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

Theresa M. Newell, Shrawan Kumar *

Department of Human Work Sciences, Division of Industrial Ergonomics, Luleå University of Technology, 971 87 Luleå, Sweden
Department of Physical Therapy, University of Alberta, 3-75 Corbett Hall, Edmonton, Alberta, Canada T6G 2G4

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Abstract

Background. Musculoskeletal disorders of back and neck among orthodontists are prevalent. Due to low instantaneous load they have not been investigated. The present study aimed to quantify and compare instantaneous and cumulative loads on low back and neck in orthodontists.

Methods. The sample included nine graduate orthodontic students from the University of Alberta and one practicing orthodontist to validate the generalization from student to professional group. The subjects were videotaped performing regular duties and the recorded postures were printed for biomechanical analysis of compression and shear loads and exposure time. Instantaneous loads were calculated using a biomechanical model developed specifically for this study and cumulative loads were calculated from the resultant loads.

Findings. The average instantaneous low back compression loads for men and women were found to be 1383N and 936N respectively. The average daily cumulative load on the other hand were found to be 16.2MN's and 9.9MN's for males and females respectively.

Interpretation. The study demonstrates that smaller loads cannot be ignored due to their magnitude if their duration is long because the time dependent properties of the tissues become modulating factor. Thus the measurement of instantaneous loads on tasks in orthodontists is not indicative of the amount of cumulative stress experienced by them.

Keywords: Cumulative load; Instantaneous load; Low back; Neck; Orthodontists

1. Introduction

Little research has been identified comparing the nature of instantaneous and cumulative loads on musculoskeletal structures. The assumption that cumulative loads have a greater influence than instantaneous loads on joints has not been sufficiently studied to understand its significance and the potential for future work-related musculoskeletal disorders (MSDs).

Previous studies have looked at peak instantaneous loads in cadavers, causing fractures under an average load of 8000N (range 6000–10,000N) (Willen et al., 1984). The ultimate compressive strength of the lumbar spinal unit was agreed to be 6700N for people under forty years and 3400N for people 60 years and over (Evans and Lissner, 1959; Sonoda, 1962). NIOSH (1981) and Waters et al. (1993) used these values in their ‘Work practices guide for manual lifting’ and the revised NIOSH equation respectively.

Cumulative loading has been studied considerably less. Kumar (1990) conducted the first study on cumulative loads as a risk factor for low back pain in institutional aides. The results showed that the pain group experienced significantly larger cumulative loads in their lifetimes than did the non-pain group. Kumar (1990)
suggested that more severe pathologies might be associated with higher cumulative loads; however this has not been investigated. Furthermore, Norman et al. (1998) performed a study comparing peak and cumulative physical work exposure risk factors for 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 the peak exposure variable multiplied linearly by time. These variables are apparently measuring different demands of the jobs as well as measuring different aspects of risk.

The relevance for the quantification of instantaneous and cumulative loads to occupational stress has not been studied nor has the magnitude of spinal loads in orthodontists been quantified. Therefore, the goal of this study was to gain further insight into the nature and magnitude of spinal loads in orthodontists. More specifically, the aim of this study was to determine and compare the cumulative and instantaneous loads on lumbosacral and cervicothoracic spinal segments in orthodontic practices and prove or disprove the hypothesis that instantaneous loads are not indicative of cumulative loads.

2. Methods

2.1. Subjects

All graduate orthodontic students enrolled in the University of Alberta, (n = 9), were subjects for the study. All student subjects had the same background education and training 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. This student sample was selected for convenience. To ensure transfer of data from students to practicing orthodontists a validation subject from a private clinic was selected for comparison purposes. The validation subject consisted of other duties such as taking photographs and exams/screening/consults. The first three consisted of the practitioner in a seated posture at the head of the patient, working inside the patient's mouth. The latter consisted of other duties such as taking photographs of teeth, talking with the patient, and writing in records. According to the private clinic reception records, it was determined that the most stressful tasks, the first three, took up about 90% of the day and thus were targeted for videotaping. Through questionnaire inquiry to practicing orthodontists, it was determined that approximately 70% of the entire day was attributed to the actual performance of seated postures. Therefore, 70% of 90%, yielding 63%, was the task duration used in the calculation of cumulative loads.

2.2. Measures and devices

Videotaping was used as a tool to indirectly calculate compression and shear loads on the lumbosacral and cervicothoracic spinal segments. A small 'micro-camera' with a wide-angle lens was used for videotaping. The 'micro-camera' was of convenient size so as to be unobtrusive to the subjects' work environment. A videotape player was used to view the recorded postures and measure time. A videotape printer printed the frames to be measured. A protractor was used to measure joint angles to the nearest 0.5° on the frames, and a grid transparency was used to aid in the measure of joint angles. Joint locations were marked using Hall (1995) as a reference.

2.3. Procedure

2.3.1. Task observation

The tasks were observed in both the graduate clinic and a private clinic to determine the tasks involved in orthodontic practice and to ensure consistency between the student and the validation subject. Private clinic reception records conveyed that orthodontists treat an average of 70 patients per day with the help of up to 5 assistants. The observed orthodontic practice was simplified into four tasks: adjustments, banding, debanding, and exams/screening/consults. The first three consisted of the practitioner in a seated posture at the head of the patient, working inside the patient's mouth. The latter consisted of other duties such as taking photographs of teeth, talking with the patient, and writing in records. According to the private clinic reception records, it was determined that the most stressful tasks, the first three, took up about 90% of the day and thus were targeted for videotaping. Through questionnaire inquiry to practicing orthodontists, it was determined that approximately 70% of the entire day was attributed to the actual performance of seated postures. Therefore, 70% of 90%, yielding 63%, was the task duration used in the calculation of cumulative loads.

2.3.2. Videotaping and biomechanical model

The postures used by the orthodontists were observed to be largely static and largely symmetrical particularly for the first three tasks. While we have considered that a deviation of one arm over the other does introduce some asymmetry, we note that the static and largely bal-

<table>
<thead>
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<th>Gender</th>
<th>Parameter</th>
<th>Age (year)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
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</thead>
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<td>Total sample (n = 9)</td>
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<td></td>
<td>SD 3</td>
<td>10.5</td>
<td>17.4</td>
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<td>Males (n = 7)</td>
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<td>87.1</td>
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<tr>
<td></td>
<td>SD 3.5</td>
<td>9.3</td>
<td>13.1</td>
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<td>57.5</td>
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<td>13.6</td>
<td>5.5</td>
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<td>Validation subject (n = 1)</td>
<td>Mean 47</td>
<td>182.9</td>
<td>84.1</td>
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</table>
anced posture on the seat pan will simply add to the spinal compression. Thus it was determined that a two-dimensional model would be sufficient to estimate the loads experienced by the orthodontists. Subjects were videotaped in a profile view 90° to the sagittal plane to allow for biomechanical analysis. To conceal their identities, the subjects wore facemasks of typical wear in dental practice.

2.4. Data analysis

2.4.1. Frame measurement

The videotaped material was viewed frame by frame for specific postures and the duration and frequency for each posture was measured. Each frame was carefully examined for anatomical landmarks (i.e. centre of gravity of the head) L5/S1 was approximated by the hip (joint and) and shoulder approximated by C7/T1). In addition, the following variables were measured for input into a biomechanical formula: trunk angle (θ1), neck angle (θ2), and shoulder angle (θ3) with respect to the vertical.

2.4.2. Validation study

Since it was not possible to place joint markers on the subjects in their practicing environments, a consistent method of ensuring accuracy of joint angles was developed. The recorded angles were then validated against direct measurements. The validation study consisted of videotaping two male volunteer subjects in two conditions. The first condition consisted of subjects wearing only a brief and markers placed on the skin at palpable joint positions, while the second condition consisted of subjects dressed in ‘casual work’ clothes, as typically seen in the practice of orthodontics. The resultant angles generated by the two conditions did not show any statistical significant difference. Therefore it was concluded that the two conditions generate the same results and the technique was validated.

2.4.3. 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 acromion taken to represent 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.

2.4.3.1. Lumbosacral load. Three external forces are acting on the L5/S1 segment of the spine while sitting: FT, FA, and FH (trunk force, arm force and head force due to gravity), shown in Fig. 1.

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

Given that Torque = Force × Distance (6 cm is the moment arm of the erector spine muscle (Kumar, 1988; Hall, 1995)), the following equation results:

\[
FE = [(FT \times t) + (FA \times a) + (FH \times h)]
\]

(1)

where (as shown in Fig. 1), t, a, and h are the moment arms of the trunk, arm, and head.

Expanding Eq. (1) adds to the following:

\[
\times (TCL\%)(sin \theta 1) + (AM\%)[(ACL\%)
\times (AL\%)(sin \theta 3 + (TL\%)(sin \theta 1)] + (HM\%)
\times [(HCL\%)(HL\%)](sin \theta 2)
\]

(2)

where, TBM and TBH = total body mass in kg and height in cm.
where, \(5\text{cm}\) is the moment arm of the cervical region as percentages of TBH (Hall, 1995).

\[ \text{TL\%}, \text{AL\%}, \text{and HL\%} = \text{trunk, arm and head length as percentages of TBH (Hall, 1995).} \]

\[ \text{TM\%}, \text{AW\%}, \text{and HM\%} = \text{trunk, arm, and head mass as percentages of TBM (Hall, 1995).} \]

\[ \text{TCL\%}, \text{ACL\%}, \text{and HCL\%} = \text{trunk, arm, and head centre of gravity location relative to segment length (Hall, 1995).} \]

Lumbosacral compression and shear can be calculated by substituting calculated elements into final FC compression and FS shear equations:

\[
\text{FC}_{\text{L5/S1}} = 9.81(\text{TBM})(\text{TM\%} + \text{AM\%} + \text{HM\%}) \times \cos \theta_1 + [9.81(\text{TBM})(\text{TBH})/6] \times \{(\text{TM\%})(\text{TL\%})(\text{TCL\%})(\sin \theta_1) + (\text{AM\%})(\text{ACL\%})(\text{AL\%})(\sin \theta_3) + (\text{TL\%})(\sin \theta_1) + (\text{HM\%})(\text{HCL\%}) \times (\text{HL\%})(\sin \theta_2 + (\text{TL\%})(\sin \theta_1)) \}
\]

\[
\text{FS}_{\text{L5/S1}} = 9.81(\text{TBM})(\text{TM\%} + \text{AM\%} + \text{HM\%}) \sin \theta_1
\]

2.4.3.2. Cervicothoracic load. Using the logic and notations described for lumbosacral disc the cervicothoracic compression and shear forces can be expressed by the following equations:

\[
\text{FC}_{\text{C7/T1}} = 9.81(\text{TBM})(\text{HM\%}) \cos \theta_2 + [9.81(\text{TBM})(\text{HM\%})(\text{HCL\%})(\text{HL\%}) \times (\text{TBH}) \sin \theta_2]/5
\]

where, \(5\text{cm}\) is the moment arm of the cervical musculature

\[
\text{FS}_{\text{C7/T1}} = 9.81(\text{TBM})(\text{HM\%}) \sin \theta_2
\]

2.4.4. Calculation of cumulative load

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

\[
\text{OL} = \sum 0.2\text{L1} + 0.2\text{L2} + 0.2\text{Ln}
\]

where, OL = overall load (compression or shear) of a single task.

\(\text{L1}\) = average compression or shear force of the first frame of the posture;

\(\text{L2}\) = average compression or shear force of the second frame of the posture;

\(\text{Ln}\) = average compression or shear force of the \(n\)th frame of the posture;

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

\(\text{Ns}\) = unit of overall and cumulative load ‘force time’ product (Newton-second).

The cumulative biomechanical loads (of all tasks) for each task and posture of each subject were determined by summing the overall loads of all tasks in following steps:

1. Identification of stressful tasks 1–\(n\).
2. Determination of compression and shear instantaneous loads (FC and FS) for tasks 1–\(n\).
3. Determination of the frequency (\(F\)) per day of tasks 1–\(n\).
4. Calculation of the cumulative compression and shear loads of all tasks combined per day (by adding) overall loads according to the following equations:

\[
\text{CDC} = \sum (\text{FC}_1 \times F_1) + (\text{FC}_2 \times F_2) + \cdots + (\text{FC}_n \times F_n)
\]

\[
\text{CDS} = \sum (\text{FS}_1 \times F_1) + (\text{FS}_2 \times F_2) + \cdots + (\text{FS}_n \times F_n)
\]

where, CDC and CDS refer to cumulative daily compression and shear loads.

5. Deduction of the cumulative loads for other time periods can be calculated by multiplying the daily cumulative load with the relevant exposure time of the period of interest.

2.5. Statistical analysis

Mean and standard deviation (SD) values were calculated for instantaneous, overall and cumulative loads. SPSS was used to perform all statistical tests. Unpaired \(t\)-tests determined any significant differences in loads between genders, validation subject and student sample, postures, and tasks.

3. Results

3.1. Tasks and postures

No statistically significant difference was shown between loads of the three targeted tasks. The characteristic posture for these tasks, depicted in Fig. 3, was observed to include: a seated posture with trunk angle between 0° and 25°, elbows flexed at approximately 90°, shoulders flexed and abducted between 0° and 90° and neck flexed between 50° and 95°. The nature of the tasks was observed to be primarily static interrupted with a brief dynamic reach movement. The average duration before small dynamic hand motions occurred while the trunk re-
mained static ranged between 10.5s and 15.1s and the dynamic hand postures had a mean duration of 3.5s (SD = 0.5). Each dynamic hand posture was observed to occur at least once per minute. Due to the static nature of the overall posture no significant differences in loads were found between any of these postures.

3.2. Instantaneous loads

The instantaneous loads for the low back and neck are given in Table 2. Males were shown to have significantly greater compression and shear loads than females, \( P < 0.007 \) and \( P = 0.035 \) respectively. In contrast the validation subject and male sample means revealed no significant differences. Compression loads on the low back ranged from 1149N to 1635N for males and 792N to 1072N for females, while shear loads ranged from 96N to 171N and 75N to 136N for males and females respectively. The compression and shear loads on the low back for the validation subject ranged from 1102N to 1320N and 90N to 146N respectively. Compression loads for the neck ranged from 137N to
149N for males and 69N to 94N for females, while shear loads ranged from 53N to 70N and 36N to 49N for males and females respectively. The compression and shear loads on the neck for the validation subject ranged from 136N to 138N and 50N to 66N respectively.

### 3.3. Cumulative loads

The cumulative load values for the low back and neck are given in Table 3. The cumulative daily compression and shear loads on the low back are 14.5MN\(\text{s}\) and 1.4MN\(\text{s}\) for males and 9.9MN\(\text{s}\) and 1.2MN\(\text{s}\) for females respectively. The cumulative yearly compression and shear loads on the low back are 353MN\(\text{s}\) and 164MN\(\text{s}\) for males and 201MN\(\text{s}\) and 111MN\(\text{s}\) for females respectively.

### 4. Discussion

#### 4.1. Postures and timing

It was determined that the majority of the orthodontist’s day is spent primarily in static, relatively symmetrical seated postures with the neck, shoulder, and elbow flexed. It was also seen that there was no variation in loads between the tasks or postures meaning their

work is significantly unvaried. It is interesting to note that Hagberg (1981) and Sjogaard (1986) have stated that even a low level contraction of 8% of maximal effort maintained for 60 minutes leads to fatigue. Whereas we have not measured the maximal effort of orthodontist to rate the magnitude of static effort, it is fair to say that largely static and deviated posture maintained for most of the working day is likely to cause physiological stress which may have detrimental effect as reported by Newell and Kumar (2004).

4.2. Compression loads

Loads were generally higher for men than for women due to the difference in proportion of the upper body weight, which is the major determinant in how much load is placed 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, (3400 N), set by NIOSH (1981). The lumbosacral compression in this study of orthodontic practice reached a maximum of 1635N for men and 1072N for women. Despite the fact that spinal loading during prolonged sitting is low, there is a concern as noted by Callaghan and McGill (2001), for fatigue mechanisms attributed to prolonged loading caused by exposure to sitting tasks.

Although the tasks appear to be light and harmless, but by virtue of the frequency and duration of their performance they are rendered hazardous. With a frequency reaching 200 times per day loads accumulated over this period of time escalated rapidly as shown in Table 3. Postures held statically for 10 and 15 s before hand motions as seen in orthodontists will result in a cumulative yearly load compression between 842 MNs and 932 MNs. Assuming that orthodontists performed all postures identified in the study for 63 percent of the day, the daily and yearly cumulative compression would be 14.5 MNs and 3480 MNs for males and 9.9 MNs and 2450 MNs for females respectively. 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 these occupations is not indicative of the amount of cumulative stress that the worker is actually receiving. Consideration of only instantaneous load has an implicit assumption that human body is a Hookean Body, an assumption that cannot be supported.

The moment that the muscles controlling the flexion of the neck must develop, will be intensified significantly with increasing flexion (Kumar and Scaife, 1979). Based on this statement combined with the observed neck flexion experienced in orthodontists, (55°–90° of flexion), it can be concluded that the load on the neck at C7/T1 may pose a risk. Likewise, 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°. 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 neck disorders.

4.3. Shear loads

The instantaneous shear loads on L5/S1 that occurred while sitting were lower than the action limit for shear load of 500N suggested by McGill et al. (1998). Furthermore, the instantaneous loads do not appear to reach anywhere near to Cyron et al. (1976), shear force fractures of the pars interarticularis of cadavers occurring between 1200N and 2800N. This instantaneous load is likely not indicative of the possible cumulative loads experienced in the prolonged static postures of orthodontics, which accrued to 1.4 MNs for one day in males and 1.2 MNs in females and a yearly total of 340 MNs for males and 303 MNs for females.

4.4. Limitations

Firstly, the measurement of angles in this field study relied on validated but subjective judgments, which may have some error. Secondly, the biomechanical model used in this study did not account for stresses caused by dynamic movements though they were slow and smooth. 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. Thirdly, the biomechanical model used did not account for asymmetric postures that may have been present. However, as indicated previously the postures were largely observed to be balanced and symmetrical across subjects. Finally, being a field study many factors could not be controlled. 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 as the reach was performed always on the right side. Angles were thus extrapolated from the left sided frames as close estimates.
5. Conclusion

From the preceding discussion, we can conclude that smaller loads cannot be ignored. The study demonstrates that instantaneous loads in orthodontists are not indicative of the amount of cumulative stress. Research in the area of cumulative load effects should be further pursued. Future research could lead to the improvement of work/equipment layout for orthodontic workers and dental professionals.

References