The previous 1984 study showed a higher prevalence for generalised back pain among the GDs, but was the same for the orthodontists.

Kerosuo et al. (2000) conducted a study on 147 GDs, 81 orthodontists, and 91 office employees in Finland. Reported MSDs for orthodontists, GDs and office employees were 72, 70 and 60 percent respectively. These symptoms were reported significantly more often by women than by men, the odds ratio being 2.0. The office employees had significantly fewer of these symptoms ($r = 0.56$) than GDs and orthodontists pooled together, where as being an orthodontist did not significantly affect the odds of any variable studied. Age or years at work did not have a significant effect on the occurrence of these or any other of the symptoms reported. In contrast to Lalumandier et al.'s study (2001), the neck (53%) and shoulders (56%) were the sites most involved, followed by back pain (28%) then arms and hands (17%).

1.2.4 Quantification of loads on the spine

Many forces are acting on the spine while performing work from the surrounding muscles, weight of the body above the spinal segment of interest and gravity. Such forces include compression, shear and torsion. Compression forces denote the vertical downward forces acting on the spinal segment, while shear describes the horizontal forces and torsion the twisting forces (Scoliosis Research Society [SRS] 2002). What's more, these forces can be quantified as instantaneous loads (i.e. the force transmitted for one task cycle or posture), or as cumulative loads, (the force transmitted over several task cycles or prolonged posture). Additionally, these forces can also be considered either static, (i.e. one sustained posture over a period of time) or dynamic (i.e. movement through a series of postures over a period of time).

1.2.5 Previous instantaneous load research

Previous studies have looked at peak instantaneous loads in cadavers, causing fractures under an average load of 8,000 N (range 6,000 N to 10,000 N) (Willen et al. 1984). However, the ultimate compressive strength of the lumbar spinal unit was agreed to be 6,700 N for people under forty years and 3,400 N for people over 60 years (Evans and Lisner 1959, and Sonoda 1962). NIOSH (1981) used these values in its 'Work practices guide for manual lifting' as the maximal allowable limits. Another study by Andersson and Schultz (1979) reported a maximal voluntary isometric stoop lifting effort of 900 N from a sample of five male subjects. This was calculated to have generated an

instantaneous compression force of 7,863 N on the lumbar spine, which greatly exceeds the NIOSH permissible limit. Studies have shown that compression forces of up to eleven times the body weight can be imposed on the lumbar spine by daily activities (Granhed et al. 1987).

Cyron et al. (1976), simulated shear forces on the pars interarticularis of cadavers. Fractures occurred between 1,200 N and 2,800 N. However, no fracture could be created in several L-5 specimens. Shear loading, combined with compression, results in the facet joints resisting as much as two-thirds of the shear force (Gatt et al. 1997).

Comparison of lumbosacral compression revealed that the static mode of lifting gave a greater compression force than the isokinetic lift (Kumar 1988)

1.2.6 Previous cumulative load research

Kumar (1990) stated that repeated load application may result in cumulative fatigue. This fatigue reduces the stress-bearing capacity of the tissues, and thus the ability of the worker will be reduced even though the job demands have not, leading to injury. The change will ultimately reduce the threshold at which the tissues fail, increasing the workers risk for injury. Studies have established that history of exposure to biomechanical stress may decrease the tissue threshold, thus instigating back disorders. Due to the viscoelastic nature of all tissues, it is well known that history of the duration of stresses has a longstanding role in injury (Kumar 1990).

Kumar (1990) conducted a study, in which, biomechanical load, exposure time over the entire work experience and back pain was investigated in a group of institutional aides. The results showed a significant difference between the total time worked between the pain group and the non-pain group. The pain group experienced longer working durations in their lifetimes than did the non-pain group. Furthermore, in the same study, the mean cumulative load in the current job was greater for the pain group, and the same was shown for their previous jobs. Kumar (1990) suggested that more severe pathologies might be associated with higher cumulative loads; however this has not been investigated.

Norman et al. (1998) performed a study comparing peak and cumulative physical work exposure risk factors and the reporting of low back pain in the automotive industry. They found that cumulative spinal load per shift provides information that is different from peak spinal load in distinguishing those who report low back pain in the workplace from those who do not. They further concluded that the cumulative loading variables were not simply the values of peak variable multiplied linearly by time. These variables are, apparently, measuring different demands of the jobs as well as measuring different aspects of risk.

1.3 The research problem

The magnitude of spinal loads in dental professionals has not been quantified. More importantly, the relevance for the quantification of instantaneous and cumulative loads to occupational stress has not been studied.

1.4 Significance and need

First of all the studies performed on dental professionals limit themselves to a homogeneous sample of GDs and less attention has been focused on other dental professionals with similar work conditions such as orthodontists. In light of this, the present research will adopt the need to obtain MSD prevalence among orthodontists to confirm previous data obtained for GDs applies to orthodontists. Secondly, a gap in the literature exists in the quantification of loads endured in the dental profession. Knowledge of this magnitude is important in understanding the causation of MSDs in the workplace. The results of this study will suggest a need for change, if needed, and for the improvement of work conditions and/or reduction of load on musculoskeletal structures in dental professionals, specifically orthodontists. More importantly, another gap exists in the previous literature for spinal load quantification. Little research has been identified comparing the nature of instantaneous and cumulative loads on musculoskeletal structures. The obvious assumption that cumulative loads are greater than instantaneous loads on joints is not enough to fully understand the significance it has to the functioning of individuals at work and the possible association to contracting work-related MSDs.

For this reason, the results of this study will also suggest the relevance in determining instantaneous and cumulative loads on the spine to the nature of an occupation.

1.5 Research questions

The following questions were developed to guide the study:

- i. What is the nature of the tasks performed by orthodontists? (How often and what duration are they performed?)
- ii. What posture angles do orthodontists assume?
- iii. What loads exist on the lumbosacral and cervicothoracic spinal segments in orthodontists?
- iv. What is the magnitude of loads on the lumbosacral and cervicothoracic spinal segments in orthodontists (compression, shear, instantaneous and cumulative)?
- v. How do cumulative and instantaneous load magnitudes compare and what do they imply about the occupation?

1.6 The hypothesis

The hypothesis for this research is stated as follows:

Instantaneous loads in orthodontists are not indicative of cumulative loads.

1.7 Purpose and objectives

The goal of this study is to gain further insight into the nature and magnitude of spinal loads in orthodontists. More specifically, the aim of this study will determine and compare the cumulative and instantaneous loads on lumbosacral and cervicothoracic spinal segments in orthodontic practices.

The following are specific objectives:

- i. To quantify instantaneous and cumulative spinal loads in orthodontic practice.
- ii. To relate the findings of the study to injury and morbidity in orthodontic practice.

1.8 Outline of procedure

Firstly, a survey regarding MSD prevalence was mailed out to all practicing orthodontists in Alberta. Secondly, graduate orthodontic students were videotaped as they performed their regular tasks in the field. The postural data recorded on video for the tasks performed was analysed using a biomechanical model developed specifically for this study. The model calculated compression and shear forces on the lumbosacral and cervicothoracic spinal segments. From this data, a descriptive accounting of the instantaneous and cumulative loads on the lumbar spine was made. In addition, the student sample was given a brief postural discomfort questionnaire to be completed four times during the course of the workday.

1.9 Limitations

The following limitations applied to this study:

- i. The measurement of posture angles was difficult at times as the assessment of joint position relied on subjective judgments, which may be prone to error.
- ii. Questionnaires or self-evaluations depended on the respondents' subjectivity and varied from one individual to another.
- iii. The biomechanical model used in this study did not account for stresses caused by dynamic movements.
- iv. Camera position was limited by objects in the environment.
- v. Only one camera angle was used, and thus only angles in the sagittal plane could be calculated.

1.10 Definitions

The following definitions were used throughout this study:

Biomechanics

The science that examines forces acting upon and within a biological structure and effects produced by such forces (Hay 1993).

Cervicothoracic

Pertaining to the segment of the spine encompassing the seventh cervical vertebra and the first thoracic vertebra (SRS 2002).

Compression load

A load that tends to shorten a structure, usually vertical in the human body due to gravity (SRS 2002).

Cumulative load

The load presented on the musculoskeletal tissue for a prolonged period of time, (i.e. over the duration of 8 hours, 1 week, 2 weeks, etc).

Dental professionals

A term encompassing all professionals working within the dental industry including: general dentists, orthodontists, dental hygienists, among other dental specialists (Alberta Dental Association and College [ADAC] 2002).

Dynamic load

Involves muscular effort in which motion of the segment exerting force is involved (Grandjean 1980).

Ergonomics

The scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance (International Ergonomics Association [IEA] 2000).

Load

An action that causes the body to displace or deform (SRS 2002).

Lumbosacral

Pertaining to the segment of the spine encompassing the fifth lumbar vertebra and first sacral vertebra joint (SRS 2002).

General dentists

Dental professionals licensed and educated to oversee all aspects of oral health. With at least six years of university education, they are highly qualified to examine and diagnose dental problems or disease and recommend treatment. Most dentists perform treatment or they refer the patient to a dental specialist, i.e. orthodontist (ADAC 2002).

Instantaneous load

The load presented on the musculoskeletal tissue for one time.

Musculoskeletal

Refers to any tissue that is related to the muscular-skeletal system. This includes structures such as muscles, tendons, ligaments, bone and cartilage (Hall 1995).

Musculoskeletal Disorder (MSD)

Any injury or discomfort to the musculoskeletal tissues. These disorders can occur from a single accident, such as lifting a heavy weight, or can develop gradually from repeated stress on a part of the body. MSDs can affect any part of the body, but most commonly occur in the back, neck, shoulder, elbow, and wrist (Graham 2002).

Orthodontists

Dental specialists who diagnose and treat a poor bite and improperly positioned teeth to improve the functioning of the teeth and their overall cosmetic appearance. (ADAC 2002).

Posture

Position of the body or of body parts. A task is made up of several postures.

Shear Load

Load parallel to the surface, horizontal to gravity in the human body (SRS 2002).

Static

A muscular effort in which a sustained contraction of a muscle or muscle group occurs (Grandjean 1980).

Task

A series of postures or actions required to achieve a goal or a structured set of postures.

2.0 Methodology

The present study was divided into three parts: part I, validation study, and part II. Part I included the collection of mail-out survey data from practicing orthodontists, while the validation study included a detailed study validating a method used in part II. Part II included the collection of videotaped and questionnaire data from graduate orthodontic students.

2.1 Part I

2.1.1 Sample

All practicing orthodontists, (61 in total), in the province of Alberta, Canada were potential subjects for part I of the study. Four questionnaires were returned to sender and thus spoiled. Therefore out of 57 potential subjects, 32 were responding participants accounting for a response rate of 56 percent. The responding sample's demographic details are presented in table 3-1, obtained from the nordic questionnaire.

2.1.2 Devices and measures

The standardized nordic questionnaire, validated by Kuroinka et al. (1987), was used to measure the prevalence MSDs among orthodontists in Alberta. The questionnaire included demographic questions regarding gender, age, height, weight, hand dominance,

years of practice, hours of work per week and percentage of day spent sitting. Categorical ‘Yes/No’ questions were used to address the incidence of any body part trouble (ache, pain, discomfort), during the whole lifespan, during the last 12 months and during the last 7 days. Questions regarding the whole life span included categorical ‘Yes/No’ questions to address any occurrence of accident, and change of job or duties related to said trouble. Questions regarding the last 12 months included categorical ‘Yes/No’ questions addressing any prevention or reduction of work and/or leisure activity and/or sought professional treatment for said trouble. Categorical questions were also used to ask respondents for total length of time experienced trouble and/or were prevented from doing normal work. The respondents were required to answer one of the following: 0 days, 1-7 days, 8-30 days, more than 30 days, or everyday. Refer to appendix VII to view the standardized nordic questionnaire.

2.1.3 Nordic questionnaire administration

The nordic questionnaire was mailed-out with a brief letter introducing the research study and a brief set of directions, (see appendix VI to view letter). A self-addressed return portion provided with a stamp was also included to facilitate return with minimum effort. The nordic questionnaire was mailed out to the 61 orthodontists in Alberta who were registered in the Alberta Dental Association and College (ADAC). Four of these questionnaires were returned to sender and thus, out of 57 distributed questionnaires, 32 orthodontists responded accounting for a response rate of 56 percent.

2.1.4 Nordic questionnaire analysis

The demographic details for every subject were entered into an excel database. Gender was encoded with the numeric values 1 and 2 for female and male respectively. Hand dominance was encoded 1 and 2 for right handed and left handed responses respectively. All 'Yes' and 'No' answers were given values of 1 and 2 respectively, and the categorical answers of 0 days, 1-7 days, 8-30 days, more than 30 days, and everyday, were given values of 1-5 respectively. All the encoded values of the categorical questions were then entered into an excel database.

2.1.5 Statistical analysis

Descriptive statistics, (mean and standard deviation (SD) values), were determined for demographic details such as age, height, weight, number of years practice, number of hours work per week, and percentage of day spent sitting. Frequencies of all encoded categorical data were tabulated. Charts were plotted for reported symptoms, and Chi-square tests were performed on all categorical variables to determine if any significant correlations existed. Paired t-tests were used to determine statistical differences between genders and between body parts. The statistical program, SPSS (Statistical Packages for the Social Sciences) was used to perform all statistical calculations.

2.2 Validation study

Since it was not possible to place joint markers on the subjects in their practicing environments or feasible to videotape the subjects without clothing, a consistent method of ensuring joint locations and thus angles to be measured was developed. The recorded angles were then validated against direct measurements. The following sections detail the validation study.

2.2.1 Validation sample

Two healthy male subjects volunteered to participate in the validation study in the ergonomic laboratory at the University of Alberta. The subjects' mean personal and anthropometric characteristics are given in table 2-1.

Table 2-1. Demographic details of validation study sample

Gender	Parameter	Age (yrs)	Height (cm)	Weight (kg)
Male (n=2)	Mean	27.5	172.5	66.3
	SD	3.5	3.5	2.5

2.2.2 Validation measurement and devices

Joint markers of uniform size, 2 cm by 2 cm, were used to mark joints on the body of subjects wearing merely a brief. A video camera was used to record two postures. The

videotape was played to record postures using a video printer on paper. A protractor was used to measure joint angles on the printed video frames, and a grid transparency was used to aid in the measure of joint angles on the printed frame. Bony landmark locations representing body joints were positioned using Hall (1995) as a reference.

2.2.3 Validation procedure

The validation study consisted of videotaping subjects in two conditions. In the first condition the subject was wearing only a brief and markers were placed on the skin at palpable joint positions of the knee, hip, elbow, wrist, and shoulder with reference to Hall (1995). The subject was positioned in a seated posture, with some degrees of trunk flexion and arms extended out in front. The video was taken of the subject's profile 90 degrees to the sagittal plane to allow measurement and visibility of joint angles and markers, (the same camera angle was used for the orthodontic graduate student subjects in part II of the study). Careful effort was taken to mark the posture to ensure the subject would be in the exact same position for the second condition. In the second condition the subject was dressed in 'casual work' clothes, as typically seen in the practice of orthodontics, and no joint markers were placed. The subject was videotaped a second time in the same posture as condition one.

2.2.4 Validation data analysis

The videotaped postures for both conditions were displayed and printed using a video printer. The marked joints shown in the print-out of the first condition were joined with their adjacent joints and angles at these joints with respect to the vertical were measured using a protractor taken to the closest 0.5 degrees. In the second print-out of the second condition, the frame was carefully examined for body landmarks through clothing and the joints were marked with points. The points were then joined as stated previously with their adjacent joints. The angles at these joints were measured with respect to the vertical using a protractor. Figure 2-1 shows the measured frames of both conditions for one subject. The resultant angles of the two conditions were then compared to verify that the method in condition two, (with clothing and no joint markers), yielded the same results as condition one, (without clothing and using joint markers). A statistical paired t-test was performed using SPSS software, to compare the means of the two methods to prove there was no significant difference.

(a) Method I

(b) Method II

Figure 2-1. Two methods of joint identification

2.2.5 Validation results

Table 2-2 shows the resultant angles of the two conditions for each subject and the paired t-test result. The resultant angles generated by the two conditions for the two subjects did not show any statistical significant difference ($p\text{-value} = 0.771$). Therefore it was concluded that the two conditions do generate the same results.

Table 2-2. Comparison of body joint identification methods

Subject (n=2)	Angle (°)	*Method I	*Method II
1	Trunk	27.5	27
	Shoulder	29.5	30
	Elbow	94	94.5
2	Trunk	27	28
	Shoulder	33	32.5
	Elbow	95.5	95
Paired t-test (p-value)		0.771	

*Method I = Condition I, joint markers and no clothing

*Method II = Condition II, clothing and no joint markers

2.3 Part II

2.3.1 Sample

All graduate orthodontic students enrolled in the University of Alberta, (nine in total), were potential subjects for the study, and all volunteered their participation. All graduate orthodontic students had the same background education and training of achieving a bachelor's degree in dentistry, making for a homogeneous sample. The sample ranged in age from 27 years to 36 years and consisted of 7 males and 2 females. Anthropometric details, (i.e. height and weight), of the subjects were obtained through private dialogue and are given in table 3-7. This sample of graduate orthodontic students was selected for convenience and not because this population was representative of all orthodontists. In order to ensure transfer of data from the graduate orthodontic students to practicing orthodontists a validation subject from a private clinic was selected for comparison purposes. The validation subject had 18.5 years of experience practicing in orthodontics.

Personal anthropometric characteristics were asked of the validation subject and are given in table 3-8. The criteria used for selecting the validation subject were a minimum of 15 years experience working as an orthodontist, and working full time hours.

2.3.2 Subject consent

2.3.2.1 Group meeting

In efforts to seek cooperation for the study, a group meeting with the graduate orthodontic students was initiated through telephone and email communication with the graduate orthodontic department head. The purpose of the group meeting was to obtain informed consent from the students for participation in the present study. The meeting consisted of an explanation of the present study and distribution of subject information and consent forms (see appendix I and II to view these forms). The subjects were given the opportunity to ask questions regarding the substance and/or procedure of the research study. The meeting was concluded with the collection of signed and witnessed consent forms. The group meeting lasted approximately 30 minutes.

2.3.2.2 Validation subject meeting

A meeting to explain the study and obtain informed consent from the validation subject was initiated by telephone. Signed consent was obtained and permission to videotape the validation subject's private clinic was granted.

2.3.3 Task observation and inquiry

Observation of students in the graduate orthodontic clinic and the validation subject in the private clinic was necessary to determine what tasks were involved in orthodontic practice and to ensure tasks observed were consistent between student and validation subject. Visits were initiated at each clinic through telephone communication with receptionists. Identified tasks were given detailed descriptions of their nature and physical attributes. Average task proportions, durations and frequencies per day were obtained from the private clinic reception records and validation subject.

2.3.4 Devices and measures

2.3.4.1 Videotaping

Videotaping was used as a tool to indirectly measure compression and shear loads, (in newtons), on the lumbosacral and cervicothoracic spinal segments. A small 'micro-camera' with a wide angle lens encased in a small box was used for videotaping. The 'micro-camera' was of convenient size so as to be unobtrusive to the subjects' work environment. A 'c-clamp' was attached to the camera box so that the camera could easily be mounted on a counter surface or tripod and positioned to obtain the necessary camera angle, (see figure 2-2). A videotape player was used to view the recorded postures and measure time. A protractor was used to measure joint angles to the nearest 0.5 degree on the printed video frames, and a grid transparency was used to aid in the measure of joint

angles on the printed frame. Joint locations were marked using Hall (1995) as a reference.

Figure 2-2. 'Micro-camera' used for videotaping

2.3.4.2 Postural discomfort questionnaire

A questionnaire was used to measure subjective qualitative judgments of the orthodontic graduate students regarding postural discomfort at various times throughout the day. The questionnaire was comprised of a simple body diagram divided into 10 regions and a visual analogue scale (VAS) to be answered for each body region. The VAS was expressed as a horizontal line of 10 cm and labelled at each end, left and right, with 'no discomfort' and 'severe discomfort' respectively. The components of this questionnaire were validated by Corlett and Bishop (1976), Huskisson (1983), and Kumar et al (1999) and can be viewed in appendix V.

2.3.5 Procedures

2.3.5.1 Videotaping

Based on task observation and inquiry findings, the tasks which were performed most frequently and deemed most stressful were targeted for videotaping. During the videotaping, the subjects were asked to wear facemasks of typical wear in dental practice, to conceal their identities. Subjects performing the tasks were photographed in profile view 90 degrees to the sagittal plane to allow for biomechanical analysis and time measurement. Due to field study limitations such as environmental obstructions, (the clinical setting was fixed and could not be altered), some of the subjects were videotaped from the left side and some from the right side. Each subject was videotaped in their own practice area in order that the study presence would not disturb the subject's work flow. Further field study limitations did not allow videotaping of all subjects performing all targeted tasks, as not all subjects had patients requiring some procedures during the video collection period.

2.3.5.1.1 Retrieving patient consent

In videotaping the orthodontist, the patient was also in view of the camera. Thus, consent had to be obtained from the patients in order to videotape the procedure. The patients were asked to wear sunglasses to conceal their identity. Most of the patients were under 18 years of age and thus signed parental consent had to be obtained. Patients and their

parents, (if required), who arrived early for their appointments, were asked permission for their procedure to be videotaped. The patients and/or parents in this time before their appointment were given an information form explaining the study and a consent form to be signed (see appendix III and IV for administered forms). It was important that this administration procedure be completed before the patient's appointment to ensure work flow and schedule of the orthodontist was not disrupted by the study.

2.3.5.2 Postural discomfort questionnaire

The postural discomfort questionnaire, shown in appendix V, was administered to subjects during one full work day. The subjects were given instructions and review of the questionnaire and opportunity to ask questions ahead of time. Four copies of the questionnaire were distributed to each subject to be filled out at four different times, (conditions), during their work day: 8:30 pm (before work begins), 12 pm (before lunch), 2 pm (after lunch), and 4:30 pm (after work). The questionnaires were collected at the end of the day, and any questions the subjects had were clarified.

2.3.6 Data analysis

2.3.6.1 Video analysis

2.3.6.1.1 Posture and timing

The videotaped material was viewed on a videotape player and postures of each task were identified. The physical characteristics of the postures were described in detail and the time duration for each posture was measured using the timer on the videotape player. Observed frequencies of each posture were also noted.

2.3.6.1.2 Frame measurement

The identified postures for each task displayed on the videotape player were paused at appropriate frames chosen for biomechanical analysis. These frames were printed using a video printer. The printed pictures were carefully examined for anatomical landmarks (i.e. centre of gravity of the head, joints of the hip (L5/S1), shoulder (C7/T1), and elbow). In addition, the following variables were measured for input into a biomechanical formula: trunk angle (θ_1), neck angle (θ_2), and shoulder angle (θ_3) with respect to the vertical, see figure 2-3. Angles were measured to the closest 0.5 degrees.

Figure 2-3. Variables measured on video frame

2.3.6.1.3 Calculation of instantaneous load

A biomechanical model was formulated to calculate instantaneous compression and shear loads on the L5/S1 (fifth lumbar and first sacral vertebrae) and C7/T1 (seventh cervical and first thoracic vertebrae) segments of the spine during a seated posture. The following sections give detailed logic behind the biomechanical equations. All variables described are denoted by an abbreviation, (i.e. FT for trunk force), which will be used consistently throughout this document. The list of all abbreviations used for this study is located on page 13.

2.3.6.1.3.1 Lumbosacral load

The following three external forces are acting on the L5/S1 segment of the spine while sitting, as shown in figure 2-4:

- F_T = trunk force due to gravity
- F_A = arm force due to gravity
- F_H = head force due to gravity

Figure 2-4. Forces on L5/S1 due to gravity

The primary internal force acting on the L5/S1 segment is generated from the muscle tension of the erector spinae, depicted in figure 2-5:

- F_E = force exerted on L5/S1 by erector spinal muscle

Figure 2-5. Forces on L5/S1 due to erector spinae muscle (Hall 1995)

The resultant shear and compression forces acting on L5/S1 are depicted in figure 2-6.

Figure 2-6. Compression and shear forces (Hall 1995)

- $FS_{L5/S1}$ = total shear force
- $FC_{L5/S1}$ = total compression force
- $Wt_{L5/S1}$ = total force due to upper body weight = $(F_T + F_A + F_H)$
- θ_1 = angle of trunk flexion with respect to the vertical

$$F_{C_{L5/S1}} = W_t \cos \theta_1 + F_E$$

$$F_{S_{L5/S1}} = W_t \sin \theta_1$$

In determining FT, FA, and FH:

Based on the simple equation: Force = mass x acceleration, FT, FA, and FH can be calculated as follows:

$$F_T = (TW\%)(TBW)(9.81m/s^2)$$

$$F_A = (AW\%)(TBW)(9.81m/s^2)$$

$$F_H = (HW\%)(TBW)(9.81m/s^2)$$

Where:

- TBW = total body weight
- *TW% = trunk weight (a percentage of total body weight)
- *AW% = arm weight (a percentage of total body weight)
- *HW% = head weight (a percentage of total body weight)
- * Percentages taken from table VIII-1 in appendix VIII, (Hall 1995).
- $9.81m/s^2$ = acceleration of gravity

Note: The trunk weight includes the weight of the trunk plus the weight of one arm. An assumption is made that one arm, (the arm that is not visible in the video frame because of profile camera angle), is always close to the body and therefore is combined into the weight of the trunk.

As stated above: $W_t = F_T + F_A + F_H$

Therefore:

$$W_t = 9.81(TBW)(TW\% + AW\% + HW\%)$$

In determining FE:

Since all external forces due to gravity generate a torque in one direction (clockwise in figure 2-4), there must be an equal and opposite torque acting on L5/S1 to maintain equilibrium ($\Sigma \text{ Torque on L5/S1} = 0$). In this case the counteracting force comes from FE (the force exerted by the erector spinae).

Given that Torque = Force x Distance, and the moment arm of the erector spinae muscle from L5/S1 is 6cm, given by Hall (1995), the following equation results:

$$\Sigma \text{ Torque on L5/S1} = 0 = (F_T \times t) + (F_A \times a) + (F_H \times h) - (F_E \times 6\text{cm})$$

$$F_E = \frac{(F_T \times t) + (F_A \times a) + (F_H \times h)}{6\text{cm}}$$

Where (as shown in figure 2-7),

- t = distance from trunk centre of gravity (c of g) to L5/S1
- a = distance from arm c of g to L5/S1
- h = distance from head c of g to L5/S1

Figure 2-7. Forces and distances from center of gravity to L5/S1

In determining distances t , a , and h :

A method of direct angle measurement on the printed frame is employed. Figure 2-8 shows a line drawing of the variables used to determine the distances (t, a, h).

Figure 2-8. Variables used in the calculation of distances t, a, h .

In determining t,

$$tl = \text{trunk length} = (TL\%)(TBH)$$

Where, *TL% = trunk length percentage (a percentage of total body height, TBH).

$$tc = \text{length from trunk cofg to L5/S1} = (TCL\%)(TL\%)(TBH)$$

Where, *TCL% = trunk cofg length percentage (a percentage of tl).

*Percentages taken from tables VIII-2 and VIII-3 in appendix VIII (Hall 1995).

As shown in figure 2-8, it can be deduced that $t = tc \sin\theta_1$ and therefore,

$$t = (TCL\%)(TL\%)(TBH)\sin\theta_1$$

In determining h,

$$hl = \text{length of head and neck} = (HL\%)(TBH)$$

Where, *HL% = head length percentage (a percentage of TBH).

$$hc = \text{length from combined neck and head cofg to C7/T1} = (HCL\%)(HL\%)(TBH)$$

Where, *HCL% = head/neck cofg length percentage (a percentage of hl).

*Percentages taken from tables VIII-2 and VIII-3 in appendix VIII (Hall 1995).

Looking at figure 2-8, it can be deduced that $h = hc \sin\theta_2 + tl \sin\theta_1$. This is because hc is only calculated to C7/T1, and thus the trunk distance must then be added in order to determine h, the total distance from head cofg to L5/S1.

Therefore, $h = (HCL\%)(HL\%)(TBH)\sin\theta_2 + (TL\%)(TBH)\sin\theta_1$, or more simplified:

$$h = (TBH) [(HCL\%)(HL\%)\sin\theta_2 + (TL\%)\sin\theta_1]$$

In determining a,

$$al = \text{length of arm (not shown in figure 2-8)} = (AL\%)(TBH)$$

Where, *AL% = arm length percentage (a percentage of TBH).

$$ac = \text{length from cofg of arm to C7/T1} = (ACL\%)(AL\%)(TBH)$$

Where, *ACL% = arm cofg length percentage (a percentage of 'al').

*Percentages taken from tables VIII-2 and VIII-3 in appendix VIII (Hall 1995).

Looking at figure 2-8, it can be deduced that $a = ac \sin\theta_3 + tl \sin\theta_1$. This is because ac is only calculated to C7/T1, and thus the trunk distance must then be added in order to determine a, the total distance from arm cofg to L5/S1.

Therefore, $a = (ACL\%)(AL\%)(TBH)\sin\theta_2 + (TL\%)(TBH)\sin\theta_1$, or more simplified:

$$a = (TBH) [(ACL\%)(AL\%) \sin\theta_3 + (TL\%) \sin\theta_1]$$

Substituting elements into FE equation

As determined before,

$$FE = \frac{(FT \times t) + (FA \times a) + (FH \times h)}{6\text{cm (erector spinae moment)}}$$

Substituting the previously calculated elements FT, t, FA, a, FH, and h, the formula becomes:

$$FE = 9.81(TW\%)(TBW)(TBH)(TL\%)(TCL\%)(\sin\theta_1) + \\ 9.81(AW\%)(TBW)(TBH)[(ACL\%)(AL\%) \sin\theta_3 + 9.81(TL\%) \sin\theta_1] + \\ \frac{9.81(HW\%)(TBW)(TBH)[(HCL\%)(HL\%) \sin\theta_2 + (TL\%) \sin\theta_1]}{6\text{cm}}$$

more simplified:

$$FE = \frac{9.81(TBW)(TBH)}{6} \left[(TW\%)(TL\%)(TCL\%)(\sin\theta_1) + (AW\%)[(ACL\%)(AL\%) \sin\theta_3 + (TL\%) \sin\theta_1] + (HW\%)[(HCL\%)(HL\%) \sin\theta_2 + (TL\%) \sin\theta_1] \right]$$

Substituting calculated elements into final FC and FS equations:

As determined before,

$$FC_{L5/S1} = Wt \cos \theta_1 + FE$$

$$FS_{L5/S1} = Wt \sin \theta_1$$

Therefore, substituting the above calculated FE and Wt, the formulas becomes:

$$FC_{L5/S1} = 9.81(TBW)(TW\% + AW\% + HW\%) \cos \theta_1 +$$

$$\frac{9.81(TBW)(TBH)}{6} \left(\begin{aligned} &(TW\%)(TL\%)(TCL\%)(\sin\theta_1) \\ &+ (AW\%)[(ACL\%)(AL\%) \sin\theta_3 + (TL\%) \sin\theta_1] \\ &+ (HW\%)[(HCL\%)(HL\%) \sin\theta_2 + (TL\%) \sin\theta_1] \end{aligned} \right)$$

$$FS_{L5/S1} = 9.81(TBW)(TW\% + AW\% + HW\%) \sin \theta_1$$

2.3.6.1.3.2 Cervicothoracic load

The following forces are acting on C7/T1, (figure 2-9):

- FH = head force due to gravity
- FN = force exerted on C7/T1 due to the neck muscles

Figure 2-9. Forces acting on C7/T1

$$FH = 9.81(TBH)(HW\%)$$

Where, *HW% is the head/neck weight percentage (a percentage of TBH).

$$Hl = \text{head/neck length} = (HL\%)(TBH)$$

Where, *HL% is the head/neck length percentage (a percentage of TBH).

$$hd = \text{distance from cofg of head/neck to C7/T1} = (HCL\%)(HL\%)(TBH)\sin\theta_2$$

Where, *HCL% is the head/neck cofg length percentage (a percentage of head/neck length).

*Percentages taken from tables VIII-2 and VIII-3 in appendix VIII (Hall 1995).

In determining FN:

$$\Sigma \text{ Torque on C7/T1} = 0$$

Therefore, $0 = FH \times hl - FN \times 5\text{cm}$, and $FN = (FH \times hl) / 5\text{cm}$

*5cm is the moment arm length of splenius capitis, extensor muscle of the neck
(Vasavada et al. 1996)

$$FN = \frac{9.81(TBW)(HW\%)(HCL\%)(HL\%)(TBH)\sin\theta_2}{5\text{cm}}$$

In determining FC and FS:

$$FC_{C7/T1} = 9.81(TBW)(HW\%) \cos \theta_2 + FN$$

Substituting FN determined above, the formula becomes:

$$FC_{C7/T1} = 9.81(TBW)(HW\%) \cos \theta_2 + \frac{9.81(TBW)(HW\%)(HCL\%)(HL\%)(TBH)\sin\theta_2}{5\text{cm}}$$

$$FS_{C7/T1} = 9.81(TBW)(HW\%) \sin \theta_2$$

2.3.6.1.3.3 Limitations

There are some limitations in using this biomechanical model. First of all, the direct measurement of angles used as input into the model is subject to human error. Secondly, this being a static model, it does not account for the dynamic components of biomechanical stresses. Therefore, compressive and shear forces were calculated for each static posture and for the initial, final and all projected intermediate postures at 200-msec intervals for all dynamic movements (Kumar 1990). However, dynamic movements were sparsely observed in orthodontic practice, and were observed to be comprised of primarily static postures. Due to the impossibility of accurate recording of the minor variations in the activities performed, the postures assumed for each subject and the calculated stresses are considered to be close approximations.

2.3.6.1.4 Calculation of cumulative load

In determining overall load (OL):

For static postures the overall load was obtained simply by multiplying the instantaneous compressive and shear forces with the duration of activity. The overall load (compression or shear) for dynamic activities was obtained as follows:

$$OL = \sum 0.2L_1 + 0.2L_2 + \dots + 0.2L_n$$

Where,

OL = overall load (compression or shear)

L1 = average compression or shear force of the first frame of the posture

L2 = average compression or shear force of the second frame of the posture

0.2 = time interval (fraction of a second, 200ms) between frames

Ns = unit of overall and cumulative load 'force time' product (Newton · second)

In determining cumulative loads:

The cumulative biomechanical loads for each task and posture of each student orthodontic subject were determined in the following steps:

1. Identification of stressful task i and j, task I and task II respectively.
2. Determination of compression and shear instantaneous loads (FC and FS) for tasks i and j.
3. Determination of the frequency (F) per day of tasks i and j according to the following steps:
 - i. Determination of average percentage of day in which orthodontists assume a sitting posture, (S%). Average obtained from nordic questionnaire (see table 3-1).
 - ii. Determination of average total number of hours worked per day, (TH). Average obtained from nordic questionnaire (see table 3-1), total hours per week divided by five.
 - iii. Calculation of duration per day spent in assumed sitting postures, (TD), according to the following equation:

$$TD = TH \times S\% \times 60\text{minutes} \times 60\text{seconds} = TD \text{ (seconds/day)}$$

- iv. Determination of percentage of day spent performing tasks I and II, (i and j), (T%). Percentages obtained from reception records of the validation subject's clinic, (refer to table 3-9, $T_i\% = 0.7$ and $T_j\% = 0.1$).
- v. Determination of frequency of posture per minute, (f/60 seconds), from video observation, (see table 3-10 and 3-11).
- vi. Finally, the total frequency, F, per day is given by the following equation:

$$F = TD \times T\% \times f/60$$

- 4. Calculation of the cumulative compression and shear loads per day for overall loads according to the following equations:

$$CDC = \sum(FC_i \times F_i) + (FC_j \times F_j)$$

$$CDS = \sum(FS_i \times F_i) + (FS_j \times F_j)$$

Where,

CDC = cumulative daily compression load

CDS = cumulative daily shear load

- 5. Deduction of the cumulative loads for other time periods as follows:

$$CWL = [CDL \times 5]$$

$$CML = [(CDL \times 5) \times 4]$$

$$CYL = [(CDL \times 5) \times 4] \times 12$$

Where,

CDL = cumulative daily load (shear or compression)

CWL = cumulative weekly load

CML = cumulative monthly load

CYL = cumulative yearly load

2.3.6.1.5 Statistical analysis

Descriptive statistics, (mean and SD values), were calculated for instantaneous, overall and cumulative loads. Charts were plotted using excel software to compare instantaneous and overall loads within gender groups, postures and tasks. All statistical tests performed on load results were executed using SPSS software. Paired t-tests were used to determine significant differences in instantaneous loads between genders, between validation subject and male student sample, between postures, and between tasks.

2.3.6.2 Questionnaire analysis

The VAS ratings given by the subjects were measured to the nearest 0.5 millimetre with a ruler. Descriptive statistics, (mean and SD values), were determined for the VAS measurements of the four conditions: 8:30 am, 12 pm, 2 pm, and 4:30 pm. The means were plotted on bar graphs using excel software for each of the four time conditions. Statistical paired t-tests were performed using SPSS software to determine if any significant differences existed between gender and reported discomfort, between reported discomfort and the four time conditions, and between reported discomfort and body regions.

3.0 Results

3.1 Part I

3.1.1 Sample demography

The details of age, height, weight, hand dominance, and job duration of the orthodontist sample as obtained in the nordic questionnaire is provided in table 3-1. Of the 61 nordic questionnaires mailed out to practicing orthodontists in Alberta, 4 were returned to sender and therefore spoiled. Thus, out of the 57 valid questionnaires, 56.1% ($n = 32$) were completed and returned. The responding sample consisted of 23 (72%) males and 9 (28%) females. Out of all responding orthodontists only two were left handed. The sample for the study had an age range of 33 years to 65 years and a mean of 48.1 years ($SD = 9.2$). The male orthodontists ranged in height from 167 cm to 190.5 cm with a mean of 179 cm ($SD = 6.7$) and ranged in weight from 64 kg to 110 kg with a mean of 82.5 kg (11.7 SD). The female orthodontists ranged in height from 156.2 cm to 175.3 cm with a mean of 168 cm ($SD = 7.4$) and ranged in weight from 50 kg to 100 kg with a mean of 70.8 ($SD = 20.1$). The responding sample had a job duration range between 2.6 years and 37 years with a mean of 18.7 years ($SD = 10.8$) and work weeks ranged from 20 hours/week to 50 hours/week with the mean being 35.3 hours/week ($SD = 6.4$). The responding orthodontists reported the proportion of the workday performed in a sitting posture to range from 20% of the day to 95% of the day, the mean being 68.9% of the day ($SD = 18.7$).

Table 3-1. Demographic variables of the responding orthodontists in the nordic questionnaire

Gender	Parameter	Age (yr)	Height (cm)	Weight (kg)	Job Duration (yr)	Job Duration (hr/wk)	Sitting Duration (%/day)	Hand Dominance
Total								
Sample (n = 32)	Mean	48.1	175.9	78.8	18.7	35.3	68.9	30 Right
	SD	9.2	8.4	15.5	10.8	6.4	18.7	2 Left
	Min	33	156.2	50	2.6	20	20	
	Max	65	190.5	110	37	50	95	
Males (n = 23)								
	Mean	50.1	179.0	82.5	20.9	35.0	69.6	22 Right
	SD	9.2	6.7	11.7	11.3	6.4	18.9	1 Left
	Min	33	167	64	2.6	20	20	
	Max	65	190.5	110	37	50	95	
Females (n = 9)								
	Mean	43.1	168.0	70.8	12.9	36.1	67.2	8 Right
	SD	7.1	7.4	20.1	6.9	6.6	19.2	1 Left
	Min	33	156.2	50	5.9	28	40	
	Max	53	175.3	100	25.3	45	90	

3.1.2 Reported symptoms

The numbers of reported symptoms occurring in the last 12 months obtained from the nordic questionnaire are given in table 3-2 and depicted in figure 3-1. Of the 32 respondents, 19 (59%) reported low back trouble, 18 (56%) neck trouble, 15 (47%) shoulder trouble, 9 (28%) upper back trouble, 6 (19%) wrist/hand trouble, 6 (19%) knee trouble, 5 (16%) hip/thigh trouble, 5 (16%) ankle/feet trouble, and 4 (13%) reported elbow trouble. A chi-square test was performed on the proportions of reported symptoms; the results are shown in table 3-3. The chi-square test revealed that all body parts, with the exception of the low back, neck and shoulder, resulted in significantly similar proportions of 'no' category answers. A reduction correspondence analysis was

performed on the data, however, no statistically significant correlations were found between any of the variables. In addition, there were no significant differences found between male and female responses using a paired t-test.

Table 3-2. Reported symptoms in nordic questionnaire respondents in the last 12 months

Gender	Total Sample (n = 32)	Male (n = 23)	Female (n = 9)
Neck	18 (56)	12 (52)	6 (67)
Shoulders	15 (47)	11 (48)	4 (44)
Right	6 (40)	5 (45)	1 (25)
Left	4 (27)	2 (18)	2 (50)
Both	5 (33)	4 (36)	1 (25)
Elbows	4 (13)	3 (13)	1 (11)
Right	1 (25)	0	1 (100)
Left	2 (50)	2 (67)	0
Both	1 (25)	1 (33)	0
Wrist/Hands	6 (19)	4 (17)	2 (22)
Right	1 (17)	1 (25)	0
Left	1 (17)	0	1 (50)
Both	4 (67)	3 (75)	1 (50)
Upper Back	9 (28)	6 (26)	3 (33)
Low back	19 (59)	16 (70)	3 (33)
Hips/Thighs	5 (16)	4 (17)	1(11)
Knees	6 (19)	3 (13)	3 (33)
Ankles/Feet	5 (16)	3 (13)	2 (22)

*Note: Percentages (in parentheses) do not total 100 as they are proportions of the total respondents.

Figure 3-1. Percentage of nordic questionnaire respondents with body part trouble

Table 3-3. Chi-square test results for reported symptoms in nordic questionnaire respondents

	Neck	Shoulder	Elbow	Wrist	Upper Back	Low back	Hip	Knee	Ankle
Sig.	.480	.724	.000	.000	.013	.289	.000	.000	.000

3.1.3 Low back symptoms

The results of the nordic questionnaire regarding low back symptoms are given in table 3-4. Of the 32 respondents, 22 (69%) reported having back trouble some time in their life. Of this 22, 5 (23%) said they also had experienced a low back related accident in their life. No orthodontist reported changing jobs due to low back trouble. Out of the 22 respondents who experienced low back trouble in their life, 3 (14%) reported having no trouble in the last 12 months. However, 6 (28%) reported having had 1-7 days of low back trouble in the last 12 months, another 6 (28%) reported having 8-30 days with low back trouble, another 6 (28%) reported having more than 30 days with low back trouble and 1 (5%) reported having low back trouble everyday. Of those who had low back trouble in the last 12 months, (n = 19), 2 (11%) reported having to reduce work activity, 9 (47%) reported having to reduce leisure activity and 8 (42%) sought professional treatment. In addition, 16 (84%) said they did not miss any days of work in the last 12 months, and 3 (16) missed 1-7 days. 11 (58%) of the 19 respondents with low back trouble in the last 12 months, experienced low back trouble in the last 7 days.

3.1.4 Neck symptoms

The results of the nordic questionnaire regarding neck symptoms are given in table 3-5. Of the 32 respondents, 22 (69%) reported having neck trouble some time in their life. Of this 22, 8 (36%) said they also had experienced a neck related accident in their life. No orthodontist reported changing jobs due to neck trouble. Out of the 22 respondents who

experienced neck trouble in their life, 4 (18%) reported having no trouble in the last 12 months. However, 10 (45%) reported having had 1-7 days of neck trouble in the last 12 months, another 2 (9%) reported having 8-30 days with neck trouble, another 5 (23%) reported having more than 30 days with neck trouble and 1 (5%) reported having neck trouble everyday. Of those who had neck trouble in the last 12 months, (n = 18), 1 (6%) reported having to reduce work activity, 7 (39%) reported having to reduce leisure activity and 5 (28%) sought professional treatment. In addition, 15 (83%) said they did not miss any days of work in the last 12 months, 2 (11%) missed 1-7 days, and 1 (6%) missed 8-30 days of work. 10 (56%) of the 18 respondents with neck trouble in the last 12 months, experienced neck trouble in the last 7 days.

3.1.5 Shoulder symptoms

The results of the nordic questionnaire regarding shoulder symptoms are given in table 3-6. Of the 32 respondents, 17 (53%) reported having shoulder trouble some time in their life. Of this 17, 9 (53%) said they also had experienced a shoulder related accident in their life. No orthodontist reported changing jobs due to shoulder trouble. Out of the 17 respondents who experienced neck trouble in their life, 2 (12%) reported having no trouble in the last 12 months. However, 5 (29%) reported having had 1-7 days of shoulder trouble in the last 12 months, another 6 (35%) reported having 8-30 days with shoulder trouble, another 2 (12%) reported having more than 30 days with shoulder trouble and another 2 (12%) reported having shoulder trouble everyday. Of those who had shoulder trouble in the last 12 months, (n = 15), 1 (7%) reported having to reduce

work activity, 10 (67%) reported having to reduce leisure activity and 4 (27%) sought professional treatment. In addition, 1 (73%) said they did not miss any days of work in the last 12 months, and 4 (27%) missed 1-7 days of work. 5 (33%) of the 15 respondents with shoulder trouble in the last 12 months experienced shoulder trouble in the last 7 days.

Table 3-4. Reported low back trouble in nordic questionnaire respondents

Trouble in the Last 12 Months (n=19,16,3)										
Gender	Ever had Low Back Trouble	Neck Related Accident	Changed Jobs Due to Trouble	Total # of Days Having Low Back Trouble in the Last 12 Months	Trouble Reduced Work Activity	Trouble Reduced Leisure Activity	Total # of Days of Work Prevented	Sought Professional Treatment	Trouble in the Last 7 Days	
Total Respondents (n = 32)	22 (69)	5 (23)	0	3 (14) 6 (28) 6 (28) 6 (28) 1 (5)	2 (11)	9 (47)	16 (84) 3 (16) 0 0	8 (42)	11 (58)	
Males (n = 23)	18 (78)	4 (22)	0	0	2 (13)	8 (50)	0	7 (44)	10 (63)	
				1-7			1-7			
				8-30			8-30			
				30+			8-30			
				Everyday			30+			
Females (n = 9)	4 (44)	1 (25)	0	0	0	1 (33)	0	1 (33)	1 (33)	
				1-7			1-7			
				8-30			8-30			
				30+			8-30			
				Everyday			30+			

*Note: Percentages (in parentheses) do not total 100 as they are proportions of the total respondents.

Table 3-5. Reported neck trouble in nordic questionnaire respondents

Gender	Ever had Neck Trouble	Neck Related Accident	Changed Jobs Due to Trouble	Total # of Days Having Neck Trouble in the Last 12 Months	Trouble in the Last 12 Months (n=18,12,6)				
					Trouble Reduced Work Activity	Trouble Reduced Leisure Activity	Total # of Days of Work Prevented	Sought Professional Treatment	Trouble in the Last 7 Days
Total Respondents (n = 32)	22 (69)	8 (36)	0	4 (18) 10 (45) 2 (9) 5 (23) 1 (5)	1 (6)	7 (39)	15 (83) 2 (11) 1 (6) 0	5 (28)	10 (56)
Males (n = 23)	14 (61)	6 (43)	0	0	1 (8)	4 (33)	10 (83) 2 (17) 0 0	4 (33)	6 (50)
				1-7					
				8-30					
				30+					
				Everyday					
Females (n =9)	8 (89)	2 (25)	0	0	0	3 (50)	5 (83) 0 1 (17) 0	1 (17)	4 (67)
				1-7					
				8-30					
				30+					
				Everyday					

*Note: Percentages (in parentheses) do not total 100 as they are proportions of the total respondents.

Table 3-6. Reported shoulder trouble in nordic questionnaire respondents

Trouble in the Last 12 Months (n=15,11,4)									
Gender	Ever had Shoulder Trouble	Neck Related Accident	Changed Jobs Due to Trouble	Total # of Days Having Neck Trouble in the Last 12 Months	Trouble Reduced Work Activity	Trouble Reduced Leisure Activity	Total # Days of Work Prevented	Sought Professional Treatment	Trouble in the Last 7 Days
Total Respondents (n = 32)	17 (53)	9 (53)	1 (17)	2 (12) 0 5 (29) 1-7 6 (35) 8-30 2 (12) 30+ 2 (12) Everyday	1 (7)	10 (67)	11 (73) 0 4 (27) 1-7 0 8-30 0 30+	4 (27)	5 (33)
Males (n = 23)	13 (57)	8 (62)	1 (8)	2 (15) 0 3 (23) 1-7 5 (38) 8-30 1 (8) 30+ 2 (15) Everyday	1 (9)	8 (73)	7 (64) 0 4 (36) 1-7 0 8-30 0 30+	4 (36)	4 (36)
Females (n = 9)	4 (44)	1 (25)	0	0 0 2 (50) 1-7 1 (25) 8-30 1 (25) 30+ 0 Everyday	0	2 (50)	4 (100) 0 0 1-7 0 8-30 0 30+	0	1 (25)

*Note: Percentages (in parentheses) do not total 100 as they are proportions of the total respondent

3.2 Part II

3.2.1 Sample demography

The details of age, height and weight of the experimental sample are provided in table 3-7. The sample consisted of 9 graduate orthodontic students; 7 males and 2 females with an age range between 28 years and 36 years. The male sample ranged in height from 170 cm to 195.6 cm and ranged in weight from 63.6 kg to 102.3 kg. The female sample ranged in height from 163.8 cm to 183 cm and weighed from 53.6 kg to 61.4 kg. The study also contained a validation subject, a practicing orthodontist with 18.5 years of experience from a private clinic. The validation subject was aged 47 years and measured 182.9 cm in height and 84.1 kg in weight (table 3-8).

Table 3-7. Demographic details of the graduate orthodontic students who participated in videotaping and postural discomfort questionnaire

Gender	Parameter	Age (yr)	Height (cm)	Weight (kg)
Total Sample (n=9)	Mean	31	181.9	80.5
	SD	3	10.5	17.4
Males (n=7)	Mean	31	184.3	87.1
	SD	3.5	9.3	13.1
Females (n=2)	Mean	31	173.4	57.5
	SD	0	13.6	5.5

Table 3-8. Demographic details of the validation subject who participated in videotaping

Gender	Age (yr)	Height (cm)	Weight (kg)	Experience (yr)
Male (n=1)	47	182.9	84.1	18.5

3.2.2 Task observation

Private clinic reception records conveyed that orthodontists see on average 70 patients per day and observation confirmed the fast pace intensity. Typically one orthodontist will have up to 5 assistants, allowing for an average of 70 patients to be treated per day. The assistants will perform the majority of the routine clinical work and preparation on the patient, (some procedures take up to 2 hours), while the orthodontist will continuously move from patient to patient performing the more complicated procedures and checking the assistants work.

The observed orthodontic tasks were simplified into four categories: adjustments, banding, debanding, and exams/screening/consults. The first three consist of clinical practice in a seated posture working inside the patient's mouth, while the latter consists of other duties such as taking photographs of teeth, talking with the patient, and writing in records. The four tasks are described in detail in table 3-9 According to the private clinic reception records, it was determined that the majority of the day, 70%, was spent performing adjustment tasks, and only 10% were attributed to the other three tasks. The

tasks requiring the orthodontist to work in a seated posture inside the patient's mouth (tasks I, II, and II), were indicated by the orthodontist to be the most stressful of the tasks and took up about 90% of the day (task I = 70%, task II = 10%, task III = 10%, table 3-9). Regarding the actual time spent in the stressful postures, responses from the nordic questionnaire indicated in table 3-1, that approximately 70%, (68.9%, SD = 18.7), of the entire day was attributed to the actual performance of seated postures.

The characteristic posture for this type of work was observed to include: a seated posture with trunk angle between 0 and 25 degrees, elbows flexed at approximately 90 degrees, shoulders flexed and abducted between 0 and 90 degrees and neck flexed between 50 and 95 degrees. The nature of the work was observed to be primarily static interrupted with a brief dynamic reach movement at an approximate frequency of once per minute.

Task I, II, and II were targeted for videotaping for being the most stressful of the observed tasks. However, only tasks I and II, adjusting and banding respectively, were actually videotaped for reasons of availability. Task III could not be videotaped as it was not being performed on any patient during the period of data collection. Task II was only recorded for males as neither of the two females or the validation subject had patients requiring task II procedures during the period of data collection. Therefore loads for task II will only have data for males.

Table 3-9. Description, duration and frequency of orthodontic tasks

Task	Name	Procedure Description	Physical Description	Average Proportion of Day Task is Performed (%)	*Average Duration of Task (min)	Frequency of Task (per day)
Task I	Adjusting (Archwire/ Retainer/ Appliance)	Changing arch wires of the braces, adjusting retainers, checking appliances	<ul style="list-style-type: none"> Seated posture Trunk flexed (0-25°) Elbows flexed (90°) Shoulders flexed + abducted (0-90°) Neck flexed (50-95°) Primarily static and unvaried 	70	20-40	60
Task II	Banding	Putting braces on	<ul style="list-style-type: none"> Seated posture Trunk flexed (0-25°) Elbows flexed (90°) Shoulders flexed + abducted (0-90°) Neck flexed (50-95°) Primarily static 	10	90-120	2
Task III	Debanding	Taking braces off	<ul style="list-style-type: none"> Seated posture Trunk flexed (0-25°) Elbows flexed (90°) Shoulders flexed + abducted (0-90°) Neck flexed (50-95°) Primarily static 	10	30-40	2
Task IV	Exams/ Screening/ Consults	Assessing need for braces or progress of braces, taking photographs of teeth	<ul style="list-style-type: none"> Walking between patients/office Sitting in office, writing reports Standing, take photos Primarily dynamic and varied 	10	30-60	2

*The average duration of the task in minutes is based on the duration one patient undergoes and is not indicative of the duration the orthodontist spends on that task since the assistant's work is also included in that time. Instead the proportion percentages (%) are more indicative of the time spent by orthodontists performing each task.

3.2.3 Postures and timing

The selected tasks I and II were broken down into a series of postures. The postures attributing to each task are detailed in table 3-10 and 3-11 and depicted in figures 3-2 and 3-3. Task I was divided into four static postures and one dynamic posture, while task II was divided into three static postures and one dynamic posture of which all were the same postures observed in task I. Since the two tasks both consisted of seated postures working inside the patient's mouth, the posture description variation between the two was minimal. The average duration of time for the static postures ranged between 10.5 seconds and 15.1 seconds and the one dynamic posture had a mean duration of 3.5 seconds (SD = 0.5). Each posture was observed to occur once per minute.

Table 3-10. Description, duration and frequency of task I postures

Posture	Description	Nature	Average Time Duration (s)		Observed Frequency (f/60s)
1	Trunk flexion (0°-25°) Neck flexion (55°-90°) Elbow flexion (approx. 90°) Shoulder angle ($\pm 10^\circ$ from neutral)	Static	Mean SD	15.1 6.4	1
2	Trunk flexion (0°-25°) Neck flexion (55°-90°) Elbow flexion (approx. 90°) Shoulder angle (10°-35°)	Static	Mean SD	12.1 7.5	1
3	Trunk flexion (0°-25°) Neck flexion (55°-90°) Elbow flexion (approx. 90°) Shoulder angle (35°-55°)	Static	Mean SD	11.4 5.5	1
4	Trunk flexion (0°-25°) Neck flexion (55°-90°) Elbow flexion (approx. 90°) Shoulder flexion (65-90°)	Static	Mean SD	10.5 3.1	1
5	Reach forward and laterally to right side, elbow extends - begins and ends at above mentioned posture 1	Dynamic	Mean SD	3.5 0.5	1

Table 3-11. Description, duration and frequency of task II postures

Posture	Description	Nature	Average Time Duration (s)		Observed Frequency (f/60s)
1	Trunk flexion (0°-25°) Neck flexion (55°-90°) Elbow flexion (approx. 90°) Shoulder angle ($\pm 10^\circ$ from neutral)	Static	Mean SD	19.5 7.8	1
2	Trunk flexion (0°-25°) Neck flexion (55°-90°) Elbow flexion (approx. 90°) Shoulder angle (10°-35°)	Static	Mean SD	17.8 12.4	1
3	Trunk flexion (0°-25°) Neck flexion (55°-90°) Elbow flexion (approx. 90°) Shoulder angle (35°-55°)	Static	Mean SD	10.8 5.8	1
5	Reach forward and laterally to right side, elbow extends - begins and ends at above mentioned posture 1	Dyna mic	Mean SD	3.5 0.4	1

(a)

(b)

(c)

(d)

(e)

Figure 3-2. Task I postures: a) P1, shoulder angle static $\pm 10^\circ$, b) P2, shoulder angle static 10° - 35° , c) P3, shoulder angle static 35° - 55° , d) P4, shoulder angle static 65° - 90° , and
e) P5, dynamic reach

(a)

(b)

(c)

(d)

Figure 3-3. Task II postures: a) P1, shoulder angle static $\pm 10^\circ$, b) P2, shoulder angle static 10° - 35° , c) P3, shoulder angle static 35° - 55° , d) P5, dynamic reach

3.2.4 Generalisation from students to orthodontists

To ensure the results of the students could be transferred to practicing orthodontists a validation subject was also measured. The findings, shown in table 3-12 and figure 3-4, revealed that the postures adopted by the students were representative of the posture assumed by the validation subject ($p = 0.340$, no significant difference). With these findings it can be assured that the results presented in this study can be applied to the orthodontic population.

(a)

(b)

(c)

(d)

Figure 3-4. Comparison of postures between validation subject and student sample: a) P1, validation subject, b) P3, validation subject, c) P1, student, d) P3, student

Table 3-12. Paired t-test p-values for comparison of instantaneous mean values between validation subject and male student sample.

Load	Male Student Sample		Validation Sample		p-value
	<i>Mean (N)</i>	<i>SD</i>	<i>Mean (N)</i>	<i>SD</i>	
L5/S1 Compression	1,383.2	212.6	1,225.4	186.0	0.340
L5/S1 Shear	133.0	28.2	136.9	46.5	0.429
C7/T1Compression	140.2	5.4	124.2	10.9	0.302
C7/T1 Shear	64.4	6.9	60.3	6.2	0.085

3.2.5 Instantaneous load

3.2.5.1 Lumbosacral loads

The instantaneous load on L5/S1 for selected tasks I and II performed by the student sample are given in tables 3-13 and 3-14 and depicted in figures 3-5 and 3-6. The instantaneous compression loads for task I ranged from 1,149 N to 1,635 N for males and 792 N to 1,072 N for females. The instantaneous shear loads for task I ranged from 96 N to 171 N for males and 75 N to 136 N for females. Task II compression loads ranged from 1,036 N to 1,477 N, and shear loads ranged from 94 N to 200 N for the male sample. The instantaneous compression and shear loads for the validation subject ranged from 1102 N to 1320 N and 90 N to 146 N respectively. Males were shown to have significantly greater shear and compression loads, $p = 0.007$ and $p = 0.035$ respectively (see table 3-16). In contrast the validation subject and male sample means revealed no

significant differences (table 3-12 and figure 3-4). Tasks I and II, as well as postures 1-5 were also compared and showed no significant differences (refer to tables 3-15 and 3-17).

3.2.5.2 Cervicothoracic load

The instantaneous load on C7/T1 for selected tasks I and II performed by the student sample are given in tables 3-13 and 3-14 and are depicted in figures 3-7 and 3-8. The instantaneous compression loads for task I ranged from 137 N to 149 N for males and 69 N to 94 N for females. The instantaneous shear loads for task I ranged from 53 N to 70 N for males and 36 N to 49 N for females. Task II compression loads ranged from 115 N to 138 N, and shear loads ranged from 54 N to 69 N for the male sample. The instantaneous compression and shear loads for the validation subject ranged from 136 N to 138 N and 50 N to 66 N respectively. The male and female means were compared and shown to be significantly different, $p = 0.000$ for compression and $p = 0.002$ for shear. Table 3-16 shows the p-values for the compared pairs. In contrast the validation subject and the male resultant means were compared and were shown to have no significant differences (see table 3-12). Figure 3-4 depicts the likeness between the validation subject and student sample. The postures (1-5) were also compared with a paired t-test which revealed no significant differences (table 3-15 displays the p-values). Task I and task II were also compared and no significant differences for shear or compression were calculated (refer to table 3-17).

Table 3-13. Mean instantaneous compression and shear load values for task I

Gender	Posture	Parameter	Lumbosacral		Cervicothoracic	
			Compression (N)	Shear (N)	Compression (N)	Shear (N)
Male (n=7)	P1	Mean	1,302.4	140.2	149.4	66.8
		SD	308.3	67.3	25.3	10.3
	P2	Mean	1,250.0	117.2	137.5	62.4
		SD	418.3	91.7	24.0	12.2
	P3	Mean	1,635.2	171.1	136.8	69.7
		SD	364.5	87.4	22.0	5.7
	P4	Mean	1,579.1	140.3	136.7	70.0
		SD	256.5	50.5	22.1	7.8
	P5	Mean	1,149.4	96.0	140.2	53.2
		SD	292.1	66.6	27.0	14.8
Task Average		Mean	1,383.2	133.0	140.2	64.4
		SD	212.6	28.2	5.4	6.9
Female (n=2)	P1	Mean	1,016.0	131.7	93.5	48.9
		SD	54.7	6.6	5.7	0.7
	P2	Mean	865.8	100.8	80.0	36.6
		SD	27.6	5.8	2.4	5.2
	P3	Mean	1,071.6	136.4	68.5	46.7
		SD	-	-	-	-
	P4	Mean	--	--	--	--
		SD	--	--	--	--
	P5	Mean	792.0	74.8	82.1	35.7
		SD	-	-	-	-
Task Average		Mean	936.3	110.9	81.0	42.0
		SD	129.7	28.8	10.2	6.8
Validation Subject Male (n=1)	P1	Mean	1,300.8	146.3	136.4	65.8
		SD	42.9	19.4	5.3	2.3
	P2	Mean	--	--	--	--
		SD	--	--	--	--
	P3	Mean	1,320.3	105.6	137.5	66.4
		SD	-	-	-	-
	P4	Mean	--	--	--	--
		SD	--	--	--	--
	P5	Mean	1,102.2	90.1	136.2	49.9
		SD	-	-	-	-
Task Average		Mean	1,241.1	114.0	136.7	60.6
		SD	120.7	29.0	0.7	9.3

- denotes that only one subject was calculated for and thus no SD was given.

-- denotes that this posture data could not be obtained due to field study constraints.

Table 3-14. Mean instantaneous compression and shear load values for task II

Gender	Posture	Parameter	Lumbosacral		Cervicothoracic	
			<i>Compression (N)</i>	<i>Shear (N)</i>	<i>Compression (N)</i>	<i>Shear (N)</i>
Male (n=3)	P1	Mean	1,477.0	199.8	138.0	68.5
		SD	247.1	76.3	25.1	6.3
	P2	Mean	1,232.0	143.0	114.6	58.7
		SD	421.0	75.2	31.6	9.5
	P3	Mean	1,156.2	110.5	116.5	60.4
		SD	403.3	56.5	31.9	12.9
	P4	Mean	--	--	--	--
		SD	--	--	--	--
	P5	Mean	1,036.5	94.4	127.8	53.6
		SD	-	-	-	-
	Task average	Mean	1,225.4	136.9	124.2	60.3
		SD	186.0	46.5	10.9	6.2

* Male data is only shown in this table as no female data could be collected for task II.

- denotes that only one subject was calculated for and thus no SD was given.

-- denotes that this posture data could not be obtained due to field study constraints.

Figure 3-5. Instantaneous compression loads for each posture in task I on L5/S1

Figure 3-6. Instantaneous compression loads for each posture in task II on L5/S1

Figure 3-7. Instantaneous compression loads of each posture of task I on C7/T1

Figure 3-8. Instantaneous compression loads of each posture of task II on C7/T1

Table 3-15. Paired t-test p-values for comparison between postures

Pairs	Sig. (2-tailed)
P1 and P2	0.865
P1 and P3	0.163
P1 and P4	0.198
P1 and P5	0.106
P2 and P3	0.411
P2 and P4	0.380
P2 and P5	0.317
P3 and P4	0.978
P3 and P5	0.114
P4 and P5	0.181

Table 3-16. Paired t-test p-values for comparison of instantaneous mean values between female and male student sample.

Load	Male Student Sample		Female Student Sample		p-value
	<i>Mean (N)</i>	<i>SD</i>	<i>Mean (N)</i>	<i>SD</i>	
L5/S1 Compression	1,383.2	212.6	936.3	129.7	0.007**
L5/S1 Shear	133.0	28.2	110.9	28.8	0.035*
C7/T1 Compression	140.2	5.4	81.0	10.2	0.000***
C7/T1 Shear	64.4	6.9	42.0	6.8	0.002**

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3-17. Paired t-test p-values for comparison of instantaneous mean values between task I and task II

Load	Task I		Task II		p-value
	<i>Mean (N)</i>	<i>SD</i>	<i>Mean (N)</i>	<i>SD</i>	
L5/S1 Compression	1,383.2	212.6	1,225.4	186.0	0.485
L5/S1 Shear	133.0	28.2	136.9	46.5	0.835
C7/T1 Comprression	140.2	5.4	124.2	10.9	0.051
C7/T1 Shear	64.4	6.9	60.3	6.2	0.350

3.2.6 Cumulative load

3.2.6.1 Lumbosacral load

The overall load on L5/S1 for selected tasks I and II performed by the student sample are given in tables 3-18 and 3-19 and are depicted in figures 3-9 and 3-10. The overall compression load time product for the postures of task I ranged from 2,667 Ns to 18,944 Ns for males and 936 Ns to 15,574 Ns for females. The shear load time product ranged from 212 Ns to 2,063 Ns for males and 49 Ns to 2,021 Ns for females. For task II the load time product ranged from 2,488 Ns to 29,763 Ns for compression and 227 Ns to 4,192 Ns for shear. The cumulative load values for tasks I and II are given in tables 3-20 to 3-23. The combined task I and II cumulative load values are given in table 3-24 for males only as no female data could be collected for task II. The combined daily cumulative load of the two tasks results in 16.2 MNs of compression and 1.6 MNs of

shear. For one year the cumulative load for males was estimated to be 3,879 MNs of compression and 389 MNs of shear.

3.2.6.2 Cervicothoracic load

The overall load on C7/T1 for selected tasks I and II performed by the student sample are given in tables 3-18 and 3-19 and are depicted in figures 3-11 to 3-12. The compression load time product for the postures of task I ranged from 309 Ns to 2,207 Ns for males and 122 Ns to 1,436 Ns for females. The shear load time product ranged from 108 Ns to 978 Ns for males and 45 Ns to 760 Ns for females. For task II the load time product ranged from 307 Ns to 2,593 Ns. The cumulative load values for tasks I and II are given in table 3-20 to 3-23. The combined task I and II cumulative load values are given in table 3-24 for males only as no female data could be collected for task II. The combined daily cumulative load of the two tasks results in 0.81 MNs of compression and 0.45 MNs of shear. For one year the cumulative load for males was estimated to be 201 MNs of compression and 111 MNs of shear.

Table 3-18. Mean overall compression and shear load values for task I

Gender	Posture	Parameter	Lumbosacral		Cervicothoracic	
			Compression (Ns)	Shear (Ns)	Compression (Ns)	Shear (Ns)
Male (n=7)	P1	Mean	18,943.8	2,062.8	2,207.3	977.9
		SD	8,072.1	1,335.3	854.9	361.2
	P2	Mean	14,685.8	1,452.8	1,572.9	704.3
		SD	9,232.2	1,370.0	868.2	375.1
	P3	Mean	17,263.6	1,646.8	1,602.2	779.4
		SD	5,970.3	952.7	879.9	333.0
	P4	Mean	17,109.0	1,521.4	1,472.0	751.8
		SD	7,851.7	799.2	657.1	311.7
	P5	Mean	2,667.4	214.7	309.1	107.9
		SD	1,115.9	212.4	44.0	30.9
Overall Task Load			70,670.1	6,898.4	7,163.5	3,321
Female (n=2)	P1	Mean	15,574.2	2,021.0	1,431.3	760.1
		SD	5,617.8	736.0	506.8	322.0
	P2	Mean	15,354.0	1,782.8	1,406.4	659.7
		SD	4,505.5	501.8	330.6	268.8
	P3	Mean	15,354.0	1,782.8	1,406.4	659.7
		SD	-	-	-	-
	P4	Mean	--	--	--	--
		SD	--	--	--	--
	P5	Mean	936.3	49.0	122.2	44.7
		SD	-	-	-	-
Overall Task Load			47,218.5	47,840	4,366.2	2,124
Validation Subject Male (n=1)	P1	Mean	15,541.1	1,734.3	1,660.3	778.9
		SD	9,101.8	1,065.4	1,009.7	433.0
	P2	Mean	--	--	--	--
		SD	--	--	--	--
	P3	Mean	23,764.8	1,901.3	2,474.8	1,190.6
		SD	-	-	-	-
	P4	Mean	--	--	--	--
		SD	--	--	--	--
	P5	Mean	2,400.2	208.6	302.7	--
		SD	-	-	-	105.3
Overall Task Load			41,706.1	3,844.2	4,437.8	2,075

- denotes that only one subject was calculated for and thus no SD was given.

-- denotes that this posture data could not be obtained due to field study constraints.

Table 3-19. Mean overall compression and shear load values for task II

Gender	Posture	Parameter	Lumbosacral		Cervicothoracic	
			<i>Compression (Ns)</i>	<i>Shear (Ns)</i>	<i>Compression (Ns)</i>	<i>Shear (Ns)</i>
Male (n=3)	P1	Mean	29,762.8	4,192.0	2,593.4	1,312
		SD	16,307.2	3,041.4	584.0	411.0
	P2	Mean	21,402.8	2,454.0	2,031.8	1,022
		SD	12,291.5	1,612.7	1,250.8	611.7
	P3	Mean	12,163.2	1,099.9	1,279.3	657.8
		SD	6,266.4	628.8	742.3	353.8
	P4	Mean	--	--	--	--
		SD	--	--	--	--
	P5	Mean	2,487.7	226.5	306.8	128.6
		SD	-	-	-	-
Overall Task Load			69,945.9	8,606.7	6,511.9	3,280

* Male data is only shown in this table as no female data could be collected for task II.

- denotes that only one subject was calculated for and thus no SD was given.

-- denotes that this posture data could not be obtained due to field study constraints.

Figure 3-9. Overall compression load of each posture in task I on L5/S1

Figure 3-10. Overall compression load of each posture in task II on L5/S1

Figure 3-11. Overall compression loads on each posture of task I on C7/T1

Figure 3-12. Overall compression loads on each posture of task II on C7/T1

Table 3-20. Mean daily cumulative compression and shear load values for task I

Gender	Posture	Parameter	Lumbosacral		Cervicothoracic	
			Compression (kN·s)	Shear (kN·s)	Compression (kN·s)	Shear (kN·s)
Male (n=7)	P1	Mean	3,886.9	423.3	452.9	200.6
		SD	1,656.2	274.0	175.4	74.1
	P2	Mean	3,013.2	298.1	322.7	144.5
		SD	1,894.2	281.1	178.1	77.0
	P3	Mean	3,542.1	337.9	328.7	159.9
		SD	1,225.0	195.5	180.5	68.3
	P4	Mean	3,510.5	312.2	302.0	154.2
		SD	1,611.0	164.0	134.8	64.0
	P5	Mean	547.3	440.4	63.4	22.1
		SD	229.0	435.9	9.0	6.3
Total Daily Cumulative Load			14,500.0	1,415.4	1,469.8	681.4
Female (n=2)	P1	Mean	3,195.5	414.7	293.7	156.0
		SD	1,152.6	151.0	104.0	66.1
	P2	Mean	3,150.3	365.8	288.6	135.4
		SD	924.4	103.0	67.8	55.1
	P3	Mean	3,517.8	447.9	225.0	153.3
		SD	-	-	-	-
	P4	Mean	--	--	--	--
		SD	--	--	--	--
	P5	Mean	27.4	1.4	3.6	1.3
		SD	-	-	-	-
Total Daily Cumulative Load			9,891.0	1,230.0	810.8	445.9
Validation Subject Male (n=1)	P1	Mean	3,188.7	355.8	340.7	159.8
		SD	1,867.5	218.6	207.2	88.8
	P2	Mean	--	--	--	--
		SD	--	--	--	--
	P3	Mean	4,876.0	390.1	507.8	244.3
		SD	-	-	-	-
	P4	Mean	--	--	--	--
		SD	--	--	--	--
	P5	Mean	537.6	430.2	60.9	20.1
		SD	-	-	-	-
Total Daily Cumulative Load			8,602.3	1,176.2	909.3	424.2

- denotes that only one subject was calculated for and thus no SD was given.

-- denotes that this posture data could not be obtained due to field study constraints.

Table 3-21. Mean daily cumulative compression and shear load values for task II

Gender	Posture	Parameter	Lumbosacral		Cervicothoracic	
			<i>Compression (kN·s)</i>	<i>Shear (kN·s)</i>	<i>Compression (kN·s)</i>	<i>Shear (kN·s)</i>
Male (n=3)	P1	Mean	605.1	93.0	44.1	23.5
		SD	293.6	53.9	22.4	10.8
	P2	Mean	627.3	71.9	59.6	30.0
		SD	360.3	47.3	36.7	17.9
	P3	Mean	356.2	32.2	37.5	19.3
		SD	183.7	18.4	21.8	10.4
	P4	Mean	--	--	--	--
		SD	--	--	--	--
	P5	Mean	72.9	6.6	9.0	3.8
		SD	-	-	-	-
Total Daily Cumulative Load			1,662.0	203.8	150.1	76.5

* Male data is only shown in this table as no female data could be collected for task II.

- denotes that only one subject was calculated for and thus no SD was given.

-- denotes that this posture data could not be obtained due to field study constraints.

Table 3-22. Mean daily, weekly, monthly, and yearly cumulative compression and shear load values for task I

Gender	*Cumulative Period	Lumbosacral		Cervicothoracic	
		<i>Compression (MN·s)</i>	<i>Shear (MN·s)</i>	<i>Compression (MN·s)</i>	<i>Shear (MN·s)</i>
Male (n=7)	CDL	14.5	1.4	1.5	0.7
	CWL	72.5	7.1	7.3	3.4
	CML	290.0	28.3	29.4	13.6
	CYL	3,480.0	339.7	352.8	163.5
Female (n=2)	CDL	9.9	1.2	0.81	0.45
	CWL	51.1	6.3	4.2	2.3
	CML	204.4	25.2	16.7	9.2
	CYL	2,452.3	302.7	200.9	110.9
Validation Subject Male (n=1)	CDL	8.6	1.2	0.9	0.4
	CWL	43.1	6.2	4.5	2.2
	CML	172.3	24.4	18.3	8.3
	CYL	2,764.2	288.5	216.2	96.5

* CDL (cumulative daily load), CWL (cumulative weekly load), CML (cumulative monthly load), CYL (cumulative yearly load).

* Numbers are lower for validation subject because only 3 of the 5 postures could be recorded and thus calculated.

Table 3-23. Mean daily, weekly, monthly, and yearly cumulative compression and shear load values for task II

Gender	*Cumulative Period	Lumbosacral		Cervicothoracic	
		<i>Compression (MN·s)</i>	<i>Shear (MN·s)</i>	<i>Compression (MN·s)</i>	<i>Shear (MN·s)</i>
Male (n=3)	CDL	1.7	0.2	0.15	0.08
	CWL	8.3	1.0	0.75	0.38
	CML	33.2	4.1	3.0	1.5
	CYL	398.9	18.9	36.0	18.4

* CDL (cumulative daily load), CWL (cumulative weekly load), CML (cumulative monthly load), CYL (cumulative yearly load).

* Male data is only shown in this table as no female data could be collected for task II.

Table 3-24. Mean daily, weekly, monthly, and yearly cumulative compression and shear load values for combined tasks I and II.

Gender	*Cumulative Period	Lumbosacral		Cervicothoracic	
		<i>Compression (MN·s)</i>	<i>Shear (MN·s)</i>	<i>Compression (MN·s)</i>	<i>Shear (MN·s)</i>
Male (n=7)	CDL	16.2	1.6	1.6	0.76
	CWL	80.8	8.1	8.1	3.8
	CML	323.2	32.4	32.4	15.2
	CYL	3,878.9	388.6	388.8	181.9

* CDL (cumulative daily load), CWL (cumulative weekly load), CML (cumulative monthly load), CYL (cumulative yearly load).

* Male data is only shown in this table as no female data could be collected for task II.

3.2.7 Questionnaire

The mean and SD results of the postural discomfort questionnaire are shown in table 3-25 for all four conditions. The mean results are also plotted on charts shown in figures 3-13 to 3-16 for each condition, showing more clearly the outcome. From the figures no apparent differences between each condition could be seen and a further paired t-test, (results shown in table 3-26), confirms no significant change occurred over the duration of the day. On the scale ranging from 0-10, with 0 meaning 'no discomfort' and 10 meaning 'severe discomfort', no mean values accrued over 2.6 or under 0.9. However, individual values did range between 0.6 and 9. The neck had the highest mean value 2.6, with shoulder and low back closest behind at 2.3 and 1.6 respectively. A paired t-test was performed comparing each of the body parts to determine if any were significantly causing more discomfort. The results shown in table 3-27 reveal the neck to be more significant than all other body parts with the exception of the shoulder and the low back. Female and male responses were also compared with a paired t-test, (table 3-28), and were shown to be insignificant.

Table 3-25. Mean and SD postural discomfort questionnaire VAS scores for four time conditions

Gender	Condition	Parameter	Neck	Shoulders	Upper back	Upper arms	Mid Back	Lower Arms	Low back	Buttocks	Thighs	Legs
Total Sample (n=9)	8:30 am Before Work	Mean	2.2	1.4	0.9	1.1	1.0	0.9	1.3	0.9	0.9	0.9
		SD	2.9	1.4	0.1	0.7	0.4	0.1	0.7	0.1	0.1	0.1
	12:00pm Before Lunch	Mean	2.4	2.3	1.0	1.7	1.4	0.9	1.3	0.9	0.9	0.9
		SD	3.1	2.6	0.4	1.8	0.8	0.1	0.8	0.1	0.2	0.2
	2:00pm After Lunch	Mean	2.4	1.7	1.1	1.3	1.1	0.9	1.3	0.9	0.9	0.9
		SD	3.1	2.1	0.8	1.4	0.6	0.1	0.8	0.1	0.1	0.1
	4:30pm After Work	Mean	2.6	1.8	1.2	1.3	1.2	0.9	1.6	0.9	0.9	0.9
		SD	3.1	2.2	0.8	1.5	0.6	0.1	0.9	0.1	0.1	0.2

Figure 3-14. Mean postural discomfort questionnaire VAS scores of orthodontic graduate students during the ‘12pm before lunch’ condition

Figure 3-13. Mean postural discomfort questionnaire VAS scores of orthodontic graduate students during the ‘8:30am before work’ condition

Figure 3-15. Mean postural discomfort questionnaire VAS scores of orthodontic graduate students during the ‘2pm after lunch’ condition.

Figure 3-16. Mean postural discomfort questionnaire VAS scores of orthodontic graduate students during the ‘4:30pm after work’ condition.

Table 3-26. Paired t-test p-values for mean postural discomfort questionnaire VAS scores compared between four time conditions

Pairs	Parameter	Neck	Shoulders	Upper Back	Upper Arms	Mid Back	Lower Arms	Low Back	Buttocks	Thighs	Legs
8:30am and 12pm	p-value	.42	.19	.40	.25	.07	.35	1.0	.50	.15	0.6
8:30am and 2pm	p-value	.40	.19	.49	.50	.53	.80	.70	.27	.27	.05
8:30am and 4:30pm	p-value	.23	.20	.33	.44	.28	.89	.23	.52	.34	.20
12pm and 2pm	p-value	.86	.40	.57	.36	.16	.67	.71	.76	.30	.70
12pm and 4:30pm	p-value	.38	.50	.30	.43	.17	.73	.22	1.0	.07	.20
2pm and 4:30pm	p-value	0.4	.49	.17	.40	.58	1.0	.16	.81	.72	.82

Table 3-27. Paired t-test p- values for postural discomfort questionnaire VAS scores
compared between body parts

Pairs	Neck	Shoulders	Upper Back	Upper Arms	Mid Back	Lower Arms	Low Back	Buttocks	Thighs	Legs
Neck	-	.210	.011*	.025*	.020*	.003**	.060	.003**	.003**	.004**
Shoulder	-	-	.034*	.003**	.103	.010**	.269	.010**	.009**	.010**
Upper Back	-	-	-	.200	.141	.103	.070	.084	.110	.149
Upper Arm	-	-	-	-	.497	.035*	.961	.033*	.033*	.036*
Mid Back	-	-	-	-	-	.004**	.196	.003**	.005**	.007**
Lower Arms	-	-	-	-	-	-	.001***	.886	.804	.427
Low Back	-	-	-	-	-	-	-	.001***	.001***	.002**
Buttocks	-	-	-	-	-	-	-	-	.499	.160
Thighs	-	-	-	-	-	-	-	-	-	.257
Legs	-	-	-	-	-	-	-	-	-	-

* $p < 0.05$,

** $p < 0.01$,

*** $p < 0.001$

Table 3-28. Paired t-test p-values for postural discomfort questionnaire VAS scores
compared between male and female responses

Pairs	Parameter	Neck	Shoulders	Upper Back	Upper Arms	Mid Back	Lower Arms	Low Back	Buttocks	Thighs	Legs
Female and Male	p-value	.41	.72	.98	.63	.52	.09	.14	.40	.24	1.0

4.0 Discussion

4.1 Part I

4.1.1 Sample demography

There was a 56 percent response rate for the nordic questionnaire meaning more than half of the orthodontists in Alberta responded to the questionnaire. The demographic details of the nordic questionnaire respondents are given in table 3-1. With review of these results, it was determined that the mean sample age was high with a mean of 48 years (SD = 9.2) and job duration was correspondingly high with a mean of 18.7 years (SD = 10.8).

4.1.2 Reported symptoms

With review of the number of respondents reporting symptoms, given in table 3-2, it was determined that the responding orthodontists experienced a high prevalence of low back (59%), neck (56%) and shoulder trouble (47%). These findings support the high loads measured and confirm their high risk as discussed in the part II. The next highest reported symptom was upper back with a response of 28 percent.

The load on the shoulder was not measured on the orthodontists in this study; however the results here show the shoulder to be of great trouble (47%), along with low back and

neck. There is evidence and support relating the postures of orthodontic practice to shoulder trouble. For instance, it has been shown that at 30 degrees of shoulder abduction, blood flow is reduced to the supraspinatus tendon of the shoulder (Lake 1995), causing possible disorders to arise. The results of this study showed that orthodontists were observed working with the shoulder flexed at greater than 30 degrees for more than 50 percent of the measured tasks, particularly postures 4 and 5 described in tables 3-10 and 3-11. In addition, Milerad and Ekenvall (1990) performed an electromyography (EMG) study of dental work to show that the trapezius muscle in the upper back region, which also aids in shoulder elevation, undergoes high loads during the practitioner's working day. Thus, shoulder and upper arm pain resulting from tendonitis and/or muscular strain are likely consequences of prolonged shoulder abduction. In coherence with the studies presented above, Milerad et al. (1991) found dental professionals to have a high prevalence of cervical spondylosis, neck symptoms and shoulder symptoms. The researchers in this study ascribe the symptoms to the high demands of precision dental work, which is often performed with the arms abducted and unsupported, and with the cervical spine flexed forward and rotated. Finally, Ohlsson et al. (1995) compared female industrial workers and found a significant association ($p < 0.05$) between shoulder diagnoses and time spent with upper arm abduction greater than 60 degrees. Orthodontists in this study were observed, in posture 4 to have upper arm abduction greater than 60 degrees, approximately 21 percent of the measured tasks (tables 3-10 and 3-11).

Lalumandier et al.'s (2001) survey on MSD prevalence among various dental professionals including GDs, dental hygienists, orthodontists and other dental specialists, showed lower results than the present study. Out of 59 orthodontists, 43 percent reported back pain compared to 59 percent in the present study, 19 percent reported neck pain compared to 56 percent, and 15 percent reported shoulder pain compared to 47 percent. Basset (1983) in contrast reported 62 percent of GDs reported low back pain. All studies, as well as the present one, suggest there is a high prevalence of low back trouble among orthodontists, however the present study reported higher results. Possible explanation for the greater prevalence in this study is suggested in section 4.1.3.

No differences in reported symptoms were found between males and females. This result confirms the findings of Basset (1983), but goes against the findings of Kuorinka et al. (1987) and Kerosuo et al. (2000), in which females reported symptoms more often than males.

No associations were found between reported symptoms and age or number of years worked. These results were also in agreement with Shugars et al. (1984), Basset (1983), and Kerosuo et al. (2000).

4.1.3 Low back, neck and shoulder symptoms

Reviewing the results shown in tables 3-4 to 3-6, out of the 59 percent who reported low back symptoms, 23 percent said they had low back related accidents. Likewise, out of the

56 percent with reported neck trouble, 36 percent said they had neck related accidents, and out of 47 percent reporting shoulder trouble, 53 percent said they had shoulder related accidents. This could possibly explain the higher percentages in this study from the previous studies of Shugars et al. (1984) and Lalumandier et al. (2001). That is, if the previous studies were able to rule out any low back, neck or shoulder trouble due to non work-related accidents. It is unclear in this study whether or not the accidents reported were work-related or not. Furthermore, 47, 39 and 67 percent reported having to reduce leisure activity due to low back, neck and shoulder trouble respectively, however only 11, 6, and 7 percent respectively reduced their work activity. This was also confirmed by Rundcrantz et al. (1991) who reported symptoms in the low back, neck and shoulder had only a moderate impact on working ability. However, of paramount importance, the majority of orthodontists with low back, neck or shoulder symptoms (84%, 83% and 73% respectively) did not miss any days of work. Basset's 1983 study also showed that 70 percent of the 62 percent reporting back pain never missed work because of back pain. Therefore, it can be concluded that although symptoms are high, the orthodontists are still managing to continue to perform their duties. However, it is of interest to note that from the responses given in tables 3-4 to 3-6 of the total number of missed days, the economical losses based on the average orthodontist salary obtained from Human Resources Development Canada (HRDC) (2002), equates to a net loss per year of approximately \$638 to \$4,457 for low back trouble, \$2,197 to \$9,359 for neck trouble, and \$851 to \$5,956 for shoulder trouble. The total net loss due to all MSDs equates to \$3,696 to \$19,771 annually, or \$319 per day per person.

4.2 Part II

4.2.1 Sample demography

The graduate orthodontic student sample demography displayed in table 3-7 revealed the sample to be younger than the average age of nordic questionnaire respondents ranging from 27 years to 36 years with a mean age of 31 years ($SD = 3$). This was to be expected as they are all orthodontic students and are naturally just beginning orthodontic practice. The responding nordic questionnaire sample demography, shown in table 3-1, yielded an age range between 33 years and 65 years with a mean age of 48 years ($SD = 9.2$). The validation subject was well representative in age (47 years) and years practicing (18.5 years) of the nordic questionnaire respondents, whose mean age and years of experience equal $48 \text{ years} \pm 9.2$ and $18.7 \text{ years} \pm 10.8$ respectively.

The student sample consisted of 9 subjects; 2 (22%) females and 7 (78%) males. This male to female ratio is well representative of Alberta's orthodontist population. Out of 61 registered orthodontists 13 (21%) are female and 48 (79%) are male (ADAC 2002). The nordic questionnaire respondents were also well representative of gender distribution. Out of 32 respondents 9 (28%) were female and 23 (72%) were male.

4.2.2 Task observation

With review of the task descriptions in table 3-9, it was evident that the majority of the orthodontist's day is spent primarily in static seated postures working inside a patient's mouth, with neck, shoulder, and elbow flexed. This observation is in line with what Graham (2002) described in his ergonomic evaluation of dental offices. Graham (2002) declared that the current workstation in most dental offices requires the practitioner to lean forward, flex the neck forward and laterally, hold the shoulders abducted with arms flexed, and hold this position statically for most of the workday. 'Most of the work day', as retrieved from observation and inquiry in this study, was revealed to be 90 percent as shown in table 3-9. The average day was reported by the nordic questionnaire respondents to be approximately 7.1 hours. However, this is not entirely truthful. For instance the 90 percent identifies how long the orthodontist spends doing those particular procedures (tasks I, II, and III), but it also includes the time it takes to stand up, walk in between patients, change gloves, consult records for the patients, etc. Thus, cross referencing this result with the nordic questionnaire results (table 3-1), the reported time spent actually sitting for the entire day (all tasks inclusive) was a mean of approximately 70 percent (68.9%, SD = 18.7). Based on this result, the conclusion for the actual time spent in the 'identified stressful postures' was deduced to be 68.9 percent of 90 percent, actually equating to 62 percent. However, in the case of the load results, only tasks I and II were measured as no data could be collected for task III, thus the results will be for 80 percent of the day instead of 90 percent and thus the load results will show to be conservative, as 68.9 percent of 80 percent equates to 55 percent. Likewise, Lake (1995)

observed dental professionals to spend approximately two-thirds of each treatment hour in 19-54 degrees of forward trunk flexion.

4.2.3 Posture and timing

From the results in tables 3-10 and 3-11 describing the postures and timing of each task, it can be seen that the postures have little variation between them and thus little variation between tasks as well. Confirming this appearance a paired t-test, (table 3-15 and 3-17) was performed on the measured loads between postures and between tasks revealing no significant difference. Since none of the postures were significantly different from one another it can be further concluded that for the 55 percent of the day, (which was decided upon in the previous section 4.2.2 as the amount of actual time spent in these postures), orthodontists do not have any variation in their practice. It is interesting to note that Grandjean (1980) deemed a static effort to be great if a high level of effort is maintained for 10 seconds or if moderate level is endured for 1-4 minutes. Grandjean (1980) also mentioned that even a slight effort, (one-third of maximal effort), is considered great if maintained for just 4 minutes or more. Compare this with the length of time the orthodontists undergo sustained postures; observed in this study to endure up to one hour.

4.2.4 Biomechanical stress in the occupation

4.2.4.1 Lumbosacral stress

4.2.4.1.1 Instantaneous compression loads

The instantaneous biomechanical loads on L5/S1 are presented in tables 3-13 and 3-14. Loads were generally higher for men than for females due to the difference in upper body weight, which is largely a determinant factor in how much load is on the lumbar spine (Hall 1995). With review of the instantaneous loads, it is not apparent that the postures performed by the orthodontists are physically demanding or biomechanically taxing. The lumbosacral compression loads do not approach the action limit, (3,400 N), set by NIOSH (1981) as the suggested maximum load that 75 percent of women and 99 percent of men can achieve without increased risk of injury. Anything beyond this should require specially trained individuals to endure such loads. The lumbosacral compression in this study of orthodontic practice reached a maximum of 1,635 N for men and 1,072 N for women. The average compression load experienced by the orthodontists was 1,313 N for men and 936 N for women. The magnitude of these loads measured on sitting postures of orthodontists were in agreement with the loads for different sitting postures in a study by Callaghan and McGill (2001), who measured loads on the low back during standing and unsupported sitting. The compressive loads on the low back while sitting in their study was found to be 1,698 N (SD = 467), slightly higher than orthodontists. This higher magnitude can be ascribed to greater trunk angles used in their study (45% -70% of full

trunk flexion) compared to trunk flexion angles of 0-25 degrees in orthodontists. Despite the fact that spinal loading during prolonged sitting is quite low, there is great concern as noted by Callaghan and McGill (2001), for fatigue mechanisms attributed to prolonged loading caused by exposure to sitting tasks. The human body requires movement both to nourish structures in the spine such as the nucleus pulposus and intervertebral disc (Holmes and Nachemson 1983), and provide periodic rest to muscles to prevent fatigue and occasional migration of loads between various passive tissues achieved from posture change (Jonsson 1978 and Veiersted et al. 1990).

Furthermore, Kelsey (1975) carried out a hospital population-based case-control study of herniated lumbar discs and their relationship to a number of workplace factors, including time spent sitting, chair type, lifting, pulling, pushing, and driving. Findings indicated that sedentary work (sitting more than half the time at work) was associated with disc herniation for the age group 35 years and older ($p = 0.02$).

It was discussed earlier in section 4.2.3 that the different postures performed by the orthodontists, were actually not significantly different, and it was therefore concluded that there is little or no variation in load on the lumbar spine during the clinical orthodontic practice. This insignificance is supported by Callaghan and McGill (2001), who found that individuals who adopted multiple sitting postures and cycled between them across a wider lumbar spinal motion created motion that appeared to prevent static load on the spine. However, although passive tissues might be relieved in these individuals, there was little difference in the magnitude of the joint compressive forces

present in the multiple positions adopted. The important finding here is that while sitting, whether completely static or not, there is always a constant compressive load on the lumbar spine, which can only be relieved while not sitting. Callaghan and McGill's (2001) study went on further to conclude that compressive loads during sitting, (1,698 N +/- 467) were significantly higher ($p < 0.001$) than standing, (1,076 N +/- 243) and that standing appears to be a good rest from sitting given the reduction in passive tissue forces. However, the constant loading with little dynamic movement characterized by both sitting and standing would provide little rest/change in muscle activation levels or lumbar spine loading (Callaghan and McGill 2001).

4.2.4.1.2 Cumulative compression loads

Although the tasks appear to be light and harmless, by virtue of the frequency of their performance they are rendered hazardous. For example, as discussed earlier in section 4.2.2, it was determined that on average orthodontists perform the same significantly unvaried static postures for approximately 70 percent of the day, which surmounts to approximately 5 hours per day. With the static postures being endured for this amount of time, (a more conservative number was actually applied), the amount of load accumulated over this period of time escalated rapidly as shown in tables 3-20 to 3-24. Even a single static posture of 3 seconds will accumulate to 547 kNs per day when performed once per minute for 70 percent (task I) of 70 percent of the day, which accounts for about 49 percent of one work day. Assuming the orthodontists do nothing but this posture, it will cause a cumulative lumbosacral compression of 131 MNs in just

one year. Postures held statically for 10 seconds will result in a cumulative load compression of 842 MNs. Postures held for 15 seconds will result in a cumulative load compression of an outstanding 932 MNs. Assuming that orthodontists performed all postures for 70 percent of the day, the yearly cumulative compression would be 3879 MNs. If the orthodontists only performed all the postures for only 20 percent of the day (the minimum amount chosen on the nordic questionnaire for percentage of day spent sitting), the yearly cumulative compression would still be 1,133 MNs.

To give perspective on these numbers, attention is brought to a study conducted by Kumar (1990) linking cumulative load as a risk factor for back pain. In the study it was concluded that institutional aides had suffered back symptoms by the time they had reached a cumulative lumbosacral compression ranging between 14.5 to 15.6 MNs. The numbers presented in this study most definitely exceeded the threshold range reported for institutional aides (Kumar 1990). Clearly the loading to which orthodontists are subjected is hazardous.

However, one may question the extreme values compared with the values given for the institutional aide reported by Kumar (1990). The values presented in this study appear to be of a completely different magnitude (3,879 MNs compared to 15.6 MNs). In addition, one may question how it can be possible that the orthodontists exceeded the threshold cumulative load reported by Kumar (1990) by such a phenomenal amount and yet some can remain uninjured and symptom free. Consequently, it must be pointed out that there are significant differences between the manners in which data was taken in the two

studies. Kumar's (1990) study included only specific tasks that were deemed most stressful, such as patient lifting, etc. which likely induced higher instantaneous loads than were seen for orthodontists, but held a lower duration and frequency. The high frequency and long duration of the static postures observed for the orthodontists is what greatly increases the cumulative load. The general prolonged 'low stress' activities were discounted in Kumar's (1990) study, and had they been included the results would have been respectively higher. The results in this study are supported by Kumar (1990) for the concept imparting that a greater total cumulative load results in greater risk for workers to develop symptoms. This clearly demonstrates that measurement of instantaneous loads on tasks in occupations is not indicative of the amount of cumulative stress and therefore risk for injury that is actually precipitating on the worker.

4.2.4.1.3 Shear loads

The instantaneous shear loads on L5/S1 that occurred while sitting were low, (see tables 3-13 and 3-14), or at least could not be calculated accurately due to limitations of the camera angle that was viewed. Only movements and angles in the sagittal plane were evaluated. If there were any movements in other planes it was not calculated here, but would definitely affect the shear load on the lumbosacral segment. However, McGill et al. (1998) suggested an action limit for shear load to be 500 N following the same principles as the NIOSH (1981) action limit. The shear loads resulting from the orthodontic postures showed lower loads ranging between 94 N to 200 N for men and 75 N to 132 N for women and therefore, appear not to be threatening. However, as was seen

for compressive loads previously discussed, this instantaneous load is likely not indicative of the possible cumulative loads experienced in the prolonged static postures of orthodontistry, which accrued to 1.6 MNs for cumulative daily loads for the combined tasks, and 389 MNs for a yearly total. Furthermore, the instantaneous loads do not appear to reach anywhere near to Cyron et al.'s (1976), shear force fractures of the pars interarticularis of cadavers occurring between 1,200 N and 2,800 N.

4.2.4.2 Cervicothoracic stress

4.2.4.2.1 Instantaneous compression loads

The instantaneous biomechanical loads on C7/T1 are presented in tables 3-13 and 3-14. Loads are generally higher for men than for women due to differences in head segment weight (Hall 1995). With review of the instantaneous loads on C7/T1, which range from 136 N to 146 N for men and 50 N to 70 N for women, it is not so apparent whether the postures performed by the orthodontists are physically demanding or biomechanically taxing because no previous load measurement was produced, (to the author's knowledge), for the cervicothoracic or cervical spine to compare with. However, given that the load measurements in this study were calculated with respect to the angle of neck flexion. The greater neck flexion experienced will considerably lengthen the lever arm on which the weight of the head acts. Thus, the moment which the muscles controlling the flexion of the cervicothoracic spine must develop, will be intensified significantly (Kumar and Scaife 1979). Based on this statement combined with the observed neck

flexion experienced in orthodontists, (55-90 degrees of flexion), it can be concluded that the load on the neck at C7/T1 is quite high and possibly dangerous if prolonged.

4.2.4.2.2 Cumulative loads

The cumulative loads for the cervicothoracic spinal segment are presented in tables 3-18 to 3-24. The combined cumulative daily load for males is 1.6 MNs and for one year is 389 MNs. In comparison to the instantaneous loads, the cumulative loads are considerably greater and thus are of great concern given that the angle of flexion of neck observed in orthodontists is great, ranging from 55-90 degrees. For instance, Ohlsson et al. (1995) compared female industrial workers performing repetitive tasks to referents without such exposure and found significant associations ($p < 0.05$) between neck diagnoses with time spent in neck flexion, of critical angles greater than 15 degrees. In addition, Kilbom et al. (1986) in a study concerning electronic workers, reported two findings: first, that the more dynamic the working technique, the fewer neck symptoms experienced, and second, that the greater the average time per work cycle spent in neck flexion, the greater the association with symptoms in the neck.. A statistically significant association ($p < 0.05$) was also obtained from the job analysis variables describing neck forward flexion and upper arm elevation and neck and neck/shoulder disorders. Further support from Bernard (1997) in a critical review of epidemiologic evidence for work-related MSDs of the neck, found some strong evidence for a positive relationship between the duration of (fixed) sedentary work postures and neck pain.

4.2.4.2.3 Shear loads

The instantaneous shear loads for orthodontists are given in tables 3-13 and 3-14. The range of cervicothoracic shear was 53 N to 70 N for men and 36 N to 49 N for women. According to McGill et al. (1998), excessive shear forces on the lumbar spine are a result of external load and reaction forces from a forward flexed upper body, which could be translated for cervical spine to result from a forward flexed head/neck. Given that the neck angle of orthodontic practice is great, 55-90 degrees (table 3-9), it would then be expected that the shear loads presented would also be great. Support for this assumption is found in Seigmund et al.'s (2001) study, which found catastrophic failure loads of isolated facet joints in cadavers ranged from 52 to 146 N with a mean of $94 \text{ N} \pm 31$. The shear loads experienced by orthodontists actually reach the lower end of this range of catastrophic failure in cadavers.

4.2.5 Questionnaire

The postural discomfort questionnaire results are show in table 3-25 and figures 3-13 to 3-16. In review of these results there were no significant differences in discomfort of any body part from the morning condition to the end of the day condition. The discomfort felt by individuals was expected to increase in discomfort for the low back and neck regions given the 'stressful' static postures that were discussed in earlier sections. Reasons for this discrepancy were thought to be related to the sample being students. Perhaps with a student sample just beginning this type of work, it is more likely to expect that they

would not experience any discomfort as of yet. Unfortunately in this case, if the situation does not change, this sample will likely feel the effects of the assumed orthodontic postures in years to come. It would be interesting to do a follow up study with the same sample in the future to confirm predictions. Likewise, if the questionnaire had been administered to the nordic questionnaire respondents, the expected results likely would be shown.

The low VAS scores, (under 2.6 out of a scale of maximum possible score being 10), were thought to be due to the recent introduction of the student sample to these postures. Although these scores were low, as expected, neck discomfort was significantly higher ($p < 0.05$), than all other body parts with the exception of low back and shoulder.

Furthermore, gender did not appear to influence results in any way. This result confirms the findings of Basset (1983), but goes against the findings of Kuorinka et al. (1987) and Kerosuo et al. (2000), in which females reported symptoms more often than males.

4.3 Limitations

This study had some limitations. Firstly, the measurement of angles in this field study was difficult at times because assessment of joint position relies on subjective judgments, which may be prone to error. Secondly, the use of questionnaires or self-evaluations depended on the respondents' subjectivity and varied from one individual to another. Thirdly, the biomechanical model used in this study did not account for stresses caused by dynamic movements. The dynamic movement was instead calculated as a series of static postures to compensate. However, the postures analysed in this study were primarily of static nature. Finally, being a field study many factors could not be controlled. For example, the position of the camera may not have been perfectly 90 degrees to the sagittal plane for every subject due to obstacles in the field environment which could not be manipulated. In the same respect, some subjects were videotaped on the left side and some on the right side, due to environmental restrictions on camera position. This was limiting for calculating loads for the dynamic reach posture, (posture 5), as the reach was performed always on the right side. Angles were extrapolated from the left sided frames as close estimates. Also, since only one camera angle was used, (profile view of the subject), only angles viewed in the coronal plane could be calculated. For example, any lateral deviation of the arm or lateral leaning or rotation of the trunk or neck could not be calculated for. Therefore, the numbers calculated for this study were estimates. In addition, not all subjects had patients requiring the targeted tasks during the period of data collection, thus some tasks had lower subject numbers, and task II in particular was only performed by the male subjects at that time.

5.0 Conclusions

From the preceding discussion, the most valuable conclusion, in favour of the hypothesis, arises that instantaneous loads are not indicative of cumulative loads, particularly in the occupation of orthodontistry. Furthermore, prolonged static sitting for extended periods of the day exerts large cumulative loads on the spine. Likewise, there is compelling evidence to show and confirm that orthodontic practice is of high risk for MSDs. It has been convincingly demonstrated that the joints most loaded are also the most affected. Research in the area of cumulative load effects should be further investigated. Specifically to the orthodontic profession, further studies would be beneficial for the shoulder, which proved to be of high MSD prevalence. Of crucial action however, it is recommended that further investigation be carried out to improve work/equipment layout for orthodontic workers and dental professionals.

References

- Alberta Dental Association and College. 2002, <http://www.abda.ab.ca>.
- Andersson, G.B.J. and Schultz, A.B. 1979, Transmission of moments across the elbow joint and the lumbar spine, *Journal of Biomechanics*, 12, 747-755.
- Basset, S. 1983, Back problems among dentists, *Journal of the Canadian Dental Association*, 49, 251-256.
- Bernard, B.P. 1997, *Musculoskeletal Disorders and Workplace Factors: A Critical Review of Epidemiologic Evidence for Work-related Musculoskeletal Disorders of the Neck, Upper Extremity, and Low Back*, 2nd ed. (Cincinnati: US Department of Health and Human Services).
- Callaghan, J.P. and McGill, S.M. 2001, Low back joint loading and kinematics during standing and unsupported sitting, *Ergonomics*, 44, 280-294.
- Corlett, E.N. and Bishop, R.P. 1976, A technique for assessing postural discomfort, *Ergonomics*, 19, 175-182.
- Cyron, B.M., Hutton, W.C. and Troupe, J.D. 1976, Spondylolytic fractures, *British Journal of Bone and Joint Surgery*, 58, 462-466.
- Diakow, P. and Cassidy, D. 1984, Back pain in dentists, *Journal of Manipulative and Physiological Therapeutics*, 7, 85-88.
- Evans, F.G. and Lissner, H.R. 1959, Biomechanical studies on the lumbar spine and pelvis, *Journal of Bone and Joint Surgery*, 41, 278-290.
- Fauchard Academy. 1968, Fauchard academy poll dental survey, *Journal of Dental Practice*, 44, 21-2.

- Fox, J.G. and Jones, J.M. 1967, Occupational stress in dental practice, *British Dental Journal*, 123, 465-470.
- Gatt, C.J., Hosea, T.M., Palumbo, R. and Zawadsky, J.P. 1997, Impact loading of the lumbar spine during football blocking, *American Journal of Sports Medicine*, 25, 317-321.
- Graham, C. 2002, Ergonomics in dentistry, part 1, *Dentistry Today*, 98-103
- Grandjean, E. 1980, *Fitting the Task to the Man: An Ergonomic Approach*. (London: Taylor & Francis).
- Granhed, H., Jonson, R. and Hansson, T. 1987, The loads on the lumbar spine during extreme weight lifting, *Spine*, 12, 146-149.
- Guay, A. 1987, Commentary: ergonomically related disorders in dental practice, *Journal of American Medical Association*, 129, 184-6.
- Hall, S.J. 1995, *Basic Biomechanics*, 2nd ed. (St.Louis: Mosby).
- Hay, J.G. 1993, *The Biomechanics of Sports Techniques*, 4th ed. (Englewood Cliffs, NJ: Prentice Hall).
- Hilderbrandt, V.H. 1987, A review of epidemiological research on risk factors of low back pain, in P Buckle (ed.), *Musculoskeletal Disorders at Work*. (London: Taylor & Francis).
- Holmes, S. and Nachemson, A. 1983, Variations in the nutrition of the canine intervertebral disc induced by motion, *Spine*, 8, 866-874.
- Human Resources Development Canada. 2002, <http://www.jobfutures.ca/noc/3113.shtml>.
- Huskisson, E.C. 1983, Visual analogue scales, in R Melzack (ed.), *Pain Measurement and Assessment*. (New York: Raven), 33-37.

- International Ergonomics Association. 2000, <http://www.iea.cc/ergonomics/>.
- Jonsson, B. 1978, Kinesiology: with special reference to electromyographic kinesiology, in W A Cobb and H Duija (eds.), Contemporary Clinical Neurophysiology. (Amsterdam: Elsevier).
- Kelsey, J.L. 1975, An epidemiological study of the relationship between occupations and acute herniated lumbar intervertebral discs, International Journal of Epidemiology, 4,197–205.
- Kerosuo, E., Kerosuo, H. and Kanerva, L. 2000, Self-reported health complaints among general dental practitioners, orthodontists, and office employees, Acta Orthodontologica Scandinavica, 58, 207-212.
- Kilbom, Å., Horst, D., Kemfert, K., Richter, A. 1986, Observation methods for reduction of load and strain on the human body: a review, Arbetarskyddsstyrelsen Publikation Service, 171, 92.
- Kumar, S. 1999, Selected theories of musculoskeletal injury causation, in S Kumar (ed.), Biomechanics in Ergonomics. (London: Taylor & Francis).
- Kumar, S., Narayan, Y. and Bjornsdottir, S. 1999, Comparison of the sensitivity of three psychophysical techniques to three manual materials handling task variables, Ergonomics, 42, 61-73.
- Kumar, S., and Mital, A. 1992, Margin of safety for the human back: a probable consensus based on published studies, Ergonomics, 35, 769-781.
- Kumar, S. 1990, Cumulative load as a risk factor for back pain, Spine, 15, 1311-1317.
- Kumar, S., Chaffin, D.B. and Redfern, M. 1988, Isometric and isokinetic back and arm lifting strengths: device and measurement, Journal of Biomechanics, 21, 35-44.

- Kumar, S. and Scaife, W.G.S. 1979, A precision task, posture, and strain, *Journal of safety research*, 11, 28-36.
- Kuorinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sørensen, F. 1990, Work related musculoskeletal disorders, occurrence, reasons and prevention, *Nordic Institute for Advanced Training in Occupational Health*, 6.
- Kuorinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sorenen, F., Andersson, G., and Jorgenson, K. 1987, Standardised nordic questionnaires for the analysis of musculoskeletal symptoms, *Applied Ergonomics*, 18, 233-237.
- Lake, J. 1995, Musculoskeletal dysfunction associated with the practice of dentistry – proposed mechanisms and management: literature review, *University of Toronto Dental Journal*, 9, 7, 9-11.
- Lalumandier, J.A., McPhee, S.D., Parrott, C.B. and Vendemia, M. 2001, Musculoskeletal pain: prevalence, prevention, and differences among dental office personnel, *General Dentistry*, 49, 160-6.
- Leigh, J., Macaskill, P., Kuosma, E. and Mandryk, J. 1999, Global burden of disease and injury due to occupational factors, *Epidemiology*, 10, 626-631.
- Marshall, E.D., Duncombe, L.M., Robinson, R.Q. and Kilbreath, S.L. 1997, Musculoskeletal symptoms in new south wales dentists, *Australian Dental Journal*, 42, 240-6.
- McGill, S.M., Norman, R.W., Yingling, V.R., Wells, R.P. and Neumann, P. 1998, Shear happens! suggested guidelines for ergonomists to reduce the risk of low back injury from shear loading, *Proceedings of Thirtieth Annual Conference of the Human Factors Association of Canada*, (Mississauga, ON:HFAC), 157-161.

- Mendenhall, W. and Ott, L. 1976, Understanding Statistics, 2nd ed. (Massachusetts: Duxbury).
- Mikheev, M. 1994, New epidemics: the challenge for international health work, in New Epidemics in Occupational Health, (Helsinki: Finnish Institute of Occupational Health), 27-33.
- Milerad, E., Ericson, M.O., Nisell, R. and Kilbom, A. 1991, An electromyographic study of dental work, *Ergonomics*, 34, 953-962.
- Milerad, E. and Ekenvall, L. 1990, Symptoms of neck and upper extremities in dentists, *Scandinavian Journal of Work Environment and Health*, 16, 129-34.
- Murray, Q.L. and Lopez, A.D. 1997, The Global Burden of Disease, Vol. 1. (Cambridge, MA: Harvard School of Public Health).
- National Institute for Occupational Safety and Health. 1981, Work practices guide for manual lifting, Technical Report 81-122, US Department of Health and Human Services, Cincinnati, OH.
- Norman, R., Wells, R., Neumann, P., Frank, J., Shannon, H., Kerr, M. and Ontario Universities Back Pain Study Group. 1998, A comparison of peak vs. cumulative physical work exposure risk factors for the reporting of low back pain in the automotive industry, *Clinical Biomechanics*, 13, 561-573.
- Norris, C. 1977, Is your back biting back? *Dental Management*, 17, 57-60.
- Occupational Safety and Health Administration. 1999, Preventing work-related musculoskeletal disorders, Ergonomic Fact Sheet, OSHA.

- Ohlsson, K., Attewell, R., Pajsson, B., Karlsson, B., Balogh, I., Johnsson, B. 1995, Repetitive industrial work and neck and upper limb disorders in females, *American Journal of Industrial Medicine*, 27, 731–747.
- Porter, R.W. 1987, Risk factors and back pain, in P Buckle (ed.), *Musculoskeletal Disorders at Work*. (London: Taylor & Francis).
- Runderantz, B., Johnsson, B. and Moritz, U. 1991, Pain and discomfort in the musculoskeletal system among dentists: a prospective study, *Swedish Dental Journal*, 15, 219-228.
- Siegmund, G.P., Myers, B.S., Davis, M.B., Bohnet, H.F., Winkelstein, B.A. 2001, Mechanical evidence of cervical facet capsule injury during whiplash: a cadaveric study using combined shear, compression, and extension loading, *Spine*, 26, 2095-2101.
- Scoliosis Research Society. 2002, http://www.srs.org/htm/glossary/spinal_deformity.htm.
- Shugars, D.A., Williams, D., Cline, S.J. and Fishburne, C. 1984, Musculoskeletal back pain among dentists, *General Dentistry*, 32, 481-5.
- Sonoda, T. 1962, Studies on the compression, tension and torsion strength of the human vertebral column, *Journal of Kyoto Prefect Medical University*, 71, 659-702.
- The Ergonomics Society. 2002, <http://www.ergonomics.org.uk/membership.htm>.
- Thornwall, B. 1977, How are the work environments of dentists?, *Tandlakartidningen*, 8, 470-476.
- Veiersted, K. B. 1994, Sustained muscle tension as a risk factor for trapezius myalgia, *International Journal of Industrial Ergonomics*, 14, 333-339.

Willen, J., Lindahl, S., Irstam, L., Aldman, B. and Nordwall, A. 1984, The thoracolumbar crush fracture, an experimental study on instant axial dynamic loading: the resulting fracture type and its stability, *Spine*, 9, 624-631.

Appendix I

Information letter to subject

Title of the research project:

Comparison of instantaneous and cumulative loads on the low back and neck in orthodontists.

Researcher:

Theresa Newell, Master of Science student at Lulea University of Sweden under the supervision of Dr. S. Kumar, Professor in the Department of Physical Therapy Faculty of Rehabilitation at the University of Alberta.

Purpose/ Background:

The purpose of this research is to gain further insight into the nature and magnitude of loads on the low back and neck tissues in orthodontists.

Procedure:

You are being asked to participate in a research study. If you decide to participate, you will be required to state your age. Your height and weight will be measured. You will be asked to perform your usual work in front of a video camera. You will be asked to wear the typical mask covering mouth and nose used in common dentistry practice as this will ensure your identity is hidden from the video recording. You will be asked to fill out a questionnaire. The same short questionnaire will be given to you to fill out at 4 different times during one full working day. This participation will not compromise your regular work. The video recordings will be used to analyse posture loads.

Benefits/ Risks:

The results of this study will be used to suggest a need for change if needed, and for the improvement of work conditions and reduction of loads on posture structures.

Privacy/ Confidentiality:

All data will be held private, except when codes of ethics or the law requires. The data you give will be kept for at least five years after the study is done. The data will be kept in a safe area (i.e. locked filing cabinet). Your name or any other identifying data will not be attached to the data you gave. Your name will also never be used in any presentations or publications of the study results. The data gathered for this study may be looked at again in the future to help us answer other study questions. If so, the ethics board will first review the study to ensure the data is used ethically.

Freedom to Withdraw:

Involvement in this study is voluntary. All subjects are free not to take part, have the right to withdraw at any time without bias to pre-existing agreements, and shall be given further opportunities to decide whether or not to continue to take part. All subjects also have the right not to answer a question.

Contact Information:

If you have any questions regarding the research and procedures, please feel free to contact myself, Theresa Newell or my supervisor mentioned above, Dr. S. Kumar at the information listed below. If you have any concerns with the study please contact Dr. Sandra Curwin, Chair of the Department of Physical Therapy at 492-5984.

Please initial if you have read and understood the information stated above.

Initial of Participant: _____ Date: _____

Initial of Researcher: _____ Date: _____

Theresa Newell
MSc Student
Lulea University of Technology, Lulea, Sweden
c/o Dr. S. Kumar
Professor
Department of Physical Therapy
3-75 Corbett Hall
Edmonton, Alberta
T6G 2G4
Tel: 780-492-3848
Fax: 780-492-4429

Dr. S. Kumar
Professor
Department of Physical Therapy
3-75 Corbett Hall
Edmonton, Alberta
T6G 2G4
Tel: 780-492-5979
Fax: 780-492-4429

Appendix II

Subject consent form

Part 1: Researcher Information		
Name of Principal Investigator:		
Affiliation:		
Contact Information:		
Name of Co-Investigator/Supervisor:		
Affiliation:		
Contact Information:		
Part 2: Consent of Subject		
	Yes	No
Do you understand that you have been asked to be in a research study?		
Have you read and received a copy of the attached information sheet?		
Do you understand the benefits and risks involved in taking part in this research study?		
Have you had an opportunity to ask questions and discuss the study?		
Do you understand that you are free to refuse to participate or withdraw from the study at any time? You do not have to give a reason and it will not affect your care.		
Has the issue of confidentiality been explained to you? Do you understand who will have access to your records/information?		
Do you want the investigator(s) to inform your family doctor that you are participating in this research study? If so, please provide your doctor's name: _____		
(This question is optional).		
Part 3: Signatures		
This study was explained to me by: _____		
Date: _____		
<i>I agree to take part in this study.</i>		
Signature of Research Participant: _____		
Printed Name: _____		
<i>Witness (if available):</i> _____		
<i>Printed Name:</i> _____		
<i>I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.</i>		
<i>Researcher:</i> _____		
<i>Printed Name:</i> _____		
* A copy of this consent form must be given to the subject.		

Appendix III

Information letter to patient

Title of the research project:

Comparison of instantaneous and cumulative loads on the low back and neck in orthodontists.

Researcher:

Theresa Newell, Master of Science student at Lulea University of Sweden under the supervision of Dr. S. Kumar, Professor in the Department of Physical Therapy Faculty of Rehabilitation at the University of Alberta.

Purpose:

A study is being done on orthodontists. The purpose of this research is to further understand the effects of work postures in orthodontists.

Procedure:

You are being asked to take part in this study. As a patient to the orthodontist you will be recorded on video. Your face will be blocked in camera view by an obstruction and so will not be visible on the video. The video will be used to analyse the posture of the orthodontist.

Benefits/ Risks:

The results of this study will be used to suggest a need for change if needed, and to improve the work conditions of orthodontists. You will derive no direct benefit from this research.

Privacy/ Confidentiality:

All data will be held confidential, except when codes of ethics or the law requires releasing them. The data you give will be kept for at least five years after the study is done. The data will be kept in a safe area (i.e. locked filing cabinet). Your name or any other identifying data will not be attached to the data you gave. Your name will also never be used in any presentations or publications of the study results. The data gathered for this study may be looked at again in the future to help us answer other study questions. If so, the ethics board will first review the study to ensure the data is used ethically.

Freedom to Withdraw:

Involvement in this study is voluntary. All subjects are free not to take part, have the right to withdraw at any time without bias to pre-existing agreements, and shall be given further opportunities to decide whether or not to continue to take part. All subjects also have the right not to answer a question.

Contact Information:

If you have any questions or concerns regarding the research and procedures, please feel free to contact myself, Theresa Newell or my supervisor mentioned above, Dr. S. Kumar at the information listed below. If you have any concerns regarding the study, please contact Dr. Sandra Curwin the Chair of the Department of Physical Therapy at the University of Alberta at 492-5984.

Please initial if you have read and understood the information stated above.

Initial of Participant: _____ Date: _____

Initial of Researcher: _____ Date: _____

Theresa Newell
MSc Student
Lulea University of Technology, Lulea, Sweden
c/o Dr. S. Kumar
Professor
Department of Physical Therapy
3-75 Corbett Hall
Edmonton, Alberta
T6G 2G4
Tel: 780-492-3848
Fax: 780-492-4429

Dr. S. Kumar
Professor
Department of Physical Therapy
3-75 Corbett Hall
Edmonton, Alberta
T6G 2G4
Tel: 780-492-5979
Fax: 780-492-4429

Appendix IV

Patient consent form

Part 1: Researcher Information		
Name of Principal Investigator:		
Affiliation:		
Contact Information:		
Name of Co-Investigator/Supervisor:		
Affiliation:		
Contact Information:		
Part 2: Consent of Subject		
	Yes	No
Do you understand that you have been asked to be in a research study?		
Have you read and received a copy of the attached information sheet?		
Do you understand the benefits and risks involved in taking part in this research study?		
Have you had an opportunity to ask questions and discuss the study?		
Do you understand that you are free to refuse to participate or withdraw from the study at any time? You do not have to give a reason and it will not affect your care.		
Has the issue of confidentiality been explained to you? Do you understand who will have access to your records/information?		
Do you want the investigator(s) to inform your family doctor that you are participating in this research study? If so, please provide your doctor's name: _____		
(This question is optional).		
Part 3: Signatures		
This study was explained to me by: _____		
Date: _____		
<i>I agree to take part in this study.</i>		
Signature of Research Participant: _____		
Printed Name: _____		
<i>Witness (if available):</i> _____		
<i>Printed Name:</i> _____		
<i>I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.</i>		
<i>Researcher:</i> _____		
<i>Printed Name:</i> _____		
* A copy of this consent form must be given to the subject.		

Appendix V

Postural discomfort questionnaire

Instructions:

Study the diagram below and indicate level of comfort for each body part on the visual analogue scales (VAS) given on the next page by marking them with a **vertical line**.

Instructions:

Indicate level of comfort for each body part (see body diagram – previous page) on the visual analogue scale (VAS) given below by marking them with a **vertical line**.

Neck	◆—————◆
	No discomfort Severe discomfort
Shoulder	◆—————◆
	No discomfort Severe discomfort
Upper Back	◆—————◆
	No discomfort Severe discomfort
Upper Arms	◆—————◆
	No discomfort Severe discomfort
Mid Back	◆—————◆
	No discomfort Severe discomfort
Lower Arms	◆—————◆
	No discomfort Severe discomfort
Low back	◆—————◆
	No discomfort Severe discomfort
Buttocks	◆—————◆
	No discomfort Severe discomfort
Thighs	◆—————◆
	No discomfort Severe discomfort
Legs	◆—————◆
	No discomfort Severe discomfort

Appendix VI

Letter to orthodontists

December 13th, 2002

Re: A study of musculoskeletal discomfort prevalence in Orthodontists

Dear Orthodontic Practitioner,

The attached questionnaire concerned with musculoskeletal discomfort prevalence among Orthodontists is part of a province wide study being carried on cooperatively by the department of Rehabilitation Ergonomics at the University of Alberta and the division of Human Work Sciences at the Lulea University of Technology in Sweden. The project is concerned specifically with determining the types and prevalence of musculoskeletal discomfort experienced by Orthodontists in our province. The results of this study will help to improve, if needed, the working conditions in your profession for the protection and prevention of musculoskeletal injuries and discomfort.

We are particularly desirous of obtaining your response because your experience in the orthodontic profession will contribute significantly toward solving some of the problems facing occupational health of Orthodontists countrywide. The enclosed questionnaire is a standardized validated questionnaire developed in the Nordic countries used to assess musculoskeletal symptoms. The average time required for individuals to fill out the questionnaire is 10 minutes.

It will be appreciated if you will return the questionnaire prior to **January 15th, 2003**; a stamped return envelope is provided for your convenience. Other phases of this research cannot be carried out until we complete analysis of this questionnaire data. We would welcome any comments that you may have concerning any aspect of musculoskeletal discomfort not covered in the questionnaire. We will be pleased to send you a summary of the results if you desire. Thank you for your cooperation.

Sincerely,

Theresa Newell (MSc Student)
Lulea University of Technology, Sweden
Email: theresa_newell@yahoo.com
c/o Dr. S. Kumar
Department of Physical Therapy
3-75 Corbett Hall, University of Alberta
Edmonton, AB T6G 2G4
Tel: 780-492-3848

Appendix VII

Standardized nordic questionnaire

The date of inquiry ____/____/____
Year month day

Sex 1 Female 2 Male

What year were you born? _____

How many years and months have you been
Doing your present type of work? _____ years + _____ months

On average, how many hours
a week do you work? _____ hours a week

How much do you weigh? _____ kg

How tall are you? _____ cm

Are you right-handed or left-handed? 1 right-handed
2 left-handed

What percent of your working day do you
spend sitting? _____ %

How to answer the questionnaire:

Please answer by circling the number of the appropriate answer – one answer circled for each question. You may be in doubt as to how to answer, but please do your best anyway. Please answer every question, even if you have never had trouble in any part of your body.

In this picture you can see the approximate position of the parts of the body referred to in the questionnaire. Limits are not sharply defined, and certain parts overlap. You should decide for yourself in which part you have or have had your trouble (if any).

Trouble with the locomotive organs

		To be answered only by those who have had trouble			
Have you at any time during the last 12 months had trouble (ach, pain, discomfort) in:		Have you at any time during the last 12 months been prevented from doing your normal work (at home or away from home) because of the trouble?		Have you had trouble at any time during the last 7 days ?	
1	Neck No 2 Yes	1	No	2	Yes
1	Shoulders No 2 Yes, in the right shoulder 3 Yes, in the left shoulder 4 Yes, in both shoulders	1	No	2	Yes
1	Elbows No 2 Yes, in the right elbow 3 Yes, in the left elbow 4 Yes, in both elbows	1	No	2	Yes
1	Wrists/hands No 2 Yes, in the right wrist/hand 3 Yes, in the left wrist/hand 4 Yes, in both wrists/hands	1	No	2	Yes
1	Upper back No 2 Yes	1	No	2	Yes
1	Low back (small of the back) No 2 Yes	1	No	2	Yes
1	One or both hips/thighs No 2 Yes	1	No	2	Yes
1	One or both knees No 2 Yes	1	No	2	Yes
1	One or both ankles/feet No 2 Yes	1	No	2	Yes

NECK

How to answer the questionnaire: By neck trouble is meant ache, pain or discomfort in the shaded area. Please concentrate on this area ignoring any trouble you may have in adjacent parts of the body. There is a separate questionnaire for shoulder trouble.

Please answer by circling the appropriate number for the answer. One answer circled for each question. You may be in doubt as to how to answer, but please do your best anyway.

1. Have you **ever** had neck trouble (ache, pain or discomfort)?

1 No 2 Yes

If you answered **No** to Question 1, do not answer the questions 2-8.

2. Have you **ever** hurt your neck in an **accident**?

1 No 2 Yes

3. Have you **ever** had to change **jobs** or **duties** because of neck trouble?

1 No 2 Yes

4. What is the **total** length of time that you have had neck trouble during the **last 12 months**?

- 1 0 days
- 2 1-7 days
- 3 8-30 days
- 4 More than 30 days, but not every day
- 5 Every day

5. Has neck trouble caused you to **reduce** your activity during the **last 12 months**?

a. Work activity (at home or away from home)?

1 No 2 Yes

b. Leisure activity?

1 No 2 Yes

6. What is the **total** length of time that neck trouble has **prevented** you from doing your normal work (at home or away from home) during the **last 12 months**?

- 1 0 days
- 2 1-7 days
- 3 8-30 days
- 4 More than 30 days

7. Have you **been seen** by a doctor, physiotherapist, chiropractor or other such person because of neck trouble during the **last 12 months**?

1 No 2 Yes

8. Have you had neck trouble at any time during the **last 7 days**?

1 No 2 Yes

If you answered **0 days** to Question 4, do not answer the questions 5-8.

LOW BACK

How to answer the questionnaire: By low back trouble is meant ache, pain or discomfort in the shaded area whether or not it extends from there to one or both legs (sciatica).

Please answer by circling the appropriate number for the answer. One answer circled for each question. You may be in doubt as to how to answer, but please do your best anyway.

1. Have you **ever** had low back trouble (ache, pain or discomfort)?

1 No 2 Yes

If you answered **No** to Question 1, do not answer the questions 2-8.

2. Have you **ever** hurt your low back in an **accident**?

1 No 2 Yes

3. Have you **ever** had to change **jobs** or **duties** because of low back trouble?

1 No 2 Yes

4. What is the **total** length of time that you have had low back trouble during the **last 12 months**?

6 0 days
7 1-7 days
8 8-30 days
9 More than 30 days, but not every day
10 Every day

If you answered **0 days** to Question 4, do not answer the questions 5-8.

5. Has low back trouble caused you to **reduce** your activity during the **last 12 months**?

a. Work activity (at home or away from home)?

1 No 2 Yes

b. Leisure activity?

1 No 2 Yes

6. What is the **total** length of time that low back trouble has **prevented** you from doing your normal work (at home or away from home) during the **last 12 months**?

5 0 days
6 1-7 days
7 8-30 days
8 More than 30 days

7. Have you **been seen** by a doctor, physiotherapist, chiropractor or other such person because of low back trouble during the **last 12 months**?

1 No 2 Yes

8. Have you had low back trouble at any time during the **last 7 days**?

1 No 2 Yes

SHOULDER

How to answer the questionnaire: By shoulder trouble is meant ache, pain or discomfort in the shaded area. Please concentrate on this area ignoring any trouble you may have in adjacent parts of the body. There is a separate questionnaire for shoulder trouble.

Please answer by circling the appropriate number for the answer. One answer circled for each question. You may be in doubt as to how to answer, but please do your best anyway.

1. Have you **ever** had shoulder trouble (ache, pain or discomfort)?

1 No 2 Yes

If you answered **No** to Question 1, do not answer the questions 2-8.

2. Have you **ever** hurt your shoulder in an **accident**?

1 No 2 Yes

3. Have you **ever** had to change **jobs** or **duties** because of shoulder trouble?

1 No 2 Yes

4. What is the **total** length of time that you have had shoulder trouble during the **last 12 months**?

- 11 0 days
- 12 1-7 days
- 13 8-30 days
- 14 More than 30 days, but not every day
- 15 Every day

If you answered **0 days** to Question 4, do not answer the questions 5-8.

5. Has shoulder trouble caused you to **reduce** your activity during the **last 12 months**?

a. Work activity (at home or away from home)?

1 No 2 Yes

b. Leisure activity?

1 No 2 Yes

6. What is the **total** length of time that shoulders trouble has **prevented** you from doing your normal work (at home or away from home) during the **last 12 months**?

- 9 0 days
- 10 1-7 days
- 11 8-30 days
- 12 More than 30 days

7. Have you **been seen** by a doctor, physiotherapist, chiropractor or other such person because of shoulder trouble during the **last 12 months**?

1 No 2 Yes

8. Have you had shoulder trouble at any time during the **last 7 days**?

1 No 2 Yes

Appendix VIII

Body segment weights and lengths

Table VIII-1. Segment weights expressed in percentages of body weight (Hall 1995)

<i>Segment</i>	<i>Males</i>	<i>Female</i>
Head (HW%)	8.26	8.20
Trunk (TW%)	46.84	45.00
Arm (AW%)	5.77	4.97
Upper arm	3.25	2.90
Forearm	1.87	1.57
Hand	0.65	0.50

Table VIII-2. Segment lengths expressed in percentages of body height (Hall 1995)

<i>Segment</i>	<i>Males</i>	<i>Female</i>
Head and neck (HL%)	10.75	10.75
Trunk (TL%)	30.00	29.00
Arm (AL%)	38.65	39.05
Upper arm	17.20	17.30
Forearm	15.70	16.00
Hand	5.75	5.75

Table VIII-3. Segmental centre of gravity locations expressed in percentages of Segment lengths (Hall 1995)

<i>Segment</i>	<i>Males</i>	<i>Female</i>
Head and neck (HCL%)	45.0	45.0
Trunk (TCL%)	37.0	43.1
Arm (ACL%)	44.4	45.3
Upper arm	43.6	45.8
Forearm	43.0	43.4
Hand	46.8	46.8

*Measured from distal ends of segments

Acknowledgements

The author wishes to acknowledge the support of Dr. Shrawan Kumar, professor in the department of Physical Therapy at the University of Alberta, for his supervision and guidance throughout this project as well as his great contribution to my personal development. I would also like to acknowledge the support of the Graduate Orthodontic Department, Students, and Clinic at the University of Alberta for their participation and encouragement. The willingness of Dr. Major to volunteer his Orthodontic Clinic for this project. The valuable assistance of Duane Lawrence, in helping with the operation and set-up of video equipment, as well as for his personal encouragement and support. The technical support from Yogesh Narayan, Manager of the Ergonomics Research Laboratory, at the University of Alberta, for the success of this project. Finally, I wish to acknowledge my friends and family, as well as my colleagues and professors from Luleå University of Technology in Sweden, for the encouragement and support they have given me throughout this year.