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Motion analysis of physicians in the field of dentistry - A kinematic comparison between dentists and orthodontists

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Abstract

Objectives: This study aims to conduct a kinematic comparison of occupational posture in orthodontists and dentists in their respective work environments.

Design: Prospective study.

Setting**:** dentist´s surgeries and departments of orthodontics at university medical centers in Germany.

Participants: A representative sample of 21 (10f/ 11m) dentists (group G1) and 21 (13f/ 8m) orthodontists (G2).

Outcome measures: The CUELA measuring system was used to conduct an ergonomic analysis of occupational posture. Parallel to the recording through the CUELA system, a software-supported analysis of the activities performed (I: treatment; II: office; III: other activities) was carried out. In line with ergonomic standards the measured body angles are categorized into neutral, moderate, and awkward postures. By means of the stratified van Elteren-U-test and the Wilcoxon-Mann-Whitney-U-Test the activities are compared between the aforementioned groups. All p-values are subject to the Bonferroni-Holm correction. The level of significance is at 5%.

Results: In terms of time the categories (I-II-III) are divided as follows: dentists 41-23-36% and orthodontists 28-37-35%. The posture analysis of both groups shows for all percentiles (P5-95) angle values that are primarily in the neutral or in the moderate range. However, depending on the activity performed between 5 and 25% of the total working hours unfavorable postures were observed, especially in the head-and-neck area. Orthodontists have a greater tendency to perform treatment activities with the head and torso in unfavorable positions than dentists. The significant differences between the statistical comparison of both groups with regard to the duration and the relevance of the activities performed affirm this assumption for all three categories ($p \leq 0.01$-0.05).

Discussion: Generally, both groups perform treatment activities in postures that are in the neutral or medium range; however, dentists were observed to take slightly more unfavorable postures during treatment for a greater share of their work day.

Strengths and limitations of this study

The kinematic comparison of occupational posture in orthodontists and dentists in their respective work environments with a particular focus on job-specific activities for the duration of one working day has not been measured so far.

The study investigates the motions and postures of the participating physicians in relation to the professional tasks, divided into the three categories (I) treatment, (II) office and (III) other activities.

This study combines two measurement methods: on the one hand participants wear the kinematic CUELA system under clothing and on the other hand two observers log in real time the activities performed with a hand-held computer.

Both groups perform treatment activities in postures that are in the neutral or medium range; however, dentists were observed to take slightly more unfavorable postures during treatment for a greater share of their work day.

The results confirm the already established correlations of musculoskeletal disorders in the dental profession.

The focus of this kinematic analysis is the posture of participants during a particular activity so that the individual variance in motion of each participant is given less consideration.

Posture analysis does not differentiate between static or dynamic execution of the working tasks.

A limitation of the CUELA system used here is the missing recording of fine motor movements in the area of the hand and arm.

Introduction

The dental profession encompasses a great number of health risks such as contact allergies, the risk of infection, eye injuries, neuropathy (1-5) as well as musculoskeletal disorders in the neck, shoulder and/ or back area (6-11). A questionnaire-based survey of 430 Greek dentists by Alexopoulus et al. (7) affirms the high incidence of musculoskeletal disorders (62%). In Poland 92% and in Germany 86.7% of surveyed dentists reported neck or back pain. 68.6% of the same group of respondents even reported to suffer from disorders on a weekly basis (8, 12). A study by Gopinadh et al. (13) shows that 73.9% of the 170 surveyed dentists in India encounter musculoskeletal pain, especially in the neck and back area, which also emphasizes a strong correlation between the increasing incidence of these symptoms with the length of the hours worked and the progressing age of the practitioner. More than half of the respondents reported to take inadequate body postures during treatment.

Furthermore, the frequency and the extent of this issue is found to result in the early retirement of dentists. With 29.5% or 55% these disorders present one of the most common medical causes for illness-related retirement among dentists (4, 14, 15).

A survey on musculoskeletal pain in Indian orthodontists distinguished between those that practioned exclusively as orthodontists and those who continued to work as dentists. In this regard, a prevalence of back pain was observed solely for respondents that worked in the field of orthodontics (16). Kerosuo et al. (17) also reach the conclusion that orthodontists more often have complaints of pain than dentists.

As a result, the questions of ways to integrate optimal and ergonomic posture in the work routine of dentists and orthodontists are more and more becoming a subject of public interest. To date, there is no data on postures taken in everyday work situations among dentists as well as orthodontists. Also, there is no side-by-side comparison of occupational posture in orthodontists and dentists that detects a possible prevalence of unfavorable patterns of posture that can result in musculoskeletal disorders for either of the professional groups.

Thus, by means of ergonomic and kinematic analysis this study aims to investigate patterns of postures that are involved in the daily routines of orthodontists and dentists and their possible impact on the pervasive development of symptoms of pain. For this purpose, the study investigates the motions and postures of the participating physicians in relation to the professional tasks, divided into the three categories (I) treatment, (II) office and (III) other activities, performed in their daily routine. In this context, the following hypotheses are being investigated:

1. The treatment stage accounts for the largest temporal share in the day-to-day work of orthodontists and dentists.
2. For both groups unfavorable postures were observed more often during treatment than during office or other activities.
3. In contrast to dentists, orthodontists more often perform treatment activities with the torso in a neutral position.

Methods

Study Participants

Overall, this study measured 42 participants (23w/18m). The participants are divided into two groups and compared with each other based on their respective professional training. Group 1 (G1) consists of 21 dentists (10 w/11 m) working in established practices in Germany that are on average 40.14 ± 10.35 years old and have had work experience in the field for 10.55 ± 9.95 years. Group 2 (G2) comprises 21 orthodontic assistants (13 w/ 7 m) of an average age of 31.48 ± 3.82 years that are currently in training at university medical centers in Germany. Work experience for this group accounted for a statistical mean value of 3.86 ± 2.48 years. One drop-out of a male participant was recorded for group 2. All study participants stated that they show no signs of functional impairment or ailments related to the musculoskeletal system. Injuries of the musculoskeletal system ought to have occurred more than two years prior to the study. This study was approved by the Ethics Committee (135/14) of the Goethe University in Frankfurt am Main. All participants signed an informed consent to take part in the study in advance.

CUELA Measuring System

The CUELA-System (Fig. 1) (computer-assisted acquisition and long-term analysis of musculoskeletal loads), developed at the Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA; Sankt Augustin / Germany), is used to record and analyze body postures (18, 19).

Fig. 1

This personal system uses sensors (accelerometers [ADXL 103/203] and gyroscopes [muRata ENC-03R] for head, arms, legs, back, potentiometers [Contelect] for back torsions) to measure the position and movements of the participants on a continuous time interval.

A sampling frequency of 50 Hz and an angular resolution of approximately 1° allows for an objective evaluation of the body postures and motions observed in the participants (20-23). Table 1 summarizes all parameters of this study that were measured and calculated with the CUELA system.

Tab. 1

Measuring System: Software-Based Activity Analysis

Participants are being observed in their day-to-day work to analyze the activities performed and the respective motions involved. A hand-held computer (UMPC Samsung Q1, Samsung Electronics GmbH. Schwalbach, Germany), which relies on data acquisition software (24, 25) specifically designed for this study, records the activities performed in real time by the second. This software was coded specifically for each group and their respective treatment spectrum (activity categories). The beginning and the end of each orthodontic or dental activity as well as its duration were recorded. A detailed description of the system has already been published (24, 25).

Experimental Procedure

For a description and summary of the daily activities performed, both groups were observed in their routine for one working day prior to the study. In this way, 22 activities were detected for G1 and 25 for G2, all of which were subsequently divided into three categories (I) treatment, (II) office and (III) other activities and implemented into the data acquisition software (Table 2).

Tab. 2

Each participant is measured on a randomly selected work day of 8 hours to ensure an authentic recording of their treatment spectrum. Participants wear the CUELA system under clothing to conduct the measurement (sensors are attached on arms, legs, head, and the spine). Parallel to the recording through the CUELA system, two observers log in real time the activities performed with a hand-held computer. However, some activities are summarized in Table 2 as "craft activities" (I) because both professional groups do not perform the exact same range of activities.

Evaluation

Once the measurement is completed, the time intervals of the activity analysis (hand-held computer) recorded in real time are synchronized with the time axis of the motion analysis (CUELA). A specially developed software (IFA; Sankt Augustin, Germany) is used to create visualizations and descriptive analysis of the retrieved results.

The descriptive analysis of the postures observed in the examined collectives is based on the indication of the arithmetic mean (AM), standard deviation (SD) as well as the percentiles P05, P25, P50, P75 and P95. The percentiles give a descriptive report of the angle values that are below the measuring time of the respective activity performed in a particular joint region. For instance, the P05 value describes the threshold value for joint angles, which 5 % of all measured data fall short of and 95 % exceed. These angle values are subsequently evaluated and assigned to a color-coded angle range (traffic light system: red/ yellow/ green) in compliance with ergonomic standards (26-28). Based on the respective colors, postures are assessed as unfavorable (awkward), moderate or neutral (29) (Table 1).

Activities of both groups are compared based on the stratified Van Elteren-test and the bilateral Wilcoxon-Mann-Whitney-test along with the Bonferroni-Holm-correction because the data retrieved was not normally distributed under the Kolmogoroff-Smirnoff-test. Following the comparison, only those activities are analyzed whose sensors show angle values that are significantly different and that are relevant with regard to the duration and the (dental or orthodontic) profession itself.

Results

Activity Analysis

On average, data was collected for both groups for a measuring period of approximately 6 h on a day-to-day basis (total measuring period: G1: 116.4 h; G2:131.9 h). The percentage of the measuring period is distributed across the three categories (I-II-III) as follows: G1: 41 - 23 - 36% und G2: 28 - 37 - 35%. A side-by-side comparison of the proportionate activity duration for each category can be found in Figure 2.

Category (I) comprises seven comparable activities of which “craft activities,” contra-angle /ultrasound,” and “examination / screening” are the activities with the longest duration and these activities with regard to treatment time account for 96% in G1 and 90% in G2. In category (II) “consult files” and “office work” account for the longest time span with 90% in G1 and 87% in G2. “Conversation” (G1: 67%; G2: 63%) along with “walk” (G1: 9%; G2: 14%) represent the largest shares of category (III). As a result, these category (III) activities account for more than ¾ of the total working time. During the aforementioned activities dentists and orthodontists take almost identical postures and, therefore, the statistical analysis of the differences between both groups disregards these postures. Instead, the rarely performed activity “laboratory” (G1:7%; G2:7%) in terms of time is analyzed.

Descriptive Posture Analysis

Table 3 shows the benchmarks for the distribution of body and joint angles (Percentile P05, P25, P50, P75 und P95) assumed during the most important activities for orthodontists and dentists.

Regarding the median (P50) for all relevant activities, it is evident that dentists and orthodontists very often work in the same angle range, which is predominantly ranked as neutral or moderate (Table 3). Neutral postures (Table 1) in category I are mainly found between P25-P75 values. This is the case for the evaluation parameters for inclination of the thoracic spine to the right (TSI_r), back torsion to the right (BT_r), inclination of the torso to the front (TI_f), inclination of the torso to the right (TI_r) as well as for inclination of the lumbar spine to the right (LSI_r). Moderate posture is found with back curvature to the front (BC_f) and head tilted to the front (HT_f). For both groups inclination of the thoracic spine to the front (TSI_f) is found to be rather in the neutral for lower percentiles and in the moderate range for higher percentiles. Unfavorable postures in P05 and P95 are primarily found in neck curvature to the right (NC_r) and to the front (NC_f), whereas medial sections are ranked as neutral. In category II for both groups several body and joint angles are predominantly in the neutral range (back curvature to the front (BC_f), inclination of the thoracic spine to the front (TSI_f), inclination of the thoracic spine to the right (TSI_r), head tilted to the front (HT_f), inclination of the lumbar spine to the right (LSI_r), back torsion to the right (BT_r) and inclination of the torso to the right (TI_r) and several angles are found to be in the moderate range at and above P50 and in the unfavorable range below P50 (neck curvature to the right (NC_r), neck curvature to the front (NC_f) and inclination of the torso to the front (TI_f)). Back curvature to the front (BC_f) prevails in the moderate range. Data retrieved for "laboratory" (III) almost concurs with data determined for office (II).

Treatment (I)

Compared to orthodontists, dentists use the contra-angle or ultrasonic handpiece more often and for a longer duration ($p \leq 0.001$). Group 1 performs this activity 797 times (total duration approx. 689 min) and group 2 only 138 times (total duration: approx. 204 min). A significant difference between both groups is found for the inclination of the thoracic spine to the front (TSI_f) in P95 ($p \leq 0.05$), neck curvature to the right (NC_r) in SD ($p \leq 0.04$) and in P95 ($p \leq 0.03$), neck curvature to the front (NC_f) in SD ($p \leq 0.05$), head tilted to the right (HT_r) in SD and in P95 ($p \leq 0.02$) as well as for back curvature to the front (BC_f) in SD ($p \leq 0.04$) during the activity "examination / screening"

Significant differences between both groups are found for the activity "examination / screening" regarding the inclination of the thoracic spine to the front (TSI_f) at P95 ($p \leq 0.05$), neck curvature to the right (NC_r) at SD ($p \leq 0.04$) and P95 ($p \leq 0.03$), neck curvature to the front (NC_f) at SD ($p \leq 0.05$), head tilted to the right (HT_r) at SD and P95 ($p \leq 0.02$) as well as back curvature to the front (BC_f) at SD ($p \leq 0.04$) (Table 4). The classification of the measured angle values according to the various class codes is identical for all sensors considered. Nevertheless, angle values are evidently higher in orthodontists than in dentists.

We also observed that both groups always perform "craft activities" in the same angle range (Table 4). The significances are found for the inclination of the thoracic spine to the right (TSI_r) at P05 ($p \leq 0.02$) as well as neck curvature to the right (NC_r) at P05 ($p \leq 0.001$ or $p \leq 0.04$), neck curvature to the front (NC_f) at SD and P95 ($p \leq 0.01$ or $p \leq 0.05$), head tilted to the right (HT_r) at SD ($p \leq 0.02$) and the inclination of the torso to the right (TI_r) at P05 ($p \leq 0.01$).

Office (II)

Among orthodontists the activity "office work" represents a long time period as it accounts for 1901 min and thus 24% of the total working hours, which results in a statistical significance in duration of $p \leq 0.01$. Another significance is found for neck curvature to the front (NC_f) at SD. For this activity, orthodontists showed greater angle values than dentists (G1 < G2).

Other Activities (III)

The activity "laboratory" shows a significant difference of $p \leq 0.02$ in SD for head tilted to the front (HT_f), whereby orthodontists exhibit greater angle values than dentists (G1 < G2).

Discussion

The comparative motion analysis of dentists and orthodontists delivers data that gives information about whether a dental or orthodontic activity is performed in an ergonomically favorable body posture or not. The classification of particular activities as "craft activities" (Table 2) and the division of the day-to-day work of both groups into three categories allows for a differentiated analysis of every activity performed and a comparison of both professional groups with regard to distinctions and commonalities.

The temporal division of one working day by percentage indicates that treatment (I) accounts for 41% among dentists and 28% among orthodontists of the day-to-day work. Orthodontists spend more time in the office (37%) or with other activities (35%) by percentage. Therefore, hypothesis 1, which states that the treatment stage accounts for the largest temporal share in the day-to-day work of orthodontists and dentists, is verified for dentists and falsified for orthodontists. Increased office work immediately relates to the necessary computer work in terms of model and X-ray analysis, which is considered essential for orthodontic treatment. Among orthodontists "conversation" is a very frequent activity because the treatment concepts as well as the treatment stages have to be explained and demonstrated to the patient. As a result, the percentage of 35% in category III is comprehensible.

Based on the kinematic analysis with the CUELA system, conclusions regarding the assumed postures can be drawn. The evaluation of the percentiles 05, 25, 50, 75 and 95 are particularly significant for hypothesis 2 as it claims that unfavorable postures occur during the treatment of patients. As a result, the classification of body angle data in category I (treatment) emphasizes that predominantly neutral or moderate postures are assumed. The range for unfavorable body and joint angles is found in the percentiles P05, P75 and P95 for neck curvature to the right and front (NC_r; NC_f), back curvature to the front (BC_f), and the inclination of the torso to the front (TI_f) (Table 3). The data obtained clearly demonstrates that 50% of the time dentists and orthodontists predominantly treat in the neutral or moderate angle range. However, for both groups the measured angles, which are all found to be in the moderate range, show greater angle values (25° - 65°) in the percentiles P25-P95 for inclination of the head to the front during treatment.

For the other two categories (II+III) similar conclusion is drawn: With the activities "office work," "consult files," and "laboratory" unfavorable postures in the angles of neck curvature to the right and front (NC_r; NC_f), tilted head to the front (HT_f), inclination of the torso to the front (TI_f), and back curvature to the front (BC_f) are observed. The negative and unfavorable inclination of the head and torso are found to develop on account of a seated position which renders participants to rest their spine comfortably against the back of the chair, a position which is not considered strenuous.

In comparison to "office work," which is performed in the angle range between 7° to 36° (30), treatment activities are increasingly conducted in forced postures, particularly observable for head inclination. In principal, angle values in the area of the head and cervical spine differentiate significantly between treatment and office activities, which points towards an increasing muscular strain during treatment. Thus, participants worked for a greater temporal proportion of their day-to-day work in unfavorable positions, which are also the cause for musculoskeletal disorders. This is particularly evident given that the P05 or P95-values of the respective body / joint angles are clearly in the unfavorable range.

The results confirm the already established correlations of musculoskeletal disorders in the dental profession (6-8, 17, 30, 31). According to Alexopoulos et al. (7) more than every other dentist is affected by back, shoulder, and/or neck problems. The side-by-side comparison between orthodontists and dentists, however, does not show a significant difference regarding the related problematic nature of unfavorable posture.

Consequently, hypothesis 2 is only partially verified. The tendency for a predominantly unfavorable posture in daily working life is thus applicable to these professional groups with regard to treatment activities. In relation to the other two categories, this tendency corresponds to office activities performed in other professions (30, 32).

Referring to hypothesis 3, postures demonstrate that there are no greater disparities regarding the mode operation among participants in both groups because all participants performed the same activities exclusively in the same angle range (neutral or moderate). Angular deviations are only found for “craft activities” with the inclination of the thoracic spine to the front (TSI_f), “examination / screening” with the inclination of the thoracic spine to the front (TSI_f), with back curvature to the right (BC_r), and for the activity “contra-angle/ ultrasonic handpiece” with neck curvature to the front (NC_f). Except for back curvature to the right (BC_r), all angle values for “examination / screening” among orthodontists are found in the worse angle range. Their thoracic spine is observed to incline further to the front and therefore demonstrates a frontal neck curvature to a greater extent (unfavorable angle range) (Table 3). Consequently, dentists on average perform activities in more favorable angle ranges than orthodontists. However, neither of the groups solely demonstrates a neutral range of angles during treatment. Considering the p-values it becomes apparent that there are significant differences between both groups, even though the angle difference between the groups is minimal. For instance, this is demonstrated with inclination of TS to the right during the execution of craft activities. The difference in the P05-value only accounts for 3° (“craft activities” inclination of TS to the right (TSI_r)) - G1: -5°; G2: -8°) (Table 4). As a result, the measured angle values are significant but the minimal difference of these angle values is, on the one hand, not clinically relevant and, on the other hand, not crucial for a different angle classification according to ergonomic norms. Consequently, hypothesis 3 is falsified.

Moreover, a comparison of both groups ought to take the average age into account, which is lower by 9 years in orthodontists as compared to dentists. This age difference along with the greater professional experience (G1: 10.55 ± 9.95 years; G2: 3.86 ± 2.48 years) could also have an effect on the postures assumed.

The focus of this kinematic analysis is the posture of participants during a particular activity. Here, the individual variance in motion of each participant is given less consideration. In this context, impact factors such as workplace organization, treatment position, as well as the choice of a patient chair (30, 32) present important components which can affect individuals in ways that can cause musculoskeletal disorders (33-36).

However, musculoskeletal disorders often develop not only on account of poor posture but also originate in multicausal conditions. Many scientific studies have affirmed that daily stress is a decisive factor (3, 37-39). Consequently, pain problems among dentists and orthodontists cannot be explained based on one factor but requires a multifactorial analysis that is essential /meaningful.

Furthermore, consideration must be given to the fact that many activities such as the preparation of a dental crown by using a contra-angle piece or the cementation of an orthodontic appliance are performed in long-lasting, static positions. These body postures assumed over a long period of time could be the potential cause for the ailments described as work performed in a static position also results in physical strain (11). In this respect, the analysis of static postures during treatment activities is considered a meaningful and desirable addition to future research in the field.

In summary, the postures analyzed in this study do not differ greatly between both surveyed groups. The same result was found in a survey about health complaints of dentists (n=147) and orthodontists (n=81) by Kerosuo et al. (17). With around the same frequency, both groups reported with 70% and 72% musculoskeletal disorders, even though a slightly increased prevalence was found among orthodontists. This slightly higher prevalence is also evident in another study by Sankar et al. (16). Following ergonomic standards, dentists as well as orthodontists primarily work in the neutral or moderate range, a conclusion, however, which requires differentiated analysis. Particularly for treatment activities the P05 or P-75-P95 values in the red range emphasize the need for action. These angle values in the red range correlate with apparent and prolonged postures in a forced position (over 4 seconds in a static position) (40). Moreover, aside from the duration of the activity individual motion control has to be considered as it bears the risk of developing muscular dysbalance and disorders.

Footnotes

a. contributorship statement

JN, CE, IH, and DO made substantial contributions to the conception and design of the manuscript. JN, CE, IH, DAG, IH, RE, DD, and DO made substantial contributions to the construction of the measurement protocol and NJ and Do has been involved in the statistical data analysis. All authors have read and approved the final manuscript.

b. competing interests

The authors declare that they have no conflict of interest.

c. funding

There is no funding of the project.

d. data sharing statement

No additional data available.

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Figures and tables

Figure 1: Illustration of the CUELA system.

Figure 2: Comparison of temporal duration of activities performed by both professional groups

Figure 1: Illustration of the CUELA system.
221x271mm (300 x 300 DPI)

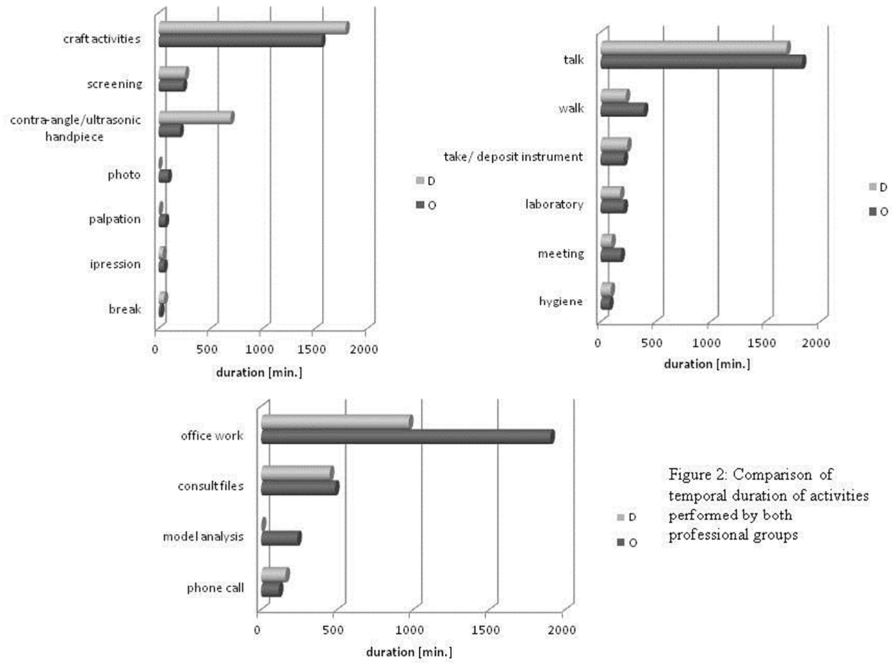

Figure 2: Comparison of temporal duration of activities performed by both professional groups
254x190mm (96 x 96 DPI)

Body areas	Joint/ Body area	Degree of freedom according to medical definitions	Evaluation parameter	Angle range according to ergonomic standards
Head/neck	Head	sagittal inclination	Head tilted to the front (HT_f) (26, 40)	Neutral: 0 bis 25° Moderate: 25 bis 85° Awkward: < 0° & > 85°
		lateral inclination	Head tilted to the right (HT_r) (40)	No ergonomic layout available
	Cervical spine (CS)	flexion/ extension	Neck curvature to the front (NC_f) *[Difference betw. Head and TS]* (26, 40)	Neutral: 0 bis 25° Awkward: < 0° & > 25°
		lateral flexion	Neck curvature to the right (NC_r) *[Difference betw. Head and TS]* (26, 40)	Neutral: -10 bis 10° Awkward: < -10° & >10°
Back	Thoracic spine (TS)	flexion/ extension	TS inclination to the front (TSI_f) (26, 40)	Neutral: 0 bis 20° Moderate: 20 bis 60° Awkward: < 0° & > 60°
		lateral flexion	TS inclination to the right (TSI_r) (26, 40)	Neutral: -10 bis 10° Moderate: -10 bis -20° Moderate: 10 bis 20° Awkward: < -20° & > 20
	Lumbar spine (LS)	flexion/ extension	LS inclination to the front (LSI_f)	No ergonomic layout available
		lateral flexion	LS inclination to the right (LSI_r)	
	Trunk (T)	flexion/ extension	Back curvature to the front (BC_f) *[Difference betw. TS and LS]* (26, 40)	Neutral: 0 bis 20° Moderate: 20 bis 40° Awkward: < 0° & > 40°
			Inclination of the torso to the front (TI_f) *[median flexion of TS and LS]* (26, 40)	Neutral: 0 bis 20° Moderate: 20 bis 60° Awkward: < 0°& > 60°
		lateral flexion	Back curvature to the right (BC_r) *[Difference betw. TS and LS] (26, 40)*	Neutral: -10 bis 10° Moderate: -10 bis -20° Moderate: 10 bis 20° Awkward: < -20° & > 20°
			Inclination of the torso to the right (TI_r) *[median lateral flexion of TS and LS]* (26, 40)	
		torsion	Back torsion to the right (BT_r) *[Difference betw. TS and LS](40)*	

Table 1 Illustration of body and joint angles measured with the CUELA system, evaluation parameters used, and assessment criteria in line with ergonomic norms.

category	work task	details
treatment	impression	Taking an impression of the patient's teeth
	photo	Camera documentation of the case
	craft activities	Umbrella term for all work stages that are not included in the aforementioned activities.
	palpation	Palpating patients' muscles/ jaw joints
	break	Short breaks during treatment
	screening	First/ check-up screening of patients
	contra-angle/ ultrasonic handpiece	Using contra-angle/ ultrasonic handpiece during treatment
office	consult files	Reading patient files (results/ tooth model/ X-ray)
	Office work	Writing entries for patient files/ computer work
	model analysis	Analysis and conception of treatment plans based on teeth models and X-rays
	phone call	Having phone conversations
other activities	meeting	Medical consultation among peers
	talk	Conversations with patients and staff as solitary activity
	hygiene	Hygienic measures (washing /desinfecting hands, wearing gloves/ face masks)
	take/ deposit instrument	Taking up instruments from a drawer / putting instruments down during and after treatment
	laboratory	Any kind of labwork
	walk	Covering distances

Table 2 Illustration of categories with the respective activities performed as well as with an explanation thereof. "Craft activities" in group 1: extraction, pain diagnostics, implantation, placing an injection; and in group 2: archwire-/ elastics-change, removable appliance, fixed appliance, mini implant, filling, prophylaxis, splint.

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descriptive body posture (P5-25-50-75-90)		craft activities					screening					contra-angle/ ultrasonic handpiece					office work					consulting files					laboratory				
percentile (in degree °)		5	25	50	75	95	5	25	50	75	95	5	25	50	75	95	5	25	50	75	95	5	25	50	75	95	5	25	50	75	95
TS inclination to the front (TSI_f [°])	D	7	14	19	24	30	7	15	19	23	27	11	20	25	28	31	3	10	14	18	24	5	14	19	23	29	6	12	17	22	30
	O	8	16	21	26	32	8	17	23	28	35	13	22	26	28	32	9	16	20	24	29	8	14	19	23	29	10	18	23	26	31
TS inclination to the right (TSI_r [°])	D	-5	0	3	6	10	-3	3	7	10	15	-3	2	4	6	10	-5	-1	1	4	7	-4	0	2	4	8	-6	-3	-1	2	7
	O	-8	-3	0	4	9	-6	0	4	8	12	-5	-2	1	5	9	-5	-2	0	1	4	-5	-2	0	3	6	-5	-1	1	2	7
Neck curvature to the right (NC_r [°])	D	-14	-5	2	8	17	-15	-6	1	9	17	-13	-2	5	12	19	-13	-7	-3	1	6	-14	-8	-4	-1	5	-17	-11	-6	-2	5
	O	-15	-4	5	14	26	-17	-4	6	16	30	-14	-2	6	14	25	-14	-7	-3	2	9	-10	-4	0	4	10	-11	-3	2	6	13
Neck curvature to the front (NC_f [°])	D	-5	9	17	23	30	-3	11	17	23	29	2	14	20	25	30	-16	-7	0	7	15	-16	-7	-1	5	14	-12	0	7	14	22
	O	-5	13	23	30	37	-8	8	17	24	32	5	21	28	33	39	-22	-12	-4	4	16	-16	-6	2	8	17	-12	6	18	26	34
Head tilted to the front (HT_f [°])	D	8	25	37	45	54	9	27	36	43	51	17	36	45	51	56	-1	8	14	20	29	2	11	17	23	31	3	17	25	32	40
	O	8	31	45	53	62	7	28	40	49	59	21	45	54	59	65	-2	7	15	23	36	1	13	21	27	36	7	25	41	49	58
Head tilted to the right (HT_r [°])	D	-15	-4	4	13	25	-14	-3	8	19	32	-13	0	10	19	29	12	-6	-2	1	8	-12	-6	-2	1	7	-17	-11	-6	-2	6
	O	-19	-6	5	16	32	-19	-2	11	24	42	-16	-3	8	18	31	15	-7	-2	2	9	-10	-4	0	4	11	-12	-3	3	8	15
LS inclination to the front (LSI_f [°])	D	-14	-9	-6	-3	0	-13	-9	-7	-5	-2	-14	-10	-7	-5	-3	-25	-22	-19	-15	-9	-13	-8	-5	-2	2	-12	-9	-6	-3	4
	O	-16	-12	-9	-6	-1	-17	-12	-10	-5	-1	-14	-10	-7	-5	-2	21	-17	-13	-10	-3	-16	-12	-9	-6	-2	-19	-15	-12	-9	-2
LS inclination to the right (LSI_r [°])	D	-7	-5	-3	-1	2	-8	-6	-4	-2	1	-7	-4	-3	-2	1	-7	-5	-3	-2	0	-8	-5	-3	-1	2	-8	-6	-4	-2	2
	O	-9	-6	-4	-2	2	-7	-3	-1	1	5	-7	-5	-4	-2	1	-7	-5	-3	-2	0	-7	-5	-3	-2	1	-7	-3	-2	0	3
Back curvature to the right (BC_r [°])	D	-1	3	6	8	11	3	7	11	14	17	2	2	5	7	12	0	3	5	7	10	-1	3	5	7	11	-1	1	3	6	10
	O	-3	1	4	7	11	-2	2	5	8	11	-1	2	5	8	11	-1	1	3	5	8	-2	2	4	6	9	-3	1	2	4	7
Back curvature to the front (BC_f [°])	D	15	21	25	30	35	16	22	25	29	33	21	28	32	35	38	20	27	33	37	41	13	20	24	27	32	11	18	24	29	34
	O	17	25	29	34	40	20	27	32	36	41	23	29	32	35	39	20	29	33	37	42	18	24	28	32	36	19	29	35	39	43
Back torsion to the right (BT_r [°])	D	-9	-5	-3	0	7	-7	-4	-1	1	7	-6	-4	-3	-1	5	-7	-3	0	3	6	-7	-4	-1	1	6	-6	-2	0	2	5
	O	-7	-3	0	3	8	-6	-2	0	3	7	-9	-6	-4	-2	6	-7	-3	-1	2	8	-6	-3	0	3	7	-5	-1	2	5	10

Inclination of the torso to the front (TI_f [°])	D	-2	3	7	10	14	-3	3	6	9	12	-1	6	9	11	13	-10	-5	-2	1	6	-3	3	7	10	15	-1	3	6	8	14
	O	-3	2	6	9	14	-4	3	7	11	16	0	6	9	11	15	-5	0	4	6	11	-3	1	5	8	13	-3	2	5	8	12
Inclination of the torso to the right (TI_r [°])	D	-5	-1	1	3	7	-4	0	4	6	10	-4	0	2	4	7	-5	-2	0	2	5	-4	-1	1	3	6	-6	-3	-1	1	5
	O	-8	-4	-1	2	7	-6	-1	3	6	10	-5	-2	0	3	6	-5	-2	-1	1	4	-5	-3	-1	0	3	-5	-1	0	2	5

Table 3: Comparative illustration of median posture; Caption: Ergonomic posture = red: awkward; yellow: moderate; green: neutral; D= dentist, O= orthodontist

Activity		Parameter	Sensor	O [°]	D [°]	Signifikance
treatment	craft activities	P05	TSI_r	-8	-5	0,02
		(MV) SD	NC_r	(5) 13	(2) 10	0,04
		(MV) SD	NC_f	(13) 20	(15) 11	0,01
		P95		37	30	0,05
		(MV) SD	HT_ r	(5) 16	(4) 13	0,02
		P05	TI_r	-8	-5	0,01
	screening	P95	TSI_f	35	27	0,05
		(MV) SD	NC_r	(6) 15	(1) 10	0,04
		P95		30	17	0,03
		(MV) SD	NC_f	(15) 13	(16) 10	0,05
		(MV) SD	HT_ r	(11) 19	(8) 15	0,02
		P95		42	32	0,02
		(MV) SD	BC_f	(31) 7	(25) 5	0,04
office	office work	(MV) SD	NC_f	(- 4) ± 12	(0) ± 10	0,02
other activities	laboratory	(MV) SD	HT_f	(37) ± 16	(24) ± 2	0,02

Table 4: Illustration of statistically relevant activities with respective sensors. Caption: ( ) = included based on affiliation; P = percentile, MV = median value, SD = standard deviation; Ergonomic posture = red: awkward; yellow: moderate; green: neutral; D= dentist, O= orthodontist

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Motion analysis in the field of dentistry - A kinematic comparison between dentists and orthodontists

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Abstract

Objectives: This study aims to conduct a kinematic comparison of occupational posture in orthodontists and dentists in their workplace.

Design: Prospective study.

Setting: Dentist' surgeries and Departments of Orthodontics at university medical centers in Germany.

Participants: A representative sample of 21 (10f/11m) dentists (group G1) and 21 (13f/8m) orthodontists (G2) with one male drop-out in G2.

Outcome measures: The CUELA (computer-assisted acquisition and long-term analysis of musculoskeletal loads) system was used to analyze the occupational posture. Parallel to the recording through the CUELA system, a software-supported analysis of the activities performed (I: treatment; II: office; III: other activities) was carried out. In line with ergonomic standards the measured body angles are categorized into neutral, moderate, and awkward postures. By means of the stratified van Elteren-U-test and the Wilcoxon-Mann-Whitney-U-Test the activities are compared between the aforementioned groups. All p-values are subject to the Bonferroni-Holm correction. The level of significance is at 5%.

Results: In terms of time the categories (I-II-III) are divided as follows: dentists 41-23-36% and orthodontists 28-37-35%. The posture analysis of both groups shows for all percentiles (P5-95) angle values primarily in the neutral or in the moderate range. However, depending on the activity performed between 5 and 25% of the working hours unfavorable postures were observed, especially in the head-and-neck area. Orthodontists have a greater tendency to perform treatment activities with the head and torso in unfavorable positions than dentists. The significant differences between the statistical comparison of both groups with regard to the duration and the relevance of the activities performed affirm this assumption for all three categories ($p \leq 0.01$-0.05).

Conclusions: Generally, both groups perform treatment activities in postures that are in the neutral or medium range; however, dentists were observed to take slightly more unfavorable postures during treatment for a greater share of their work day.

Strengths and limitations of this study

To date, a kinematic comparison of occupational posture in orthodontists and dentists in their respective work environments with a particular focus on job-specific activities ((I) treatment, (II) office and (III) other activities) for the duration of one working day has not been conducted yet

This study combines two measurement methods: on the one hand participants wear the kinematic CUELA system under clothing and, on the other hand, two observers log in real time the activities performed with a hand-held computer.

The results confirm the already established correlations of musculoskeletal disorders in the dental profession. However, dentists were observed to be slightly more likely to take unfavorable postures during treatment for a greater share of their work day.

Posture analysis does not differentiate between static or dynamic execution of the working tasks.

One limitation of the CUELA system is that it does not record fine motor movements in the area of the hands and arms.

Introduction

The dental profession encompasses a great number of health risks such as contact allergies, the risk of infection, eye injuries, neuropathy (1-5) as well as musculoskeletal disorders in the neck, shoulder and/ or back area (6-11). A questionnaire-based survey of 430 Greek dentists by Alexopoulus et al. (7) affirms the high incidence of musculoskeletal disorders (62%). In Poland 92% and in Germany 86.7% of surveyed dentists reported neck or back pain. 68.6% of the same group of respondents even reported to suffer from disorders on a weekly basis (8, 12). A study by Gopinadh et al. (13) demonstrates that 73.9% of the 170 surveyed dentists in India encounter musculoskeletal pain, especially in the neck and back area, which also shows a correlation between the increasing incidence of these symptoms with the length of the hours worked and the progressing age of the practitioner. More than half of the respondents reported to take inadequate body postures during treatment.

Furthermore, the frequency and the extent of this issue is found to result in the early retirement of dentists. With 29.5% to 55% these disorders present one of the most common medical causes for illness-related retirement among dentists (4, 14, 15).

A survey on musculoskeletal pain in Indian orthodontists distinguished between those that practioned exclusively as orthodontists and those who continued to work as dentists. In this regard, a prevalence of back pain was observed solely for respondents that worked in the field of orthodontics (16). Kerosuo et al. (17) also reach the conclusion that orthodontists more often have complaints of pain than dentists.

As a result, the questions of ways to integrate optimal and ergonomic posture in the work routine of dentists and orthodontists are more and more becoming a subject of public interest. To date, there is no data on postures taken in everyday work situations among dentists as well as orthodontists. Also, there is no side-by-side comparison of occupational posture in orthodontists and dentists that detects a possible prevalence of unfavorable patterns of posture that can result in musculoskeletal disorders for either of the professional groups.

Thus, by means of ergonomic and kinematic analysis this study aims to investigate patterns of postures that are involved in the daily routines of orthodontists and dentists and their possible impact on the pervasive development of symptoms of pain. For this purpose, the study investigates the motions and postures of the participating physicians in relation to the professional tasks, divided into the three categories (I) treatment, (II) office and (III) other activities, performed in their daily routine. In this context, the following hypotheses are being investigated:

1. The treatment stage accounts for the largest temporal share in the day-to-day work of orthodontists and dentists.
2. For both groups unfavorable postures were observed more often during treatment than during office or other activities.
3. In contrast to dentists, orthodontists more often perform treatment activities with the torso in a neutral position.

Methods

Study Participants

Overall, this study measured 42 participants (23f/19m). The participants are divided into two groups and compared with each other based on their respective professional training. Group 1 (G1) consists of 21 dentists (10f/11m) working in established practices in Germany that are on average 40.14 ± 10.35 years old and have had work experience in the field for 10.55 ± 9.95 years. Group 2 (G2) comprises 21 orthodontic residents (13 w/ 7 m) of an average age of 31.48 ± 3.82 years that are currently in training at three university medical centers in Germany. One drop-out of a male participant was recorded for group 2 due to incorrect measurement. Work experience for this group accounted for a statistical mean value of 3.86 ± 2.48 years. All study participants stated that they show no signs of functional impairment or ailments related to the musculoskeletal system. Injuries of the musculoskeletal system ought to have occurred more than two years prior to the study. This study was approved by the Ethics Committee (135/14) of the Goethe University in Frankfurt am Main. Prior to the study, all participants signed an informed consent to take part in the study. The authors obtained informed consent from the participant in figure 1 for publication.

The comparison of postures is expected to show a greater difference between dentists and orthodontists. According to Cohen an effect size with a standard deviation of 0,8-1 is considered a significant difference. The power of this study was set at 80% to calculate with approximately 20 study participants.

CUELA Measuring System

The CUELA-System (Fig. 1) (computer-assisted acquisition and long-term analysis of musculoskeletal loads), developed at the Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA; Sankt Augustin / Germany), is used to record and analyze body postures (18, 19).

Fig. 1

This personal system uses sensors (accelerometers [ADXL 103/203] and gyroscopes [muRata ENC-03R] for head, arms, legs, back, as well as potentiometers [Contelect] for back torsions) to measure the position and movements of the participants on a continuous time interval.

A sampling frequency of 50 Hz and an angular resolution of approximately 1° allows for an objective evaluation of the body postures and motions observed in the participants (20-23). Table 1 summarizes all parameters of this study that were measured and calculated with the CUELA system.

Table 1 Illustration of body and joint angles measured with the CUELA system, evaluation parameters used, and assessment criteria in line with ergonomic norms.

Body areas	Joint/ Body area	Degree of freedom according to medical definitions	Evaluation parameter	Angle range according to ergonomic standards
Head/neck	Head	sagittal inclination	Head tilted to the front (HT_f) (24, 25)	Neutral: 0 to 25° Moderate: 25 to 85° Awkward: < 0° & > 85°
		lateral inclination	Head tilted to the right (HT_r) (25)	Neutral: -10 to 10° Awkward: < -10° & >10°
	Cervical spine (CS)	flexion/ extension	Neck curvature to the front (NC_f) *[Difference betw. Head and TS]* (24, 25)	Neutral: 0 to 25° Awkward: < 0° & > 25°
		lateral flexion	Neck curvature to the right (NC_r) *[Difference betw. Head and TS]* (24, 25)	Neutral: -10 to 10° Awkward: < -10° & >10°
Back	Thoracic spine (TS)	flexion/ extension	TS inclination to the front (TSI_f) (24, 25)	Neutral: 0 to 20° Moderate: 20 to 60° Awkward: < 0° & > 60°
		lateral flexion	TS inclination to the right (TSI_r) (24, 25)	Neutral: -10 to 10° Moderate: -10 to -20° Moderate: 10 to 20° Awkward: < -20° & > 20
	Lumbar spine (LS)	flexion/ extension	LS inclination to the front (LSI_f)	No ergonomic layout available
		lateral flexion	LS inclination to the right (LSI_r)	
	Trunk (T)	flexion/ extension	Back curvature to the front (BC_f) *[Difference betw. TS and LS]* (24, 25)	Neutral: 0 to 20° Moderate: 20 to 40° Awkward: < 0° & > 40°
			Inclination of the torso to the front (TI_f) *[median flexion of TS and LS]* (24, 25)	Neutral: 0 to 20° Moderate: 20 to 60° Awkward: < 0°& > 60°
		lateral flexion	Back curvature to the right (BC_r) *[Difference betw. TS and LS] (24, 25)*	Neutral: -10 to 10° Moderate: -10 to -20° Moderate: 10 to 20° Awkward: < -20° & > 20°
			Inclination of the torso to the right (TI_r) *[median lateral flexion of TS and LS]* (24, 25)	
		torsion	Back torsion to the right (BT_r) *[Difference betw. TS and LS](25)*	

Measuring System: Software-Based Activity Analysis

Participants are being observed in their day-to-day work to analyze the activities performed and the respective motions involved. A hand-held computer (UMPC Samsung Q1, Samsung Electronics GmbH. Schwalbach, Germany), which relies on data acquisition software (26, 27) specifically designed for this study, records the activities performed in real time by the second. This software was coded specifically for each group and their respective treatment spectrum (activity categories). The beginning and the end of each orthodontic or dental activity as well as its duration were recorded. A detailed description of the system has already been published (26, 27).

Experimental Procedure

For a description and summary of the daily activities performed, both groups were observed in their routine for one working day prior to the study. In this way, 22 activities were detected for G1 and 25 for G2, all of which were subsequently divided into three categories (I) treatment, (II) office and (III) other activities and implemented into the data acquisition software (Table 2).

Table 2 Illustration of categories with the respective activities performed as well as with an explanation thereof. “Craft activities” in group 1: extraction, pain diagnostics, implantation, placing an injection; and in group 2: archwire-/ elastics-change, removable appliance, fixed appliance, mini implant, filling, prophylaxis, splint.

category	work task	details
treatment	impression	Taking an impression of the patient’s teeth
	photo	Camera documentation of the case
	craft activities	Umbrella term for all work stages that are not included in the aforementioned activities.
	palpation	Palpating patients’ muscles/ jaw joints
	break	Short breaks during treatment
	screening	First/ check-up screening of patients
	contra-angle/ ultrasonic handpiece	Using contra-angle/ ultrasonic handpiece during treatment
office	consult files	Reading patient files (results/ tooth model/ X-ray)
	Office work	Writing entries for patient files/ computer work
	model analysis	Analysis and conception of treatment plans based on teeth models and X-rays
	phone call	Having phone conversations
other activities	meeting	Medical consultation among peers
	talk	Conversations with patients and staff as solitary activity
	hygiene	Hygienic measures (washing /desinfecting hands, wearing gloves/ face masks)
	take/ deposit instrument	Taking up instruments from a drawer / putting instruments down during and after treatment
	laboratory	Any kind of labwork
	walk	Covering distances

Each participant is measured on a randomly selected work day of 8 hours to ensure an authentic recording of their treatment spectrum. Participants wear the CUELA system under clothing to conduct the measurement (sensors are attached on arms, legs, head, and the spine). Parallel to the recording through the CUELA system, two observers log in real time the activities performed with a hand-held computer. However, some activities are summarized in

Table 2 as "craft activities" (I) because the professional groups do not perform the exact same range of activities.

Evaluation

Once the measurement is completed, the time intervals of the activity analysis (hand-held computer) recorded in real time are synchronized with the time axis of the motion analysis (CUELA). A specially developed software (IFA; Sankt Augustin, Germany) is used to create visualizations and descriptive analysis of the retrieved results.

The descriptive analysis of the postures observed in the examined collectives is based on the indication of the arithmetic mean (AM), standard deviation (SD) as well as the percentiles P05, P25, P50, P75 and P95. The percentiles give a descriptive report of the angle values that are below the measuring time of the respective activity performed in a particular joint region. For instance, the P05 value describes the threshold value for joint angles, which 5 % of all measured data fall short of and 95 % exceed. These angle values are subsequently evaluated and assigned to a color-coded angle range (traffic light system: red/ yellow/ green) in compliance with ergonomic standards (24, 28, 29). Based on the respective colors, postures are assessed as unfavorable (awkward), moderate or neutral (30) (Table 1).

Activities of both groups are compared based on the stratified Van Elteren-test and the bilateral Wilcoxon-Mann-Whitney-test along with the Bonferroni-Holm-correction because the data retrieved was not normally distributed under the Kolmogoroff-Smirnoff-test. Following the comparison, only those activities are analyzed whose sensors show angle values that are significantly different and that are relevant with regard to the duration and the (dental or orthodontic) profession itself.

Results

Activity Analysis

On average, data was collected for both groups for a measuring period of approximately 6 h on a day-to-day basis (total measuring period: G1: 116.4 h; G2:131.9 h). The percentage of the measuring period is distributed across the three categories (I-II-III) as follows: G1: 41 - 23 - 36% and G2: 28 - 37 - 35%. A side-by-side comparison of the proportionate activity duration for each category can be found in Figure 2.

Category (I) comprises seven comparable activities of which "craft activities," contra-angle /ultrasound," and "examination / screening" are the activities with the longest duration and these activities with regard to treatment time account for 96% in G1 and 90% in G2. In category (II) "consult files" and "office work" account for the longest time span with 90% in G1 and 87% in G2. "Conversation" (G1: 67%; G2: 63%) along with "walk" (G1: 9%; G2: 14%) represent the largest shares of category (III). As a result, these category (III) activities account for more than ¾ of the total working time. During the aforementioned category III activities dentists and orthodontists take almost identical postures and, therefore, the statistical analysis of the differences between both groups disregards these postures. Instead, the rarely performed activity "laboratory" (G1:7%; G2:7%) in terms of time is analyzed.

Descriptive Posture Analysis

Table 3 shows the benchmarks for the distribution of body and joint angles (Percentile P05, P25, P50, P75 and P95) assumed during the most important activities for orthodontists and dentists.

descriptive body posture (P5-25-50-75-90)		craft activities					screening					contra-angle/ ultrasonic handpiece					office work					consulting files					laboratory				
percentile (in degree °)		5	25	50	75	95	5	25	50	75	95	5	25	50	75	95	5	25	50	75	95	5	25	50	75	95	5	25	50	75	95
TS inclination to the front (TSI_f [°])	D	7	14	19	24	30	7	15	19	23	27	11	20	25	28	31	3	10	14	18	24	5	14	19	23	29	6	12	17	22	30
	O	8	16	21	26	32	8	17	23	28	35	13	22	26	28	32	9	16	20	24	29	8	14	19	23	29	10	18	23	26	31
TS inclination to the right (TSI_r [°])	D	-5	0	3	6	10	-3	3	7	10	15	-3	2	4	6	10	-5	-1	1	4	7	-4	0	2	4	8	-6	-3	-1	2	7
	O	-8	-3	0	4	9	-6	0	4	8	12	-5	-2	1	5	9	-5	-2	0	1	4	-5	-2	0	3	6	-5	-1	1	2	7
Neck curvature to the right (NC_r [°])	D	-14	-5	2	8	17	-15	-6	1	9	17	-13	-2	5	12	19	-13	-7	-3	1	6	-14	-8	-4	-1	5	-17	-11	-6	-2	5
	O	-15	-4	5	14	26	-17	-4	6	16	30	-14	-2	6	14	25	-14	-7	-3	2	9	-10	-4	0	4	10	-11	-3	2	6	13
Neck curvature to the front (NC_f [°])	D	-5	9	17	23	30	-3	11	17	23	29	2	14	20	25	30	-16	-7	0	7	15	-16	-7	-1	5	14	-12	0	7	14	22
	O	-5	13	23	30	37	-8	8	17	24	32	5	21	28	33	39	-22	-12	-4	4	16	-16	-6	2	8	17	-12	6	18	26	34
Head tilted to the front (HT_f [°])	D	8	25	37	45	54	9	27	36	43	51	17	36	45	51	56	-1	8	14	20	29	2	11	17	23	31	3	17	25	32	40
	O	8	31	45	53	62	7	28	40	49	59	21	45	54	59	65	-2	7	15	23	36	1	13	21	27	36	7	25	41	49	58
Head tilted to the right (HT_r [°])	D	-15	-4	4	13	25	-14	-3	8	19	32	-13	0	10	19	29	12	-6	-2	1	8	-12	-6	-2	1	7	-17	-11	-6	-2	6
	O	-19	-6	5	16	32	-19	-2	11	24	42	-16	-3	8	18	31	15	-7	-2	2	9	-10	-4	0	4	11	-12	-3	3	8	15
LS inclination to the front (LSI_f [°])	D	-14	-9	-6	-3	0	-13	-9	-7	-5	-2	-14	-10	-7	-5	-3	-25	-22	-19	-15	-9	-13	-8	-5	-2	2	-12	-9	-6	-3	4
	O	-16	-12	-9	-6	-1	-17	-12	-10	-5	-1	-14	-10	-7	-5	-2	21	-17	-13	-10	-3	-16	-12	-9	-6	-2	-19	-15	-12	-9	-2
LS inclination to the right (LSI_r [°])	D	-7	-5	-3	-1	2	-8	-6	-4	-2	1	-7	-4	-3	-2	1	-7	-5	-3	-2	0	-8	-5	-3	-1	2	-8	-6	-4	-2	2
	O	-9	-6	-4	-2	2	-7	-3	-1	1	5	-7	-5	-4	-2	1	-7	-5	-3	-2	0	-7	-5	-3	-2	1	-7	-3	-2	0	3
Back curvature to the right (BC_r [°])	D	-1	3	6	8	11	3	7	11	14	17	2	2	5	7	12	0	3	5	7	10	-1	3	5	7	11	-1	1	3	6	10
	O	-3	1	4	7	11	-2	2	5	8	11	-1	2	5	8	11	-1	1	3	5	8	-2	2	4	6	9	-3	1	2	4	7
Back curvature to the	D	15	21	25	30	35	16	22	25	29	33	21	28	32	35	38	20	27	33	37	41	13	20	24	27	32	11	18	24	29	34

front (BC_f [°])	O	17	25	29	34	40	20	27	32	36	41	23	29	32	35	39	20	29	33	37	42	18	24	28	32	36	19	29	35	39	43
Back torsion to the right (BT_r [°])	D	-9	-5	-3	0	7	-7	-4	-1	1	7	-6	-4	-3	-1	5	-7	-3	0	3	6	-7	-4	-1	1	6	-6	-2	0	2	5
	O	-7	-3	0	3	8	-6	-2	0	3	7	-9	-6	-4	-2	6	-7	-3	-1	2	8	-6	-3	0	3	7	-5	-1	2	5	10
Inclination of the torso to the front (TI_f [°])	D	-2	3	7	10	14	-3	3	6	9	12	-1	6	9	11	13	-10	-5	-2	1	6	-3	3	7	10	15	-1	3	6	8	14
	O	-3	2	6	9	14	-4	3	7	11	16	0	6	9	11	15	-5	0	4	6	11	-3	1	5	8	13	-3	2	5	8	12
Inclination of the torso to the right (TI_r [°])	D	-5	-1	1	3	7	-4	0	4	6	10	-4	0	2	4	7	-5	-2	0	2	5	-4	-1	1	3	6	-6	-3	-1	1	5
	O	-8	-4	-1	2	7	-6	-1	3	6	10	-5	-2	0	3	6	-5	-2	-1	1	4	-5	-3	-1	0	3	-5	-1	0	2	5

Table 3: Comparative illustration of median posture; Caption: Ergonomic posture = red: awkward; yellow: moderate; green: neutral; D= dentist, O= orthodontist

Regarding the median (P50) for all relevant activities, it is evident that dentists and orthodontists very often work in the same angle range, which is predominantly ranked as neutral or moderate (Table 3). Neutral postures (Table 1) in category are mainly found between P25-P75 values. This is the case for the evaluation parameters for inclination of the thoracic spine to the right (TSI_r), back torsion to the right (BT_r), inclination of the torso to the front (TI_f), inclination of the torso to the right (TI_r) as well as for inclination of the lumbar spine to the right (LSI_r). Moderate posture is found with back curvature to the front (BC_f) and head tilted to the front (HT_f). For both groups inclination of the thoracic spine to the front (TSI_f) is found to be rather in the neutral for lower percentiles and in the moderate range for higher percentiles. Unfavorable postures in P05 and P95 are primarily found in neck curvature to the right (NC_r), head tilted to the right (HT_r) and to the front (NC_f), whereas medial sections are ranked as neutral. In category II for both groups several body and joint angles are predominantly in the neutral range (back curvature to the front (BC_f), inclination of the thoracic spine to the front (TSI_f), inclination of the thoracic spine to the right (TSI_r), head tilted to the front (HT_f), head tilted to the front (HT_r), inclination of the lumbar spine to the right (LSI_r), back torsion to the right (BT_r) and inclination of the torso to the right (TI_r) and several angles are found to be in the moderate range at and above P50 and in the unfavorable range below P50 (neck curvature to the right (NC_r), neck curvature to the front (NC_f), head tilted to the front (HT_r), and inclination of the torso to the front (TI_f)). Back curvature to the front (BC_f) prevails in the moderate range. Data retrieved for "laboratory" (III) almost concurs with data determined for office (II).

Treatment (I)

Compared to orthodontists, dentists use the contra-angle or ultrasonic handpiece more often and for a longer duration ($p \leq 0.001$). Group 1 performs this activity 797 times (total duration approx. 689 min) and group 2 only 138 times (total duration: approx. 204 min). A significant difference between both groups is found for the inclination of the thoracic spine to the front (TSI_f) in P95 ($p \leq 0.05$), neck curvature to the right (NC_r) in SD ($p \leq 0.04$) and in P95 ($p \leq 0.03$), neck curvature to the front (NC_f) in SD ($p \leq 0.05$), head tilted to the right (HT_r) in SD and in P95 ($p \leq 0.02$) as well as for back curvature to the front (BC_f) in SD ($p \leq 0.04$) during the activity "examination / screening."

Significant differences between both groups are found for the activity "examination / screening" regarding the inclination of the thoracic spine to the front (TSI_f) at P95 ($p \leq 0.05$), neck curvature to the right (NC_r) at SD ($p \leq 0.04$) and P95 ($p \leq 0.03$), neck curvature to the front (NC_f) at SD ($p \leq 0.05$), head tilted to the right (HT_r) at SD and P95 ($p \leq 0.02$) as well as back curvature to the front (BC_f) at SD ($p \leq 0.04$) (Table 4). The classification of the measured angle values according to the various class codes is identical for all sensors considered. Nevertheless, angle values are evidently higher in orthodontists than in dentists.

We also observed that both groups always perform “craft activities” in the same angle range (Table 4). The significances are found for the inclination of the thoracic spine to the right (TSI_r) at P05 ($p \leq 0.02$) as well as neck curvature to the right (NC_r) at P05 ($p \leq 0.001$ or $p \leq 0.04$), neck curvature to the front (NC_f) at SD and P95 ($p \leq 0.01$ or $p \leq 0.05$), head tilted to the right (HT_r) at SD ($p \leq 0.02$) and the inclination of the torso to the right (TI_r) at P05 ($p \leq 0.01$).

Office (II)

Among orthodontists the activity “office work” represents a long time period as it accounts for 1901 min and thus 24% of the total working hours, which results in a statistical significance in duration of $p \leq 0.01$. Another significance is found for neck curvature to the front (NC_f) at SD. For this activity, orthodontists showed greater angle values than dentists (G1 < G2).

Other Activities (III)

The activity “laboratory” shows a significant difference of $p \leq 0.02$ in SD for head tilted to the front (HT_f), whereby orthodontists exhibit greater angle values than dentists (G1 < G2).

Activity		Parameter	Sensor	Orthodontis [°]	Dentist [°]	Signifiance
Treatment (I)	craft activities	P05	TS inclination to the right (TSI_r)	-8	-5	0,02
		(MV) SD	Neck curvature to the right (NC_r)	(5) 13	(2) 10	0,04
		(MV) SD	Neck curvature to the front (NC_f)	(13) 20	(15) 11	0,01
		P95		37	30	0,05
		(MV) SD	Head tilted to the right (HT_r)	(5) 16	(4) 13	0,02
		P05	Inclination of the torso to the right (TI_r)	-8	-5	0,01
	screening	P95	TS inclination to the front (TSI_f)	35	27	0,05
		(MV) SD	Neck curvature to the right (NC_r)	(6) 15	(1) 10	0,04
		P95		30	17	0,03
		(MV) SD	Neck curvature to the front (NC_f)	(15) 13	(16) 10	0,05
		(MV) SD	Head tilted to the right (HT_r)	(11) 19	(8) 15	0,02
		P95		42	32	0,02
		(MV) SD	Back curvature to the front (BC_f)	(31) 7	(25) 5	0,04
Office (II)	office work	(MV) SD	Neck curvature to the front (NC_f)	(- 4) ± 12	(0) ± 10	0,02
other activities (III)	laboratory	(MV) SD	Head tilted to the front (HT_f)	(37) ± 16	(24) ± 2	0,02

Table 4: Illustration of statistically relevant activities with respective sensors. Caption: ( ) = included based on affiliation; P = percentile, MV = median value, SD = standard deviation; Ergonomic posture of the percentiles = red: awkward; yellow: moderate; green: neutral

Discussion

The comparative motion analysis of dentists and orthodontists delivers data that gives information about whether a dental or orthodontic activity is performed in an ergonomically favorable body posture or not. The classification of particular activities as “craft activities” (Table 2) and the division of the day-to-day work of both groups into three categories allows for a differentiated analysis of every activity performed and a comparison of both professional groups with regard to distinctions and commonalities.

The temporal division of one working day by percentage indicates that treatment (I) accounts for 41% among dentists and 28% among orthodontists of the day-to-day work. Orthodontists spend more time in the office (37%) or with other activities (35%) by percentage. Therefore, hypothesis 1, which states that the treatment stage accounts for the largest temporal share in the day-to-day work of orthodontists and dentists, is verified for dentists and falsified for orthodontists. Increased office work immediately relates to the necessary computer work in terms of model and X-ray analysis, which is considered essential for orthodontic treatment. Among orthodontists “conversation” is a very frequent activity because the treatment concepts as well as the treatment stages have to be explained and demonstrated to the patient. As a result, the percentage of 35% in category III is comprehensible.

Based on the kinematic analysis with the CUELA system, conclusions regarding the assumed postures can be drawn. The evaluation of the percentiles 05, 25, 50, 75 and 95 are particularly significant for hypothesis 2 as it claims that unfavorable postures occur during the treatment of patients. As a result, the classification of body angle data in category I (treatment) emphasizes that predominantly neutral or moderate postures are assumed. The range for unfavorable body and joint angles is found in the percentiles P05, P75 and P95 for neck curvature to the right and front (NC_r; NC_f), back curvature to the front (BC_f), head tilted to the front (HT_r), and the inclination of the torso to the front (TI_f) (Table 3). The data obtained clearly demonstrates that 50% of the time dentists and orthodontists predominantly treat in the neutral or moderate angle range. However, for both groups the measured angles, which are all found to be in the moderate range, show greater angle values (25° - 65°) in the percentiles P25-P95 for inclination of the head to the front during treatment.

For the other two categories (II+III) similar conclusion is drawn: With the activities "office work," "consult files," and "laboratory" unfavorable postures in the angles of neck curvature to the right and front (NC_r; NC_f), tilted head to the front (HT_f), head tilted to the front (HT_r), inclination of the torso to the front (TI_f), and back curvature to the front (BC_f) are observed. The negative and unfavorable inclination of the head and torso are found to develop on account of a seated position which renders participants to rest their spine comfortably against the back of the chair, a position which is not considered strenuous.

In comparison to "office work," which is performed in the angle range between 7° to 36° (31), treatment activities are increasingly conducted in forced postures, particularly observable for head inclination. In principal, angle values in the area of the head and cervical spine differentiate significantly between treatment and office activities, which points towards an increasing muscular strain during treatment. Thus, participants worked for a greater temporal proportion of their day-to-day work in unfavorable positions, which are also the cause for musculoskeletal disorders. This is particularly evident given that the P05 or P95-values of the respective body or joint angles are clearly in the unfavorable range.

The results confirm the already established correlations of musculoskeletal disorders in the dental profession (6-8, 17, 31, 32). According to Alexopoulos et al. (7) more than every other dentist is affected by back, shoulder, and/or neck problems. The side-by-side comparison between orthodontists and dentists, however, does not show a significant difference regarding the related problematic nature of unfavorable posture.

Consequently, hypothesis 2 is only verified. The tendency for a predominantly unfavorable posture in daily working life is thus applicable to these professional groups with regard to treatment activities. In relation to the other two categories, this tendency corresponds to office activities performed in other professions (31, 33).

Referring to hypothesis 3, the measured postures demonstrate that there are no great disparities regarding the mode of operation among participants in both groups because all participants performed the same activities exclusively in the same angle range (neutral or moderate). Angular deviations are only found for "craft activities" with the inclination of the thoracic spine to the front (TSI_f), "examination / screening" with the inclination of the thoracic spine to the front (TSI_f), head tilted to the front (HT_r), with back curvature to the right (BC_r), and for the activity "contra-angle/ ultrasonic handpiece" with neck curvature to the front (NC_f). Except for back curvature to the right (BC_r), all angle values for "examination / screening" among orthodontists are found in the worse angle range. Their thoracic spine is observed to incline further to the front and therefore demonstrates a frontal neck curvature to a greater extent (unfavorable angle range) (Table 3). Consequently, dentists on average perform activities in more favorable angle ranges than orthodontists. However, neither of the groups solely demonstrates a neutral range of angles during treatment. Considering the p-values it becomes apparent that there are significant differences between both groups, even though the angle difference between the groups is minimal. For instance, this is demonstrated with inclination of TS to the right during the execution of craft activities. The difference in the P05-value only accounts for 3° ("craft activities" inclination of TS to the right (TSI_r)) - G1: -5°; G2: -8°) (Table 4). As a result, the measured angle values are significant but the minimal difference of these angle values is, on the one hand, not clinically relevant and, on the other hand, not crucial for a different angle classification according to ergonomic norms. Consequently, hypothesis 3 is falsified.

Moreover, a comparison of both groups ought to take the average age into account, which is lower by 9 years in orthodontists as compared to dentists. This age difference along with the greater professional experience (G1: 10.55 ± 9.95 years; G2: 3.86 ± 2.48 years) could also have an effect on the postures assumed.

As most orthodontists do divide their work day between working as residents at university medical centers and private practices, we find that they are familiar with private practice routines and, as a result, apply their experience to their day-to-day work at university medical centers. Moreover, it is worthwhile mentioning that these three university medical centers treat a great number of patients on a day-to day basis. In view of these findings, the proposed comparison is valid and essential.

The focus of this kinematic analysis is the posture of participants during a particular activity. Here, the individual variance in motion of each participant is given less consideration. In this context, impact factors such as workplace organization, treatment position, as well as the choice of a patient chair (31, 33) present important components, which can affect individuals in ways that can cause musculoskeletal disorders (34-37).

However, musculoskeletal disorders often develop not only on account of poor posture but also originate in multicausal conditions. Many scientific studies have affirmed that daily stress is a decisive factor (3, 38-40). Consequently, pain problems among dentists and orthodontists cannot be explained based on one factor but requires a multifactorial analysis that is essential.

The study is limited because it does not record the fine motor movements of the fingers and arms. As most dental tasks depend on fine motor movement, this aspect should be considered for future studies. Moreover, the study did not consider the potential malposition of the participants' bodies because the measurement was calibrated anew for each participant after the measuring unit / device was attached. As a result, given malposture is cancelled out because of the procedure used.

Related to the approach to observe participants, another limitation is represented by the well-known Hawthorne effect (41). This effect describes the phenomenon in which participants change their behavior once they learn they are being observed. In this study, however, this effect has little impact on the participants because the measurement duration lasted for at least or more than 5 hours in their familiar work environment. In view of this long measurement period, it is highly unlikely that participants maintain work habits that deviate gravely from their usual routine. In addition, evaluators remained in the background and refrained from being in the participants' visual field. In this way, participants hardly noticed the presence of the evaluators and performed their tasks naturally.

Furthermore, consideration must be given to the fact that many activities such as the preparation of a dental crown by using a contra-angle piece or the cementation of an orthodontic appliance are performed in long-lasting, static positions. These body postures assumed over a long period of time could be the potential cause for the ailments described as work performed in a static position also results in physical strain (11). In this respect, the analysis of static postures during treatment activities is considered a meaningful and desirable addition to future research in the field. In summary, the postures analyzed in this study do not differ greatly between both surveyed groups. The same result was found in a survey about health complaints of dentists (n=147) and orthodontists (n=81) by Kerosuo et al. (17). With around the same frequency, both groups reported with 70% and 72% musculoskeletal disorders, even though a slightly increased prevalence was found among orthodontists. This slightly higher prevalence is also evident in another study by Sankar et al. (16). Following ergonomic standards, dentists as well as orthodontists primarily work in the neutral or moderate range, a conclusion, however, which requires differentiated analysis. Particularly for treatment activities the P05 or P75-P95 values in the red range emphasize the need for action.

These angle values in the red range correlate with apparent and prolonged postures in a forced position (over 4 seconds in a static position) (25). Moreover, aside from the duration of the activity individual motion control has to be considered as it bears the risk of developing muscular dysbalance and disorders.

In conclusion, the study emphasizes the importance of educating orthodontists and dentists about ergonomic treatment or intensive ergonomic training to prevent musculoskeletal disorders in future. Furthermore, the present results should be taken into account for future studies and used to initiate possible modifications to the work environment of dentists.

Footnotes

a. contributorship statement

JN, CE, IH, and DO made substantial contributions to the conception and design of the manuscript. JN, CE, IH, DAG, IH, RE, DD, and DO made substantial contributions to the construction of the measurement protocol and NJ and Do has been involved in the statistical data analysis. All authors have read and approved the final manuscript.

b. competing interests

The authors declare that they have no conflict of interest.

c. funding

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d. data sharing statement

No additional data available.

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Figures and tables

Figure 1: Illustration of the CUELA system.

Figure 2: Comparison of temporal duration of activities performed by both professional groups

Figure 1: Illustration of the CUELA system.
221x271mm (300 x 300 DPI)

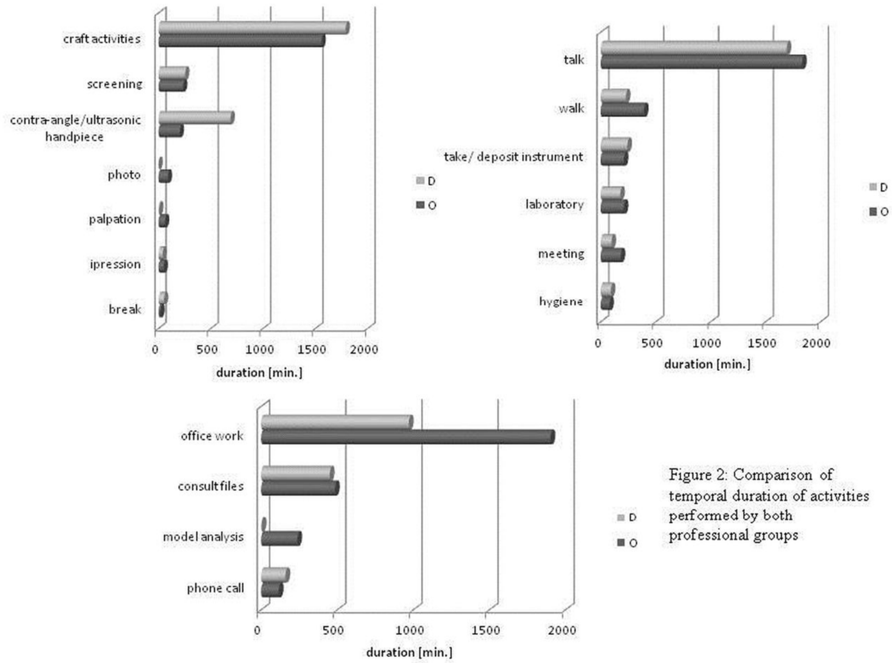

Figure 2: Comparison of temporal duration of activities performed by both professional groups
119x90mm (300 x 300 DPI)

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Motion analysis in the field of dentistry - A kinematic comparison between dentists and orthodontists

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Motion analysis in the field of dentistry -

A kinematic comparison between dentists and orthodontists

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Abstract

Objectives: This study aims to conduct a kinematic comparison of occupational posture in orthodontists and dentists in their workplace.

Design: Observational study.

Setting: Dentist' surgeries and Departments of Orthodontics at university medical centers in Germany.

Participants: A representative sample of 21 (10f/11m) dentists (group G1) and 21 (13f/8m) orthodontists (G2) with one male drop-out in G2.

Outcome measures: The CUELA (computer-assisted acquisition and long-term analysis of musculoskeletal loads) system was used to analyze the occupational posture. Parallel to the recording through the CUELA system, a software-supported analysis of the activities performed (I: treatment; II: office; III: other activities) was carried out. In line with ergonomic standards the measured body angles are categorized into neutral, moderate, and awkward postures. By means of the stratified van Elteren-U-test and the Wilcoxon-Mann-Whitney-U-Test the activities are compared between the aforementioned groups. All p-values are subject to the Bonferroni-Holm correction. The level of significance is at 5%.

Results: In terms of time the categories (I-II-III) are divided as follows: dentists 41-23-36% and orthodontists 28-37-35%. The posture analysis of both groups shows for all percentiles (P5-95) angle values primarily in the neutral or in the moderate range. However, depending on the activity performed between 5 and 25% of the working hours unfavorable postures were observed, especially in the head-and-neck area. Orthodontists have a greater tendency to perform treatment activities with the head and torso in unfavorable positions than dentists. The significant differences between the statistical comparison of both groups with regard to the duration and the relevance of the activities performed affirm this assumption for all three categories ($p < 0.01$-0.05).

Conclusions: Generally, both groups perform treatment activities in postures that are in the neutral or medium range; however, dentists were observed to take slightly more unfavorable postures during treatment for a greater share of their work day.

Strengths and limitations of this study

This study is a kinematic comparison of occupational posture in orthodontists and dentists in their respective work environments with a particular focus on job-specific activities ((I) treatment, (II) office and (III) other activities) for the duration of one working day .

This study combines two measurement methods: on the one hand participants wear the kinematic CUELA system under clothing and, on the other hand, two observers log in real time the activities performed with a hand-held computer.

One limitation of the CUELA system is that it does not record fine motor movements in the area of the hands and arms.

In addition, this posture analysis does not differentiate between static or dynamic execution of the working tasks.

The results highlight the already established association of musculoskeletal disorders with the dental profession: dentists were observed to be slightly more likely to take unfavorable postures during treatment for a greater share of their work day.

Introduction

The dental profession encompasses a great number of health risks such as contact allergies, the risk of infection, eye injuries, neuropathy (1-5) as well as musculoskeletal disorders in the neck, shoulder and/ or back area (6-11). A questionnaire-based survey of 430 Greek dentists by Alexopoulus et al. (7) affirms the high incidence of musculoskeletal disorders (62%). In Poland 92% and in Germany 86.7% of surveyed dentists reported neck or back pain. 68.6% of the same group of respondents even reported to suffer from disorders on a weekly basis (8, 12). A study by Gopinadh et al. (13) demonstrates that 73.9% of the 170 surveyed dentists in India encounter musculoskeletal pain, especially in the neck and back area, which also shows a correlation between the increasing incidence of these symptoms with the length of the hours worked and the progressing age of the practitioner. More than half of the respondents reported to take inadequate body postures during treatment.

Furthermore, the frequency and the extent of this issue is found to result in the early retirement of dentists. With 29.5% to 55% these disorders present one of the most common medical causes for illness-related retirement among dentists (4, 14, 15).

A survey on musculoskeletal pain in Indian orthodontists distinguished between those that practioned exclusively as orthodontists and those who continued to work as dentists. In this regard, a prevalence of back pain was observed solely for respondents that worked in the field of orthodontics (16). Kerosuo et al. (17) also reach the conclusion that orthodontists more often have complaints of pain than dentists.

As a result, the questions of ways to integrate optimal and ergonomic posture in the work routine of dentists and orthodontists are more and more becoming a subject of public interest. To date, there is no data on postures taken in everyday work situations among dentists as well as orthodontists. Also, there is no side-by-side comparison of occupational posture in orthodontists and dentists that detects a possible prevalence of unfavorable patterns of posture that can result in musculoskeletal disorders for either of the professional groups.

Thus, by means of ergonomic and kinematic analysis this study aims to investigate patterns of postures that are involved in the daily routines of orthodontists and dentists and their possible impact on the pervasive development of symptoms of pain. For this purpose, the study investigates the motions and postures of the participating physicians in relation to the professional tasks, divided into the three categories (I) treatment, (II) office and (III) other activities, performed in their daily routine. In this context, the following hypotheses are being investigated:

1. The treatment stage accounts for the largest temporal share in the day-to-day work of orthodontists and dentists.
2. For both groups unfavorable postures were observed more often during treatment than during office or other activities.
3. In contrast to dentists, orthodontists more often perform treatment activities with the torso in a neutral position.

Methods

Study Participants

Overall, this study measured 42 participants (23f/19m). The participants are divided into two groups and compared with each other based on their respective professional training. Group 1 (G1) consists of 21 dentists (10f/11m) working in established practices in Germany that are on average 40.14 ± 10.35 years old and have had work experience in the field for 10.55 ± 9.95 years. Group 2 (G2) comprises 21 orthodontic residents (13 f/ 8 m) of an average age of 31.48

± 3.82 years that are currently in training at three university medical centers in Germany. One drop-out of a male participant was recorded for group 2 due to incorrect measurement. Work experience for this group accounted for a statistical mean value of 3.86 ± 2.48 years.

Inclusion criteria were working as a dentist in a private dental clinic or as orthodontic resident working at university medical centers in Germany. Subjects were asked to participate by an official letter to the practice owner or to the senior physician or head of department heralding about the planned investigation. The letter contained the most basic information. Following their agreement to participate the physicians were informed in person about the goals and the approach of the study.

All study participants stated that they show no signs of functional impairment or ailments related to the musculoskeletal system. Injuries of the musculoskeletal system ought to have occurred more than two years prior to the study. This study was approved by the Ethics Committee (135/14) of the Goethe University in Frankfurt am Main. Prior to the study, all participants signed an informed consent to take part in the study. The authors obtained informed consent from the participant in figure 1 for publication.

The comparison of postures is expected to show a greater difference between dentists and orthodontists. According to Cohen an effect size with a standard deviation of 0,8-1 is considered a significant difference. The power of this study was set at 80% to calculate with approximately 20 study participants.

CUELA Measuring System

The CUELA-System (Fig. 1) (computer-assisted acquisition and long-term analysis of musculoskeletal loads), developed at the Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA; Sankt Augustin / Germany), is used to record and analyze body postures (18, 19).

Fig. 1

This personal system uses sensors (accelerometers [ADXL 103/203] and gyroscopes [muRata ENC-03R] for head, arms, legs, back, as well as potentiometers [Contelect] for back torsions) to measure the position and movements of the participants on a continuous time interval.

A sampling frequency of 50 Hz and an angular resolution of approximately 1° allows for an objective evaluation of the body postures and motions observed in the participants (20-23). Table 1 summarizes all parameters of this study that were measured and calculated with the CUELA system.

Table 1 Illustration of body and joint angles measured with the CUELA system, evaluation parameters used, and assessment criteria in line with ergonomic norms.

Body areas	Joint/ Body area	Degree of freedom according to medical definitions	Evaluation parameter	Angle range according to ergonomic standards
Head/neck	Head	sagittal inclination	Head tilted to the front (HT_f) (24, 25)	Neutral: 0 to 25° Moderate: 25 to 85° Awkward: < 0° & > 85°
		lateral inclination	Head tilted to the right (HT_r) (25)	Neutral: -10 to 10° Awkward: < -10° & >10°
	Cervical spine (CS)	flexion/ extension	Neck curvature to the front (NC_f) *[Difference betw. Head and TS]* (24, 25)	Neutral: 0 to 25° Awkward: < 0° & > 25°
		lateral flexion	Neck curvature to the right (NC_r) *[Difference betw. Head and TS]* (24, 25)	Neutral: -10 to 10° Awkward: < -10° & >10°
Back	Thoracic spine (TS)	flexion/ extension	TS inclination to the front (TSI_f) (24, 25)	Neutral: 0 to 20° Moderate: 20 to 60° Awkward: < 0° & > 60°
		lateral flexion	TS inclination to the right (TSI_r) (24, 25)	Neutral: -10 to 10° Moderate: -10 to -20° Moderate: 10 to 20° Awkward: < -20° & > 20
	Lumbar spine (LS)	flexion/ extension	LS inclination to the front (LSI_f)	No ergonomic layout available
		lateral flexion	LS inclination to the right (LSI_r)	
	Trunk (T)	flexion/ extension	Back curvature to the front (BC_f) *[Difference betw. TS and LS]* (24, 25)	Neutral: 0 to 20° Moderate: 20 to 40° Awkward: < 0° & > 40°
			Inclination of the torso to the front (TI_f) *[median flexion of TS and LS]* (24, 25)	Neutral: 0 to 20° Moderate: 20 to 60° Awkward: < 0°& > 60°
		lateral flexion	Back curvature to the right (BC_r) *[Difference betw. TS and LS] (24, 25)*	Neutral: -10 to 10° Moderate: -10 to -20° Moderate: 10 to 20° Awkward: < -20° & > 20°
			Inclination of the torso to the right (TI_r) *[median lateral flexion of TS and LS]* (24, 25)	
		torsion	Back torsion to the right (BT_r) *[Difference betw. TS and LS](25)*	

Measuring System: Software-Based Activity Analysis

Participants are being observed in their day-to-day work to analyze the activities performed and the respective motions involved. A hand-held computer (UMPC Samsung Q1, Samsung Electronics GmbH. Schwalbach, Germany), which relies on data acquisition software (26, 27) specifically designed for this study, records the activities performed in real time by the second. This software was coded specifically for each group and their respective treatment spectrum (activity categories). The beginning and the end of each orthodontic or dental activity as well as its duration were recorded. A detailed description of the system has already been published (26, 27).

Experimental Procedure

For a description and summary of the daily activities performed, both groups were observed in their routine for one working day prior to the study. In this way, 22 activities were detected for G1 and 25 for G2, all of which were subsequently divided into three categories (I) treatment, (II) office and (III) other activities and implemented into the data acquisition software (Table 2).

Table 2 Illustration of categories with the respective activities performed as well as with an explanation thereof. “Craft activities” in group 1: extraction, pain diagnostics, implantation, placing an injection; and in group 2: archwire-/ elastics-change, removable appliance, fixed appliance, mini implant, filling, prophylaxis, splint.

category	work task	details
treatment	impression	Taking an impression of the patient’s teeth
	photo	Camera documentation of the case
	craft activities	Umbrella term for all work stages that are not included in the aforementioned activities.
	palpation	Palpating patients’ muscles/ jaw joints
	break	Short breaks during treatment
	screening	First/ check-up screening of patients
	contra-angle/ ultrasonic handpiece	Using contra-angle/ ultrasonic handpiece during treatment
office	consult files	Reading patient files (results/ tooth model/ X-ray)
	Office work	Writing entries for patient files/ computer work
	model analysis	Analysis and conception of treatment plans based on teeth models and X-rays
	phone call	Having phone conversations
other activities	meeting	Medical consultation among peers
	talk	Conversations with patients and staff as solitary activity
	hygiene	Hygienic measures (washing /desinfecting hands, wearing gloves/ face masks)
	take/ deposit instrument	Taking up instruments from a drawer / putting instruments down during and after treatment
	laboratory	Any kind of labwork
	walk	Covering distances

Each participant is measured on a randomly selected work day of 8 hours to ensure an authentic recording of their treatment spectrum. Participants wear the CUELA system under clothing to conduct the measurement (sensors are attached on arms, legs, head, and the spine). Parallel to the recording through the CUELA system, two observers log in real time the activities performed with a hand-held computer. However, some activities are summarized in Table 2 as “craft activities” (I) because the professional groups do not perform the exact same range of activities.

Evaluation

Once the measurement is completed, the time intervals of the activity analysis (hand-held computer) recorded in real time are synchronized with the time axis of the motion analysis (CUELA). A specially developed software (IFA; Sankt Augustin, Germany) is used to create visualizations and descriptive analysis of the retrieved results.

The descriptive analysis of the postures observed in the examined collectives is based on the indication of the arithmetic mean (AM), standard deviation (SD) as well as the percentiles P05, P25, P50, P75 and P95. The percentiles give a descriptive report of the angle values that are below the measuring time of the respective activity performed in a particular joint region. For instance, the P05 value describes the threshold value for joint angles, which 5 % of all measured data fall short of and 95 % exceed. These angle values are subsequently evaluated and assigned to a color-coded angle range (traffic light system: red/ yellow/ green) in compliance with ergonomic standards (24, 28, 29). Based on the respective colors, postures are assessed as unfavorable (awkward), moderate or neutral (30) (Table 1).

Activities of both groups are compared based on the stratified Van Elteren-test and the bilateral Wilcoxon-Mann-Whitney-test along with the Bonferroni-Holm-correction because the data retrieved was not normally distributed under the Kolmogoroff-Smirnoff-test. Following the comparison, only those activities are analyzed whose sensors show angle values that are significantly different and that are relevant with regard to the duration and the (dental or orthodontic) profession itself.

Results

Activity Analysis

On average, data was collected for both groups for a measuring period of approximately 6 h on a day-to-day basis (total measuring period: G1: 116.4 h; G2:131.9 h). The percentage of the measuring period is distributed across the three categories (I-II-III) as follows: G1: 41 - 23 - 36% and G2: 28 - 37 - 35%. A side-by-side comparison of the proportionate activity duration for each category can be found in Figure 2.

Category (I) comprises seven comparable activities of which “craft activities,” contra-angle /ultrasound,” and “examination / screening” are the activities with the longest duration and these activities with regard to treatment time account for 96% in G1 and 90% in G2. In category (II) “consult files” and “office work” account for the longest time span with 90% in G1 and 87% in G2. “Conversation” (G1: 67%; G2: 63%) along with “walk” (G1: 9%; G2:

14%) represent the largest shares of category (III). As a result, these category (III) activities account for more than ¾ of the total working time. During the aforementioned category III activities dentists and orthodontists take almost identical postures and, therefore, the statistical analysis of the differences between both groups disregards these postures. Instead, the rarely performed activity "laboratory" (G1:7%; G2:7%) in terms of time is analyzed.

Descriptive Posture Analysis

Table 3 shows the benchmarks for the distribution of body and joint angles (Percentile P05, P25, P50, P75 and P95) assumed during the most important activities for orthodontists and dentists.

descriptive body posture (P5-25-50-75-90)		craft activities					screening					contra-angle/ ultrasonic handpiece					office work					consulting files					laboratory				
percentile (in degree °)		5	25	50	75	95	5	25	50	75	95	5	25	50	75	95	5	25	50	75	95	5	25	50	75	95	5	25	50	75	95
TS inclination to the front (TSI_f [°])	D	7	14	19	24	30	7	15	19	23	27	11	20	25	28	31	3	10	14	18	24	5	14	19	23	29	6	12	17	22	30
	O	8	16	21	26	32	8	17	23	28	35	13	22	26	28	32	9	16	20	24	29	8	14	19	23	29	10	18	23	26	31
TS inclination to the right (TSI_r [°])	D	-5	0	3	6	10	-3	3	7	10	15	-3	2	4	6	10	-5	-1	1	4	7	-4	0	2	4	8	-6	-3	-1	2	7
	O	-8	-3	0	4	9	-6	0	4	8	12	-5	-2	1	5	9	-5	-2	0	1	4	-5	-2	0	3	6	-5	-1	1	2	7
Neck curvature to the right (NC_r [°])	D	-14	-5	2	8	17	-15	-6	1	9	17	-13	-2	5	12	19	-13	-7	-3	1	6	-14	-8	-4	-1	5	-17	-11	-6	-2	5
	O	-15	-4	5	14	26	-17	-4	6	16	30	-14	-2	6	14	25	-14	-7	-3	2	9	-10	-4	0	4	10	-11	-3	2	6	13
Neck curvature to the front (NC_f [°])	D	-5	9	17	23	30	-3	11	17	23	29	2	14	20	25	30	-16	-7	0	7	15	-16	-7	-1	5	14	-12	0	7	14	22
	O	-5	13	23	30	37	-8	8	17	24	32	5	21	28	33	39	-22	-12	-4	4	16	-16	-6	2	8	17	-12	6	18	26	34
Head tilted to the front (HT_f [°])	D	8	25	37	45	54	9	27	36	43	51	17	36	45	51	56	-1	8	14	20	29	2	11	17	23	31	3	17	25	32	40
	O	8	31	45	53	62	7	28	40	49	59	21	45	54	59	65	-2	7	15	23	36	1	13	21	27	36	7	25	41	49	58
Head tilted to the right (HT_r [°])	D	-15	-4	4	13	25	-14	-3	8	19	32	-13	0	10	19	29	12	-6	-2	1	8	-12	-6	-2	1	7	-17	-11	-6	-2	6
	O	-19	-6	5	16	32	-19	-2	11	24	42	-16	-3	8	18	31	15	-7	-2	2	9	-10	-4	0	4	11	-12	-3	3	8	15
LS inclination to the front (LSI_f [°])	D	-14	-9	-6	-3	0	-13	-9	-7	-5	-2	-14	-10	-7	-5	-3	-25	-22	-19	-15	-9	-13	-8	-5	-2	2	-12	-9	-6	-3	4
	O	-16	-12	-9	-6	-1	-17	-12	-10	-5	-1	-14	-10	-7	-5	-2	21	-17	-13	-10	-3	-16	-12	-9	-6	-2	-19	-15	-12	-9	-2
LS inclination to the right (LSI_r [°])	D	-7	-5	-3	-1	2	-8	-6	-4	-2	1	-7	-4	-3	-2	1	-7	-5	-3	-2	0	-8	-5	-3	-1	2	-8	-6	-4	-2	2
	O	-9	-6	-4	-2	2	-7	-3	-1	1	5	-7	-5	-4	-2	1	-7	-5	-3	-2	0	-7	-5	-3	-2	1	-7	-3	-2	0	3
Back curvature to the right (BC_r [°])	D	-1	3	6	8	11	3	7	11	14	17	2	2	5	7	12	0	3	5	7	10	-1	3	5	7	11	-1	1	3	6	10
	O	-3	1	4	7	11	-2	2	5	8	11	-1	2	5	8	11	-1	1	3	5	8	-2	2	4	6	9	-3	1	2	4	7
Back curvature to the	D	15	21	25	30	35	16	22	25	29	33	21	28	32	35	38	20	27	33	37	41	13	20	24	27	32	11	18	24	29	34

front (BC_f [°])	O	17	25	29	34	40	20	27	32	36	41	23	29	32	35	39
Back torsion to the right (BT_r [°])	D	-9	-5	-3	0	7	-7	-4	-1	1	7	-6	-4	-3	-1	5
	O	-7	-3	0	3	8	-6	-2	0	3	7	-9	-6	-4	-2	6
Inclination of the torso to the front (TI_f [°])	D	-2	3	7	10	14	-3	3	6	9	12	-1	6	9	11	13
	O	-3	2	6	9	14	-4	3	7	11	16	0	6	9	11	15
Inclination of the torso to the right (TI_r [°])	D	-5	-1	1	3	7	-4	0	4	6	10	-4	0	2	4	7
	O	-8	-4	-1	2	7	-6	-1	3	6	10	-5	-2	0	3	6

front (BC_f [°])	O	20	29	33	37	42	18	24	28	32	36	19	29	35	39	43
Back torsion to the right (BT_r [°])	D	-7	-3	0	3	6	-7	-4	-1	1	6	-6	-2	0	2	5
	O	-7	-3	-1	2	8	-6	-3	0	3	7	-5	-1	2	5	10
Inclination of the torso to the front (TI_f [°])	D	-10	-5	-2	1	6	-3	3	7	10	15	-1	3	6	8	14
	O	-5	0	4	6	11	-3	1	5	8	13	-3	2	5	8	12
Inclination of the torso to the right (TI_r [°])	D	-5	-2	0	2	5	-4	-1	1	3	6	-6	-3	-1	1	5
	O	-5	-2	-1	1	4	-5	-3	-1	0	3	-5	-1	0	2	5

Table 3: Comparative illustration of median posture; Caption: Ergonomic posture = red: awkward; yellow: moderate; green: neutral; D= dentist, O= orthodontist

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Regarding the median (P50) for all relevant activities, it is evident that dentists and orthodontists very often work in the same angle range, which is predominantly ranked as neutral or moderate (Table 3). Neutral postures (Table 1) in category are mainly found between P25-P75 values. This is the case for the evaluation parameters for inclination of the thoracic spine to the right (TSI_r), back torsion to the right (BT_r), inclination of the torso to the front (TI_f), inclination of the torso to the right (TI_r) as well as for inclination of the lumbar spine to the right (LSI_r). Moderate posture is found with back curvature to the front (BC_f) and head tilted to the front (HT_f). For both groups inclination of the thoracic spine to the front (TSI_f) is found to be rather in the neutral for lower percentiles and in the moderate range for higher percentiles. Unfavorable postures in P05 and P95 are primarily found in neck curvature to the right (NC_r), head tilted to the right (HT_r) and to the front (NC_f), whereas medial sections are ranked as neutral. In category II for both groups several body and joint angles are predominantly in the neutral range (back curvature to the front (BC_f), inclination of the thoracic spine to the front (TSI_f), inclination of the thoracic spine to the right (TSI_r), head tilted to the front (HT_f), head tilted to the front (HT_r), inclination of the lumbar spine to the right (LSI_r), back torsion to the right (BT_r) and inclination of the torso to the right (TI_r) and several angles are found to be in the moderate range at and above P50 and in the unfavorable range below P50 (neck curvature to the right (NC_r), neck curvature to the front (NC_f), head tilted to the front (HT_r), and inclination of the torso to the front (TI_f)). Back curvature to the front (BC_f) prevails in the moderate range. Data retrieved for “laboratory” (III) almost concurs with data determined for office (II).

Treatment (I)

Compared to orthodontists, dentists use the contra-angle or ultrasonic handpiece more often and for a longer duration ($p<0.001$). Group 1 performs this activity 797 times (total duration approx. 689 min) and group 2 only 138 times (total duration: approx. 204 min). A significant difference between both groups is found for the inclination of the thoracic spine to the front (TSI_f) in P95 ($p<0.05$), neck curvature to the right (NC_r) in SD ($p<0.04$) and in P95 ($p<0.03$), neck curvature to the front (NC_f) in SD ($p<0.05$), head tilted to the right (HT_r) in SD and in P95 ($p<0.02$) as well as for back curvature to the front (BC_f) in SD ($p<0.04$) during the activity “examination / screening.”

Significant differences between both groups are found for the activity “examination / screening” regarding the inclination of the thoracic spine to the front (TSI_f) at P95 ($p<0.05$), neck curvature to the right (NC_r) at SD ($p<0.04$) and P95 ($p<0.03$), neck curvature to the front (NC_f) at SD ($p<0.05$), head tilted to the right (HT_r) at SD and P95 ($p<0.02$) as well as back curvature to the front (BC_f) at SD ($p<0.04$) (Table 4). The classification of the measured angle values according to the various class codes is identical for all sensors considered. Nevertheless, angle values are evidently higher in orthodontists than in dentists.

We also observed that both groups always perform “craft activities” in the same angle range (Table 4). The significances are found for the inclination of the thoracic spine to the right (TSI_r) at P05 ($p<0.02$) as well as neck curvature to the right (NC_r) at P05 ($p<0.001$ or $p<0.04$), neck curvature to the front (NC_f) at SD and P95 ($p<0.01$ or $p<0.05$), head tilted to the right (HT_r) at SD ($p<0.02$) and the inclination of the torso to the right (TI_r) at P05 ($p<0.01$).

Office (II)

Among orthodontists the activity “office work” represents a long time period as it accounts for 1901 min and thus 24% of the total working hours, which results in a statistical significance in duration of $p<0.01$. Another significance is found for neck curvature to the front (NC_f) at SD. For this activity, orthodontists showed greater angle values than dentists (G1 < G2).

Other Activities (III)

The activity “laboratory” shows a significant difference of $p<0.02$ in SD for head tilted to the front (HT_f), whereby orthodontists exhibit greater angle values than dentists (G1 < G2).

Activity		Parameter	Sensor	Orthodontis [°]	Dentist [°]	Signifiance
Treatment (I)	craft activities	P05	TS inclination to the right (TSI_r)	-8	-5	0,02
		(MV) SD	Neck curvature to the right (NC_r)	(5) 13	(2) 10	0,04
		(MV) SD	Neck curvature to the front (NC_f)	(13) 20	(15) 11	0,01
		P95		37	30	0,05
		(MV) SD	Head tilted to the right (HT_r)	(5) 16	(4) 13	0,02
		P05	Inclination of the torso to the right (TI_r)	-8	-5	0,01
	screening	P95	TS inclination to the front (TSI_f)	35	27	0,05
		(MV) SD	Neck curvature to the right (NC_r)	(6) 15	(1) 10	0,04
		P95		30	17	0,03
		(MV) SD	Neck curvature to the front (NC_f)	(15) 13	(16) 10	0,05
		(MV) SD	Head tilted to the right (HT_r)	(11) 19	(8) 15	0,02
		P95		42	32	0,02
		(MV) SD	Back curvature to the front (BC_f)	(31) 7	(25) 5	0,04
Office (II)	office work	(MV) SD	Neck curvature to the front (NC_f)	(- 4) ± 12	(0) ± 10	0,02
other activities (III)	laboratory	(MV) SD	Head tilted to the front (HT_f)	(37) ± 16	(24) ± 2	0,02

Table 4: Illustration of statistically relevant activities with respective sensors. Caption: ( ) = included based on affiliation; P = percentile, MV = median value, SD = standard deviation; Ergonomic posture of the percentiles = red: awkward; yellow: moderate; green: neutral

Discussion

The comparative motion analysis of dentists and orthodontists delivers data that gives information about whether a dental or orthodontic activity is performed in an ergonomically favorable body posture or not. The classification of particular activities as “craft activities” (Table 2) and the division of the day-to-day work of both groups into three categories allows for a differentiated analysis of every activity performed and a comparison of both professional groups with regard to distinctions and commonalities.

The temporal division of one working day by percentage indicates that treatment (I) accounts for 41% among dentists and 28% among orthodontists of the day-to-day work. Orthodontists spend more time in the office (37%) or with other activities (35%) by percentage. Therefore, hypothesis 1, which states that the treatment stage accounts for the largest temporal share in the day-to-day work of orthodontists and dentists, is verified for dentists and falsified for orthodontists. Increased office work immediately relates to the necessary computer work in terms of model and X-ray analysis, which is considered essential for orthodontic treatment. Among orthodontists “conversation” is a very frequent activity because the treatment concepts as well as the treatment stages have to be explained and demonstrated to the patient. As a result, the percentage of 35% in category III is comprehensible.

Based on the kinematic analysis with the CUELA system, conclusions regarding the assumed postures can be drawn. The evaluation of the percentiles 05, 25, 50, 75 and 95 are particularly significant for hypothesis 2 as it claims that unfavorable postures occur during the treatment of patients. As a result, the classification of body angle data in category I (treatment) emphasizes that predominantly neutral or moderate postures are assumed. The range for unfavorable body and joint angles is found in the percentiles P05, P75 and P95 for neck curvature to the right and front (NC_r; NC_f), back curvature to the front (BC_f), head tilted to the front (HT_r), and the inclination of the torso to the front (TI_f) (Table 3). The data obtained clearly demonstrates that 50% of the time dentists and orthodontists predominantly treat in the neutral or moderate angle range. However, for both groups the measured angles, which are all found to be in the moderate range, show greater angle values (25° - 65°) in the percentiles P25-P95 for inclination of the head to the front during treatment.

For the other two categories (II+III) similar conclusion is drawn: With the activities “office work,” “consult files,” and “laboratory” unfavorable postures in the angles of neck curvature to the right and front (NC_r; NC_f), tilted head to the front (HT_f), head tilted to the front (HT_r), inclination of the torso to the front (TI_f), and back curvature to the front (BC_f) are observed. The negative and unfavorable inclination of the head and torso are found to develop on account of a seated position which renders participants to rest their spine comfortably against the back of the chair, a position which is not considered strenuous.

In comparison to “office work,” which is performed in the angle range between 7° to 36° (31), treatment activities are increasingly conducted in forced postures, particularly observable for head inclination. In principal, angle values in the area of the head and cervical spine differentiate significantly between treatment and office activities, which points towards an increasing muscular strain during treatment. Thus, participants worked for a greater temporal proportion of their day-to-day work in unfavorable positions, which are also the cause for musculoskeletal disorders. This is particularly evident given that the P05 or P95-values of the respective body or joint angles are clearly in the unfavorable range.

The results confirm the already established correlations of musculoskeletal disorders in the dental profession (6-8, 17, 31, 32). According to Alexopoulos et al. (7) more than every other dentist is affected by back, shoulder, and/or neck problems. The side-by-side comparison between orthodontists and dentists, however, does not show a significant difference regarding the related problematic nature of unfavorable posture.

Consequently, hypothesis 2 is verified. The tendency for a predominantly unfavorable posture in daily working life is thus applicable to these professional groups with regard to treatment activities. In relation to the other two categories, this tendency corresponds to office activities performed in other professions (31, 33).

Referring to hypothesis 3, the measured postures demonstrate that there are no great disparities regarding the mode of operation among participants in both groups because all participants performed the same activities exclusively in the same angle range (neutral or moderate). Angular deviations are only found for "craft activities" with the inclination of the thoracic spine to the front (TSI_f), "examination / screening" with the inclination of the thoracic spine to the front (TSI_f), head tilted to the front (HT_r), with back curvature to the right (BC_r), and for the activity "contra-angle/ ultrasonic handpiece" with neck curvature to the front (NC_f). Except for back curvature to the right (BC_r), all angle values for "examination / screening" among orthodontists are found in the worse angle range. Their thoracic spine is observed to incline further to the front and therefore demonstrates a frontal neck curvature to a greater extent (unfavorable angle range) (Table 3). Consequently, dentists on average perform activities in more favorable angle ranges than orthodontists. However, neither of the groups solely demonstrates a neutral range of angles during treatment. Considering the p-values it becomes apparent that there are significant differences between both groups, even though the angle difference between the groups is minimal. For instance, this is demonstrated with inclination of TS to the right during the execution of craft activities. The difference in the P05-value only accounts for 3° ("craft activities" inclination of TS to the right (TSI_r)) - G1: -5°; G2: -8°) (Table 4). As a result, the measured angle values are significant but the minimal difference of these angle values is, on the one hand, not clinically relevant and, on the other hand, not crucial for a different angle classification according to ergonomic norms. Consequently, hypothesis 3 is falsified.

Moreover, a comparison of both groups ought to take the average age into account, which is lower by 9 years in orthodontists as compared to dentists. This age difference along with the greater professional experience (G1: 10.55 ± 9.95 years; G2: 3.86 ± 2.48 years) could also have an effect on the postures assumed.

As most orthodontists do divide their work day between working as residents at university medical centers and private practices, we find that they are familiar with private practice routines and, as a result, apply their experience to their day-to-day work at university medical centers. Moreover, it is worthwhile mentioning that these three university medical centers treat a great number of patients on a day-to day basis. In view of these findings, the proposed comparison is valid and essential.

The focus of this kinematic analysis is the posture of participants during a particular activity. Here, the individual variance in motion of each participant is given less consideration. In this context, impact factors such as workplace organization, treatment position, as well as the choice of a patient chair (31, 33) present important components, which can affect individuals in ways that can cause musculoskeletal disorders (34-37).

However, musculoskeletal disorders often develop not only on account of poor posture but also originate in multicausal conditions. Many scientific studies have affirmed that daily stress is a decisive factor (3, 38-40). Consequently, pain problems among dentists and orthodontists cannot be explained based on one factor but requires a multifactorial analysis that is essential.

The study is limited because it does not record the fine motor movements of the fingers and arms. As most dental tasks depend on fine motor movement, this aspect should be considered for future studies. Moreover, the study did not consider the potential malposition of the participants' bodies because the measurement was calibrated anew for each participant after the measuring unit / device was attached. As a result, given malposture is cancelled out because of the procedure used.

Related to the approach to observe participants, another limitation is represented by the well-known Hawthorne effect (41). This effect describes the phenomenon in which participants change their behavior once they learn they are being observed. In this study, however, this effect has little impact on the participants because the measurement duration lasted for at least or more than 5 hours in their familiar work environment. In view of this long measurement period, it is highly unlikely that participants maintain work habits that deviate gravely from their usual routine. In addition, evaluators remained in the background and refrained from being in the participants' visual field. In this way, participants hardly noticed the presence of the evaluators and performed their tasks naturally.

Furthermore, consideration must be given to the fact that many activities such as the preparation of a dental crown by using a contra-angle piece or the cementation of an orthodontic appliance are performed in long-lasting, static positions. These body postures assumed over a long period of time could be the potential cause for the ailments described as work performed in a static position also results in physical strain (11). In this respect, the analysis of static postures during treatment activities is considered a meaningful and desirable addition to future research in the field. In summary, the postures analyzed in this study do not differ greatly between both surveyed groups. The same result was found in a survey about health complaints of dentists (n=147) and orthodontists (n=81) by Kerosuo et al. (17). With around the same frequency, both groups reported with 70% and 72% musculoskeletal disorders, even though a slightly increased prevalence was found among orthodontists. This slightly higher prevalence is also evident in another study by Sankar et al. (16). Following ergonomic standards, dentists as well as orthodontists primarily work in the neutral or moderate range, a conclusion, however, which requires differentiated analysis. Particularly for treatment activities the P05 or P75-P95 values in the red range emphasize the need for action.

These angle values in the red range correlate with apparent and prolonged postures in a forced position (over 4 seconds in a static position) (25). Moreover, aside from the duration of the activity individual motion control has to be considered as it bears the risk of developing muscular dysbalance and disorders.

In conclusion, the study emphasizes the importance of educating orthodontists and dentists about ergonomic treatment or intensive ergonomic training to prevent musculoskeletal disorders in future. Furthermore, the present results should be taken into account for future studies and used to initiate possible modifications to the work environment of dentists.

Footnotes

a. contributorship statement

JN, CE, IH, and DO made substantial contributions to the conception and design of the manuscript. JN, CE, IH, DAG, IH, RE, DD, and DO made substantial contributions to the construction of the measurement protocol and NJ and Do has been involved in the statistical data analysis. All authors have read and approved the final manuscript.

b. competing interests

The authors declare that they have no conflict of interest.

c. funding

There is no funding of the project.

d. data sharing statement

No additional data available.

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Figures and tables

Figure 1: Illustration of the CUELA system.

Figure 2: Comparison of temporal duration of activities performed by both professional groups

Figure 1: Illustration of the CUELA system.
221x271mm (300 x 300 DPI)

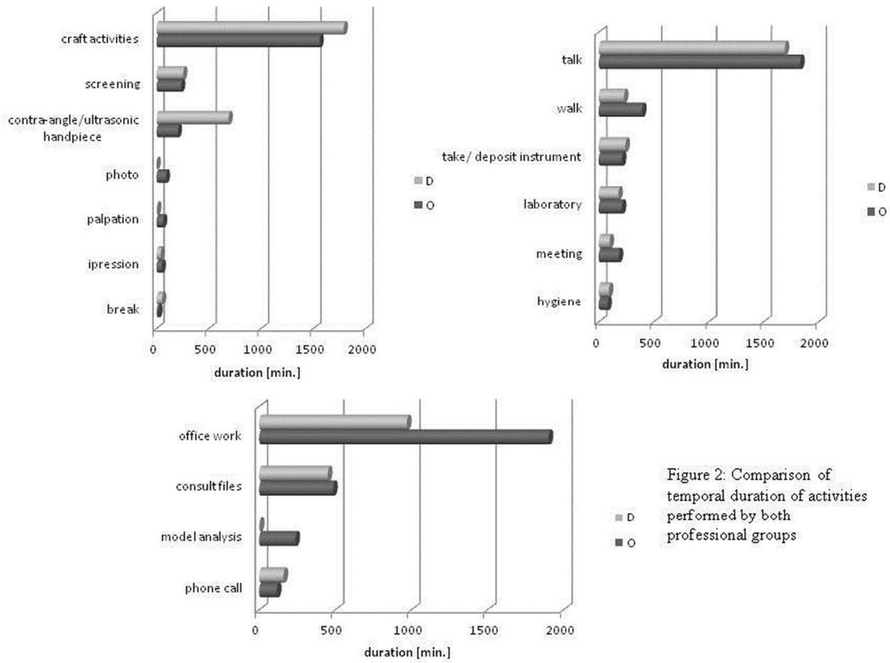

Figure 2: Comparison of temporal duration of activities performed by both professional groups
119x90mm (300 x 300 DPI)

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Motion analysis in the field of dentistry - A kinematic comparison between dentists and orthodontists

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Motion analysis in the field of dentistry - A kinematic comparison between dentists and orthodontists

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Abstract

Objectives: This study aims to conduct a kinematic comparison of occupational posture in orthodontists and dentists in their workplace.

Design: Observational study.

Setting: Dentist surgeries and Departments of Orthodontics at university medical centers in Germany.

Participants: A representative sample of 21 (10f/11m) dentists (group G1) and 21 (13f/8m) orthodontists (G2) with one male drop-out in G2.

Outcome measures: The CUELA (computer-assisted acquisition and long-term analysis of musculoskeletal loads) system was used to analyze the occupational posture. Parallel to the recording through the CUELA system, a software-supported analysis of the activities performed (I: treatment; II: office; III: other activities) was carried out. In line with ergonomic standards the measured body angles are categorized into neutral, moderate, and awkward postures. By means of the stratified van Elteren-U-test and the Wilcoxon-Mann-Whitney-U-Test the activities are compared between the aforementioned groups. All p-values are subject to the Bonferroni-Holm correction. The level of significance is at 5%.

Results: In terms of time the categories (I-II-III) are divided as follows: dentists 41-23-36% and orthodontists 28-37-35%. The posture analysis of both groups shows for all percentiles (P5-95) angle values primarily in the neutral or in the moderate range. However, depending on the activity performed between 5 and 25% of the working hours unfavorable postures were observed, especially in the head-and-neck area. Orthodontists have a greater tendency to perform treatment activities with the head and torso in unfavorable positions than dentists. The significant differences between the statistical comparison of both groups with regard to the duration and the relevance of the activities performed affirm this assumption for all three categories ($p < 0.01$, $p < 0.05$).

Conclusions: Generally, both groups perform treatment activities in postures that are in the neutral or medium range; however, dentists were observed to take slightly more unfavorable postures during treatment for a greater share of their work day.

Strengths and limitations of this study

One of the strengths of this study is that we were able to separate the categories: dental treatment, dental office and other dental activities.

We could combine the kinematic CUELA system data with the actual activities performed.

One limitation of the CUELA system is the exclusion of fine motor movements in the hands.

Another limitation is the lack of differentiation between static or dynamic execution of the working tasks.

Introduction

The dental profession encompasses a great number of health risks such as contact allergies, the risk of infection, eye injuries, neuropathy (1-5) as well as musculoskeletal disorders in the neck, shoulder and/ or back area (6-11). A questionnaire-based survey of 430 Greek dentists by Alexopoulus et al. (7) affirms the high incidence of musculoskeletal disorders (62%). In Poland 92% and in Germany 86.7% of surveyed dentists reported neck or back pain. 68.6% of the same group of respondents even reported to suffer from disorders on a weekly basis (8, 12). A study by Gopinadh et al. (13) demonstrates that 73.9% of the 170 surveyed dentists in India encounter musculoskeletal pain, especially in the neck and back area, which also shows a correlation between the increasing incidence of these symptoms with the length of the hours worked and the progressing age of the practitioner. More than half of the respondents reported to take inadequate body postures during treatment.

Furthermore, the frequency and the extent of this issue is found to result in the early retirement of dentists. With 29.5% to 55% these disorders present one of the most common medical causes for illness-related retirement among dentists (4, 14, 15).

A survey on musculoskeletal pain in Indian orthodontists distinguished between those that practioned exclusively as orthodontists and those who continued to work as dentists. In this regard, a prevalence of back pain was observed solely for respondents that worked in the field of orthodontics (16). Kerosuo et al. (17) also reach the conclusion that orthodontists more often have complaints of pain than dentists.

As a result, the questions of ways to integrate optimal and ergonomic posture in the work routine of dentists and orthodontists are more and more becoming a subject of public interest. To date, there is no data on postures taken in everyday work situations among dentists as well as orthodontists. Also, there is no side-by-side comparison of occupational posture in orthodontists and dentists that detects a possible prevalence of unfavorable patterns of posture that can result in musculoskeletal disorders for either of the professional groups.

Thus, by means of ergonomic and kinematic analysis this study aims to investigate patterns of postures that are involved in the daily routines of orthodontists and dentists and their possible impact on the pervasive development of symptoms of pain. For this purpose, the study investigates the motions and postures of the participating physicians in relation to the professional tasks, divided into the three categories (I) treatment, (II) office and (III) other activities, performed in their daily routine. In this context, the following hypotheses are being investigated:

1. The treatment stage accounts for the largest temporal share in the day-to-day work of orthodontists and dentists.
2. For both groups unfavorable postures were observed more often during treatment than during office or other activities.
3. In contrast to dentists, orthodontists more often perform treatment activities with the torso in a neutral position.

Methods

Study Participants

Overall, this study measured 42 participants (23f/19m). The participants are divided into two groups and compared with each other based on their respective professional training. Group 1 (G1) consists of 21 dentists (10f/11m) working in established practices in Germany that are on average 40.14 ± 10.35 years old and have had work experience in the field for 10.55 ± 9.95 years. Group 2 (G2) comprises 21 orthodontic residents (13 f/ 8 m) of an average age of 31.48 ± 3.82 years that are currently in training at three university medical centers in Germany. One drop-out of a male participant was recorded for group 2 due to incorrect measurement. Work experience for this group accounted for a statistical mean value of 3.86 ± 2.48 years.

Inclusion criteria were working as a dentist in a private dental clinic or as orthodontic resident working at university medical centers in Germany. Subjects were asked to participate by an official letter to the practice owner or to the senior physician or head of department heralding about the planned investigation. The letter contained the most basic information. Following their agreement to participate the physicians were informed in person about the goals and the approach of the study.

All study participants stated that they show no signs of functional impairment or ailments related to the musculoskeletal system. Injuries of the musculoskeletal system ought to have occurred more than two years prior to the study. This study was approved by the Ethics Committee (135/14) of the Goethe University in Frankfurt am Main. Prior to the study, all participants signed an informed consent to take part in the study. The authors obtained informed consent from the participant in figure 1 for publication.

The comparison of postures is expected to show a greater difference between dentists and orthodontists. According to Cohen an effect size with a standard deviation of 0,8-1 is considered a significant difference. The power of this study was set at 80% to calculate with approximately 20 study participants.

CUELA Measuring System

The CUELA-System (Fig. 1) (computer-assisted acquisition and long-term analysis of musculoskeletal loads), developed at the Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA; Sankt Augustin / Germany), is used to record and analyze body postures (18, 19).

Fig. 1

This personal system uses sensors (accelerometers [ADXL 103/203] and gyroscopes [muRata ENC-03R] for head, arms, legs, back, as well as potentiometers [Contelect] for back torsions) to measure the position and movements of the participants on a continuous time interval.

A sampling frequency of 50 Hz and an angular resolution of approximately 1° allows for an objective evaluation of the body postures and motions observed in the participants (20-23). Table 1 summarizes all parameters of this study that were measured and calculated with the CUELA system.

Table 1 Illustration of body and joint angles measured with the CUELA system, evaluation parameters used, and assessment criteria in line with ergonomic norms.

Body areas	Joint/ Body area	Degree of freedom according to medical definitions	Evaluation parameter	Angle range according to ergonomic standards
Head/neck	Head	sagittal inclination	Head tilted to the front (HT_f) (24, 25)	Neutral: 0 to 25° Moderate: 25 to 85° Awkward: < 0° & > 85°
		lateral inclination	Head tilted to the right (HT_r) (25)	Neutral: -10 to 10°

				Awkward: < -10° & >10°
	Cervical spine (CS)	flexion/ extension	Neck curvature to the front (NC_f) *[Difference betw. Head and TS]* (24, 25)	Neutral: 0 to 25° Awkward: < 0° & > 25°
		lateral flexion	Neck curvature to the right (NC_r) *[Difference betw. Head and TS]* (24, 25)	Neutral: -10 to 10° Awkward: < -10° & >10°
Back	Thoracic spine (TS)	flexion/ extension	TS inclination to the front (TSI_f) (24, 25)	Neutral: 0 to 20° Moderate: 20 to 60° Awkward: < 0° & > 60°
		lateral flexion	TS inclination to the right (TSI_r) (24, 25)	Neutral: -10 to 10° Moderate: -10 to -20° Moderate: 10 to 20° Awkward: < -20° & > 20
	Lumbar spine (LS)	flexion/ extension	LS inclination to the front (LSI_f)	No ergonomic layout available
		lateral flexion	LS inclination to the right (LSI_r)	
	Trunk (T)	flexion/ extension	Back curvature to the front (BC_f) *[Difference betw. TS and LS]* (24, 25)	Neutral: 0 to 20° Moderate: 20 to 40° Awkward: < 0° & > 40°
			Inclination of the torso to the front (TI_f) *[median flexion of TS and LS]* (24, 25)	Neutral: 0 to 20° Moderate: 20 to 60° Awkward: < 0°& > 60°
		lateral flexion	Back curvature to the right (BC_r) *[Difference betw. TS and LS] (24, 25)*	Neutral: -10 to 10° Moderate: -10 to -20° Moderate: 10 to 20° Awkward: < -20° & > 20°
			Inclination of the torso to the right (TI_r) *[median lateral flexion of TS and LS]* (24, 25)	
		torsion	Back torsion to the right (BT_r) *[Difference betw. TS and LS](25)*	

Measuring System: Software-Based Activity Analysis

Participants are being observed in their day-to-day work to analyze the activities performed and the respective motions involved. A hand-held computer (UMPC Samsung Q1, Samsung Electronics GmbH. Schwalbach, Germany), which relies on data acquisition software (26, 27) specifically designed for this study, records the activities performed in real time by the second. This software was coded specifically for each group and their respective treatment spectrum (activity categories). The beginning and the end of each orthodontic or dental activity as well as its duration were recorded. A detailed description of the system has already been published (26, 27).

Experimental Procedure

For a description and summary of the daily activities performed, both groups were observed in their routine for one working day prior to the study. In this way, 22 activities were detected for G1 and 25 for G2, all of which were subsequently divided into three categories (I) treatment, (II) office and (III) other activities and implemented into the data acquisition software (Table 2).

Table 2 Illustration of categories with the respective activities performed as well as with an explanation thereof. "Craft activities" in group 1: extraction, pain diagnostics, implantation, placing an injection; and in group 2: archwire-/ elastics-change, removable appliance, fixed appliance, mini implant, filling, prophylaxis, splint.

category	work task	details
treatment	impression	Taking an impression of the patient's teeth
	photo	Camera documentation of the case
	craft activities	Umbrella term for all work stages that are not included in the aforementioned activities.
	palpation	Palpating patients' muscles/ jaw joints
	break	Short breaks during treatment
	screening	First/ check-up screening of patients
	contra-angle/ ultrasonic handpiece	Using contra-angle/ ultrasonic handpiece during treatment
office	consult files	Reading patient files (results/ tooth model/ X-ray)
	Office work	Writing entries for patient files/ computer work
	model analysis	Analysis and conception of treatment plans based on teeth models and X-rays
	phone call	Having phone conversations
other activities	meeting	Medical consultation among peers
	talk	Conversations with patients and staff as solitary activity
	hygiene	Hygienic measures (washing /desinfecting hands, wearing gloves/ face masks)
	take/ deposit instrument	Taking up instruments from a drawer / putting instruments down during and after treatment
	laboratory	Any kind of labwork
	walk	Covering distances

Each participant is measured on a randomly selected work day of 8 hours to ensure an authentic recording of their treatment spectrum. Participants wear the CUELA system under clothing to conduct the measurement (sensors are attached on arms, legs, head, and the spine). Parallel to the recording through the CUELA system, two observers log in real time the activities performed with a hand-held computer. However, some activities are summarized in Table 2 as "craft activities" (I) because the professional groups do not perform the exact same range of activities.

Evaluation

Once the measurement is completed, the time intervals of the activity analysis (hand-held computer) recorded in real time are synchronized with the time axis of the motion analysis (CUELA). A specially developed software (IFA; Sankt Augustin, Germany) is used to create visualizations and descriptive analysis of the retrieved results.

The descriptive analysis of the postures observed in the examined collectives is based on the indication of the arithmetic mean (AM), standard deviation (SD) as well as the percentiles P05, P25, P50, P75 and P95. The percentiles give a descriptive report of the angle values that are below the measuring time of the respective activity performed in a particular joint region. For instance, the P05 value describes the threshold value for joint angles, which 5 % of all measured data fall short of and 95 % exceed. These angle values are subsequently evaluated and assigned to a color-coded angle range (traffic light system: red/ yellow/ green) in compliance with ergonomic standards (24, 28, 29). Based on the respective colors, postures are assessed as unfavorable (awkward), moderate or neutral (30) (Table 1).

Activities of both groups are compared based on the stratified Van Elteren-test and the bilateral Wilcoxon-Mann-Whitney-test along with the Bonferroni-Holm-correction because the data retrieved was not normally distributed under the Kolmogoroff-Smirnoff-test. Following the comparison, only those activities are analyzed whose sensors show angle values that are significantly different and that are relevant with regard to the duration and the (dental or orthodontic) profession itself.

Results

Activity Analysis

On average, data was collected for both groups for a measuring period of approximately 6 h on a day-to-day basis (total measuring period: G1: 116.4 h; G2:131.9 h). The percentage of the measuring period is distributed across the three categories (I-II-III) as follows: G1: 41 - 23 - 36% and G2: 28 - 37 - 35%. A side-by-side comparison of the proportionate activity duration for each category can be found in Figure 2.

Category (I) comprises seven comparable activities of which "craft activities," contra-angle /ultrasound," and "examination / screening" are the activities with the longest duration and these activities with regard to treatment time account for 96% in G1 and 90% in G2. In category (II) "consult files" and "office work" account for the longest time span with 90% in G1 and 87% in G2. "Conversation" (G1: 67%; G2: 63%) along with "walk" (G1: 9%; G2: 14%) represent the largest shares of category (III). As a result, these category (III) activities account for more than ¾ of the total working time. During the aforementioned category III activities dentists and orthodontists take almost identical postures and, therefore, the statistical analysis of the differences between both groups disregards these postures. Instead, the rarely performed activity "laboratory" (G1:7%; G2:7%) in terms of time is analyzed.

Descriptive Posture Analysis

Table 3 shows the benchmarks for the distribution of body and joint angles (Percentile P05, P25, P50, P75 and P95) assumed during the most important activities for orthodontists and dentists.

descriptive body posture (P5-25-50-75-90)		craft activities					screening					contra-angle/ ultrasonic handpiece					office work					consulting files					laboratory				
percentile (in degree °)		5	25	50	75	95	5	25	50	75	95	5	25	50	75	95	5	25	50	75	95	5	25	50	75	95	5	25	50	75	95
TS inclination to the front (TSI_f [°])	D	7	14	19	24	30	7	15	19	23	27	11	20	25	28	31	3	10	14	18	24	5	14	19	23	29	6	12	17	22	30
	O	8	16	21	26	32	8	17	23	28	35	13	22	26	28	32	9	16	20	24	29	8	14	19	23	29	10	18	23	26	31
TS inclination to the right (TSI_r [°])	D	-5	0	3	6	10	-3	3	7	10	15	-3	2	4	6	10	-5	-1	1	4	7	-4	0	2	4	8	-6	-3	-1	2	7
	O	-8	-3	0	4	9	-6	0	4	8	12	-5	-2	1	5	9	-5	-2	0	1	4	-5	-2	0	3	6	-5	-1	1	2	7
Neck curvature to the right (NC_r [°])	D	-14	-5	2	8	17	-15	-6	1	9	17	-13	-2	5	12	19	-13	-7	-3	1	6	-14	-8	-4	-1	5	-17	-11	-6	-2	5
	O	-15	-4	5	14	26	-17	-4	6	16	30	-14	-2	6	14	25	-14	-7	-3	2	9	-10	-4	0	4	10	-11	-3	2	6	13
Neck curvature to the front (NC_f [°])	D	-5	9	17	23	30	-3	11	17	23	29	2	14	20	25	30	-16	-7	0	7	15	-16	-7	-1	5	14	-12	0	7	14	22
	O	-5	13	23	30	37	-8	8	17	24	32	5	21	28	33	39	-22	-12	-4	4	16	-16	-6	2	8	17	-12	6	18	26	34
Head tilted to the front (HT_f [°])	D	8	25	37	45	54	9	27	36	43	51	17	36	45	51	56	-1	8	14	20	29	2	11	17	23	31	3	17	25	32	40
	O	8	31	45	53	62	7	28	40	49	59	21	45	54	59	65	-2	7	15	23	36	1	13	21	27	36	7	25	41	49	58
Head tilted to the right (HT_r [°])	D	-15	-4	4	13	25	-14	-3	8	19	32	-13	0	10	19	29	12	-6	-2	1	8	-12	-6	-2	1	7	-17	-11	-6	-2	6
	O	-19	-6	5	16	32	-19	-2	11	24	42	-16	-3	8	18	31	15	-7	-2	2	9	-10	-4	0	4	11	-12	-3	3	8	15
LS inclination to the front (LSI_f [°])	D	-14	-9	-6	-3	0	-13	-9	-7	-5	-2	-14	-10	-7	-5	-3	-25	-22	-19	-15	-9	-13	-8	-5	-2	2	-12	-9	-6	-3	4
	O	-16	-12	-9	-6	-1	-17	-12	-10	-5	-1	-14	-10	-7	-5	-2	21	-17	-13	-10	-3	-16	-12	-9	-6	-2	-19	-15	-12	-9	-2
LS inclination to the right (LSI_r [°])	D	-7	-5	-3	-1	2	-8	-6	-4	-2	1	-7	-4	-3	-2	1	-7	-5	-3	-2	0	-8	-5	-3	-1	2	-8	-6	-4	-2	2
	O	-9	-6	-4	-2	2	-7	-3	-1	1	5	-7	-5	-4	-2	1	-7	-5	-3	-2	0	-7	-5	-3	-2	1	-7	-3	-2	0	3
Back curvature to the right (BC_r [°])	D	-1	3	6	8	11	3	7	11	14	17	2	2	5	7	12	0	3	5	7	10	-1	3	5	7	11	-1	1	3	6	10
	O	-3	1	4	7	11	-2	2	5	8	11	-1	2	5	8	11	-1	1	3	5	8	-2	2	4	6	9	-3	1	2	4	7
Back curvature to the	D	15	21	25	30	35	16	22	25	29	33	21	28	32	35	38	20	27	33	37	41	13	20	24	27	32	11	18	24	29	34

front (BC_f [°])	O	17	25	29	34	40	20	27	32	36	41	23	29	32	35	39	20	29	33	37	42	18	24	28	32	36	19	29	35	39	43
Back torsion to the right (BT_r [°])	D	-9	-5	-3	0	7	-7	-4	-1	1	7	-6	-4	-3	-1	5	-7	-3	0	3	6	-7	-4	-1	1	6	-6	-2	0	2	5
	O	-7	-3	0	3	8	-6	-2	0	3	7	-9	-6	-4	-2	6	-7	-3	-1	2	8	-6	-3	0	3	7	-5	-1	2	5	10
Inclination of the torso to the front (TI_f [°])	D	-2	3	7	10	14	-3	3	6	9	12	-1	6	9	11	13	-10	-5	-2	1	6	-3	3	7	10	15	-1	3	6	8	14
	O	-3	2	6	9	14	-4	3	7	11	16	0	6	9	11	15	-5	0	4	6	11	-3	1	5	8	13	-3	2	5	8	12
Inclination of the torso to the right (TI_r [°])	D	-5	-1	1	3	7	-4	0	4	6	10	-4	0	2	4	7	-5	-2	0	2	5	-4	-1	1	3	6	-6	-3	-1	1	5
	O	-8	-4	-1	2	7	-6	-1	3	6	10	-5	-2	0	3	6	-5	-2	-1	1	4	-5	-3	-1	0	3	-5	-1	0	2	5

Table 3: Comparative illustration of median posture; Caption: Ergonomic posture = red: awkward; yellow: moderate; green: neutral; D= dentist, O= orthodontist

Regarding the median (P50) for all relevant activities, it is evident that dentists and orthodontists very often work in the same angle range, which is predominantly ranked as neutral or moderate (Table 3). Neutral postures (Table 1) in category are mainly found between P25-P75 values. This is the case for the evaluation parameters for inclination of the thoracic spine to the right (TSI_r), back torsion to the right (BT_r), inclination of the torso to the front (TI_f), inclination of the torso to the right (TI_r) as well as for inclination of the lumbar spine to the right (LSI_r). Moderate posture is found with back curvature to the front (BC_f) and head tilted to the front (HT_f). For both groups inclination of the thoracic spine to the front (TSI_f) is found to be rather in the neutral for lower percentiles and in the moderate range for higher percentiles. Unfavorable postures in P05 and P95 are primarily found in neck curvature to the right (NC_r), head tilted to the right (HT_r) and to the front (NC_f), whereas medial sections are ranked as neutral. In category II for both groups several body and joint angles are predominantly in the neutral range (back curvature to the front (BC_f), inclination of the thoracic spine to the front (TSI_f), inclination of the thoracic spine to the right (TSI_r), head tilted to the front (HT_f), head tilted to the front (HT_r), inclination of the lumbar spine to the right (LSI_r), back torsion to the right (BT_r) and inclination of the torso to the right (TI_r) and several angles are found to be in the moderate range at and above P50 and in the unfavorable range below P50 (neck curvature to the right (NC_r), neck curvature to the front (NC_f), head tilted to the front (HT_r), and inclination of the torso to the front (TI_f)). Back curvature to the front (BC_f) prevails in the moderate range. Data retrieved for "laboratory" (III) almost concurs with data determined for office (II).

Treatment (I)

Compared to orthodontists, dentists use the contra-angle or ultrasonic handpiece more often and for a longer duration ($p<0.001$). Group 1 performs this activity 797 times (total duration approx. 689 min) and group 2 only 138 times (total duration: approx. 204 min).

Statistically significant differences between both groups are found for the activity "examination / screening" regarding the inclination of the thoracic spine to the front (TSI_f) at P95 ($p<0.05$), neck curvature to the right (NC_r) at SD ($p<0.05$) and P95 ($p<0.05$), neck curvature to the front (NC_f) at SD ($p<0.05$), head tilted to the right (HT_r) at SD and P95 ($p<0.05$) as well as back curvature to the front (BC_f) at SD ($p<0.05$) (Table 4). The classification of the measured angle values according to the various class codes is identical for all sensors considered. Nevertheless, angle values are evidently higher in orthodontists than in dentists.

We also observed that both groups always perform “craft activities” in the same angle range (Table 4). The statistical significances are found for the inclination of the thoracic spine to the right (TSI_r) at P05 ($p<0.05$) as well as neck curvature to the right (NC_r) at SD ($p<0.05$), neck curvature to the front (NC_f) at SD and P95 ($p<0.01$ or $p<0.05$), head tilted to the right (HT_r) at SD ($p<0.01$) and the inclination of the torso to the right (TI_r) at P05 ($p<0.01$).

Office (II)

Among orthodontists the activity “office work” represents a long time period as it accounts for 1901 min and thus 24% of the total working hours, which results in a statistical significance in duration of $p<0.01$. Another statistical significance is found for neck curvature to the front (NC_f) at SD ($p< 0.05$). For this activity, orthodontists showed greater angle values than dentists (G1 < G2).

Other Activities (III)

The activity “laboratory” shows a statistical significant difference of $p<0.05$ in SD for head tilted to the front (HT_f), whereby orthodontists exhibit greater angle values than dentists (G1 < G2).

Activity		Parameter	Sensor	Orthodontis [°]	Dentist [°]	Signifiance
Treatment (I)	craft activities	P05	TS inclination to the right (TSI_r)	-8	-5	0,05
		(MV) SD	Neck curvature to the right (NC_r)	(5) 13	(2) 10	0,05
		(MV) SD	Neck curvature to the front (NC_f)	(13) 20	(15) 11	0,01
		P95		37	30	0,05
		(MV) SD	Head tilted to the right (HT_r)	(5) 16	(4) 13	0,01
		P05	Inclination of the torso to the right (TI_r)	-8	-5	0,01
	screening	P95	TS inclination to the front (TSI_f)	35	27	0,05
		(MV) SD	Neck curvature to the right (NC_r)	(6) 15	(1) 10	0,05
		P95		30	17	0,05
		(MV) SD	Neck curvature to the front (NC_f)	(15) 13	(16) 10	0,05
		(MV) SD	Head tilted to the right (HT_r)	(11) 19	(8) 15	0,05
		P95		42	32	0,05
		(MV) SD	Back curvature to the front (BC_f)	(31) 7	(25) 5	0,05
Office (II)	office work	(MV) SD	Neck curvature to the front (NC_f)	(- 4) ± 12	(0) ± 10	0,05
Other activities (III)	laboratory	(MV) SD	Head tilted to the front (HT_f)	(37) ± 16	(24) ± 2	0,05

Table 4: Illustration of statistically relevant activities with respective sensors. Caption: ( ) = included based on affiliation; P = percentile, MV = median value, SD = standard deviation; Ergonomic posture of the percentiles = red: awkward; yellow: moderate; green: neutral

Discussion

The comparative motion analysis of dentists and orthodontists delivers data that gives information about whether a dental or orthodontic activity is performed in an ergonomically favorable body posture or not. The classification of particular activities as "craft activities" (Table 2) and the division of the day-to-day work of both groups into three categories allows for a differentiated analysis of every activity performed and a comparison of both professional groups with regard to distinctions and commonalities.

The temporal division of one working day by percentage indicates that treatment (I) accounts for 41% among dentists and 28% among orthodontists of the day-to-day work. Orthodontists spend more time in the office (37%) or with other activities (35%) by percentage. Therefore, hypothesis 1, which states that the treatment stage accounts for the largest temporal share in the day-to-day work of orthodontists and dentists, is verified for dentists and falsified for orthodontists. Increased office work immediately relates to the necessary computer work in terms of model and X-ray analysis, which is considered essential for orthodontic treatment. Among orthodontists "conversation" is a very frequent activity because the treatment concepts as well as the treatment stages have to be explained and demonstrated to the patient. As a result, the percentage of 35% in category III is comprehensible.

Based on the kinematic analysis with the CUELA system, conclusions regarding the assumed postures can be drawn. The evaluation of the percentiles 05, 25, 50, 75 and 95 are particularly significant for hypothesis 2 as it claims that unfavorable postures occur during the treatment of patients. As a result, the classification of body angle data in category I (treatment) emphasizes that predominantly neutral or moderate postures are assumed. The range for unfavorable body and joint angles is found in the percentiles P05, P75 and P95 for neck curvature to the right and front (NC_r; NC_f), back curvature to the front (BC_f), head tilted to the front (HT_r), and the inclination of the torso to the front (TI_f) (Table 3). The data obtained clearly demonstrates that 50% of the time dentists and orthodontists predominantly treat in the neutral or moderate angle range. However, for both groups the measured angles, which are all found to be in the moderate range, show greater angle values (25° - 65°) in the percentiles P25-P95 for inclination of the head to the front during treatment.

For the other two categories (II+III) similar conclusion is drawn: With the activities "office work," "consult files," and "laboratory" unfavorable postures in the angles of neck curvature to the right and front (NC_r; NC_f), tilted head to the front (HT_f), head tilted to the front

(HT_r), inclination of the torso to the front (TI_f), and back curvature to the front (BC_f) are observed. The negative and unfavorable inclination of the head and torso are found to develop on account of a seated position which renders participants to rest their spine comfortably against the back of the chair, a position which is not considered strenuous.

In comparison to "office work," which is performed in the angle range between 7° to 36° (31), treatment activities are increasingly conducted in forced postures, particularly observable for head inclination. In principal, angle values in the area of the head and cervical spine differentiate significantly between treatment and office activities, which points towards an increasing muscular strain during treatment. Thus, participants worked for a greater temporal proportion of their day-to-day work in unfavorable positions, which are also the cause for musculoskeletal disorders. This is particularly evident given that the P05 or P95-values of the respective body or joint angles are clearly in the unfavorable range.

The results confirm the already established correlations of musculoskeletal disorders in the dental profession (6-8, 17, 31, 32). According to Alexopoulos et al. (7) more than every other dentist is affected by back, shoulder, and/or neck problems. The side-by-side comparison between orthodontists and dentists, however, does not show a significant difference regarding the related problematic nature of unfavorable posture.

Consequently, hypothesis 2 is verified. The tendency for a predominantly unfavorable posture in daily working life is thus applicable to these professional groups with regard to treatment activities. In relation to the other two categories, this tendency corresponds to office activities performed in other professions (31, 33).

Referring to hypothesis 3, the measured postures demonstrate that there are no great disparities regarding the mode of operation among participants in both groups because all participants performed the same activities exclusively in the same angle range (neutral or moderate). Angular deviations are only found for "craft activities" with the inclination of the thoracic spine to the front (TSI_f), "examination / screening" with the inclination of the thoracic spine to the front (TSI_f), head tilted to the front (HT_r), with back curvature to the right (BC_r), and for the activity "contra-angle/ ultrasonic handpiece" with neck curvature to the front (NC_f). Except for back curvature to the right (BC_r), all angle values for "examination / screening" among orthodontists are found in the worse angle range. Their thoracic spine is observed to incline further to the front and therefore demonstrates a frontal neck curvature to a greater extent (unfavorable angle range) (Table 3). Consequently, dentists on average perform activities in more favorable angle ranges than orthodontists. However, neither of the groups solely demonstrates a neutral range of angles during treatment.

Considering the p-values it becomes apparent that there are significant differences between both groups, even though the angle difference between the groups is minimal. For instance, this is demonstrated with inclination of TS to the right during the execution of craft activities. The difference in the P05-value only accounts for 3° ("craft activities" inclination of TS to the right (TSI_r)) - G1: -5°; G2: -8°) (Table 4). As a result, the measured angle values are significant but the minimal difference of these angle values is, on the one hand, not clinically relevant and, on the other hand, not crucial for a different angle classification according to ergonomic norms. Consequently, hypothesis 3 is falsified.

Moreover, a comparison of both groups ought to take the average age into account, which is lower by 9 years in orthodontists as compared to dentists. This age difference along with the greater professional experience (G1: 10.55 ± 9.95 years; G2: 3.86 ± 2.48 years) could also have an effect on the postures assumed.

As most orthodontists do divide their work day between working as residents at university medical centers and private practices, we find that they are familiar with private practice routines and, as a result, apply their experience to their day-to-day work at university medical centers. Moreover, it is worthwhile mentioning that these three university medical centers treat a great number of patients on a day-to day basis. In view of these findings, the proposed comparison is valid and essential.

The focus of this kinematic analysis is the posture of participants during a particular activity. Here, the individual variance in motion of each participant is given less consideration. In this context, impact factors such as workplace organization, treatment position, as well as the choice of a patient chair (31, 33) present important components, which can affect individuals in ways that can cause musculoskeletal disorders (34-37).

However, musculoskeletal disorders often develop not only on account of poor posture but also originate in multicausal conditions. Many scientific studies have affirmed that daily stress is a decisive factor (3, 38-40). Consequently, pain problems among dentists and orthodontists cannot be explained based on one factor but requires a multifactorial analysis that is essential.

The study is limited because it does not record the fine motor movements of the fingers. As most dental tasks depend on fine motor movement, this aspect should be considered for future studies. Moreover, the study did not consider the potential malposition of the participants' bodies because the measurement was calibrated anew for each participant after the measuring unit / device was attached. As a result, given malposture is cancelled out because of the procedure used.

Related to the approach to observe participants, another limitation is represented by the well-known Hawthorne effect (41). This effect describes the phenomenon in which participants change their behavior once they learn they are being observed. In this study, however, this effect has little impact on the participants because the measurement duration lasted for at least or more than 5 hours in their familiar work environment. In view of this long measurement period, it is highly unlikely that participants maintain work habits that deviate gravely from their usual routine. In addition, evaluators remained in the background and refrained from being in the participants' visual field. In this way, participants hardly noticed the presence of the evaluators and performed their tasks naturally.

Furthermore, consideration must be given to the fact that many activities such as the preparation of a dental crown by using a contra-angle piece or the cementation of an orthodontic appliance are performed in long-lasting, static positions. These body postures assumed over a long period of time could be the potential cause for the ailments described as work performed in a static position also results in physical strain (11). In this respect, the analysis of static postures during treatment activities is considered a meaningful and desirable addition to future research in the field. In summary, the postures analyzed in this study do not differ greatly between both surveyed groups. The same result was found in a survey about health complaints of dentists (n=147) and orthodontists (n=81) by Kerosuo et al. (17). With around the same frequency, both groups reported with 70% and 72% musculoskeletal disorders, even though a slightly increased prevalence was found among orthodontists. This slightly higher prevalence is also evident in another study by Sankar et al. (16). Following ergonomic standards, dentists as well as orthodontists primarily work in the neutral or moderate range, a conclusion, however, which requires differentiated analysis. Particularly for treatment activities the P05 or P75-P95 values in the red range emphasize the need for action. These angle values in the red range correlate with apparent and prolonged postures in a forced position (over 4 seconds in a static position) (25). Moreover, aside from the duration of the activity individual motion control has to be considered as it bears the risk of developing muscular dysbalance and disorders.

In conclusion, the study emphasizes the importance of educating orthodontists and dentists about ergonomic treatment or intensive ergonomic training to prevent musculoskeletal disorders in future. Furthermore, the present results should be taken into account for future studies and used to initiate possible modifications to the work environment of dentists.

Footnotes

a. contributorship statement

JN, CE, IH, and DO made substantial contributions to the conception and design of the manuscript. JN, CE, IH, DAG, IH, RE, DD, and DO made substantial contributions to the construction of the measurement protocol and NJ and Do has been involved in the statistical data analysis. All authors have read and approved the final manuscript.

b. competing interests

The authors declare that they have no conflict of interest.

c. funding

There is no funding of the project.

d. data sharing statement

No additional data available.

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Figures and tables

Figure 1: Illustration of the CUELA system.

Figure 2: Comparison of temporal duration of activities performed by both professional groups

Figure 1: Illustration of the CUELA system.
221x271mm (300 x 300 DPI)

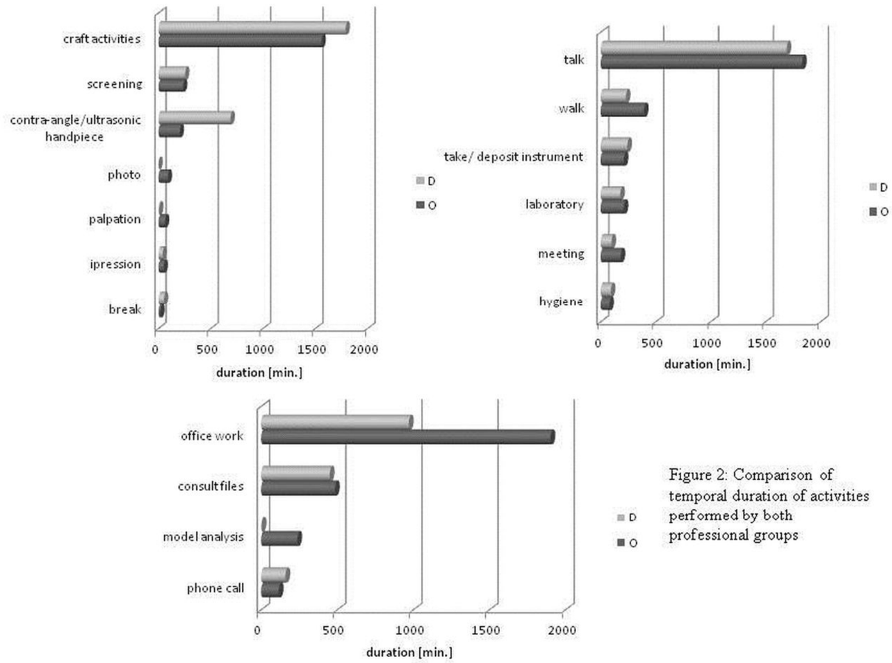

Figure 2: Comparison of temporal duration of activities performed by both professional groups
119x90mm (300 x 300 DPI)