ERGONOMICS, 2001, VOL. 44, NO. 7, 739–750

Effects of dynamic office chairs on trunk kinematics, trunk extensor EMG and spinal shrinkage

J. H. VAN DIEËN†*, M. P. DE LOOZE‡ and V. HERMANS†

†Institute for Fundamental and Clinical Human Movement Science, Faculty of Human Movement Science, Vrije Universiteit Amsterdam, Amsterdam NL-1081 BT, The Netherlands

‡TNO Work and Employment, Hoofddorp, The Netherlands

Keywords: Sitting posture; electromyography; spine.

Seated work has been shown to constitute a risk factor for low-back pain. This is attributed to the prolonged and monotonous low-level mechanical load imposed by a seated posture. To evaluate the potential health effects with respect to the low back of office chairs with a movable seat and back rest, trunk kinematics, erector spinae EMG, spinal shrinkage and local discomfort were assessed in 10 subjects performing simulated office work. On three separate occasions subjects performed a 3 h task consisting of word processing, computer-aided design and reading. Three chairs were used, one with a fixed seat and back rest and two dynamic chairs, one with a seat and back rest movable in a fixed ratio with respect to each other, and one with a freely movable seat and back rest. Spinal shrinkage measurements showed a larger stature gain when working on the two dynamic chairs as compared with working on the chair with fixed seat and back rest. Trunk kinematics and erector spinae EMG were strongly affected by the task performed but not by the chair type. The results imply that dynamic office chairs offer a potential advantage over fixed chairs, but the effects of the task on the indicators of trunk load investigated were more pronounced than the effects of the chair.

1. Introduction

Technological and economical developments have led to an increase of the proportion of the workforce performing tasks while seated in an office chair. Although seated work is known to be energetically less demanding than standing work, several drawbacks have become apparent. It has been demonstrated that prolonged sitting constitutes a potential risk factor for the development of low-back pain (Hales and Bernard 1996). In practice, it has been attempted to ameliorate this problem by means of optimizing the design of office chairs. One fairly common aspect of office chairs is that they have been designed to accommodate a substantial amount of movement. So-called dynamic chairs allow movement of the chair seat and back support either in a fixed ratio or independently. Several authors have advocated this principle as a means of preventing low-back pain associated with sitting (Kroemer 1994, Serber 1994, Suzuki *et al.* 1994). However, to the authors' knowledge, no scientific studies have been performed to support or refute this

---

*Author for correspondence. e-mail: J_H_van_Dieen@fbw.vu.nl

Ergonomics ISSN 0014-0139 print/ISSN 1366-5847 online
http://www.tandf.co.uk/journals
DOI: 10.1080/00140130110045794

claim. In addition, a theoretical evaluation of this is hampered by the lack of knowledge of the mechanism explaining the association between sitting and low-back pain.

Some studies have demonstrated associations between a history of sedentary work, low-back pain prevalence and degenerative changes of the intervertebral disc (Evans *et al.* 1989, Videman *et al.* 1990). It has been shown that sustained compression on the discs, as occurs during sitting, hampers fluid flow into the disc (Kingma *et al.* 2000), which consequently affects disc nutrition adversely (Maroudas *et al.* 1975, Holm *et al.* 1981). Reducing the compression force acting on the spine (Kraemer *et al.* 1985) or imposing movements (Deursen *et al.* 2001) may both reduce or reverse the flow of fluid from the disc. This would result in reduced spinal shrinkage or enhanced recovery of shrinkage, since spinal shrinkage is in part accounted for by fluid flow from the intervertebral discs (Roberts *et al.* 1998). This can therefore explain the reduced spinal shrinkage when using, for instance, a chair with a back rest as opposed to one without back rest (Eklund and Corlett 1987, Althoff *et al.* 1992) or when using a chair which imposes trunk movements by a motor (Deursen *et al.* 1999). Following this rationale, these effects can be interpreted as beneficial with respect to disc nutrition. However, the studies cited were not made on dynamic office chairs. Jensen and Bendix (1992), who studied this type of chair, found no effect of a movable chair seat (with a fixed back support) on the amount of trunk movement.

In addition to effects on the spinal column, the prolonged low-level static load on the back during sitting can be hypothesized to affect back muscles adversely. Prolonged low-level activity of muscle has been implicated to lead to muscle pain in other muscle groups due to the continuous and relatively high activity of a fraction of the motor units in the muscle (Hägg 1991, Westgaard and DeLuca 1999). In addition, contraction levels of the trunk extensors of as low as 2% of maximum voluntary force have been shown to impair oxygenation of this musculature (McGill *et al.* 2000). Dynamic office chairs allow opposite movements of seat and back support, which accommodate a reclining posture allowing for relaxation of back muscles. If subjects use this opportunity, as they appear to do (Miedema *et al.* 1999), sitting on a dynamic chair might entail more opportunity for relaxation of the type I motor units and recovery of oxygenation. In addition, if this type of chair does facilitate changes of posture, this might also stimulate alternation of activity of different parts of the extensor musculature (Dieën *et al.* 1993), which would also prevent continuous activation of type I motor units. Both more frequent postural changes and more frequent periods of relaxation of parts of the extensor musculature have been indicated to prevent back discomfort experienced during prolonged sitting (Salewytsch and Callaghan 1999).

Finally, even if subjects do not move more on a dynamic chair, the movable backrest on these chairs might optimize support by following the trunk movements. This could lead to a reduced mean activity of back muscles and consequently to a reduction in disc compression (Andersson *et al.* 1974).

The aim of the present study was to study the effects of dynamic office chairs on the low back. Following the above theoretical considerations, the amount of trunk movement, the activity of the back muscles and spinal shrinkage were measured in subjects working on a stationary office chair and on two types of dynamic chairs. In addition, the subjects rated their perceived discomfort.

2. Methods

2.1. *Subjects*

Ten healthy subjects, three females and seven males, participated in the experiment after signing an informed consent form. Their mean age was 21 (range 21 – 24) years, mean height was 1.81 (1.71 – 1.90) m and mean body mass was 75 (65 – 87) kg. All subjects were experienced users of word-processing and computer-aided design software.

2.2. *Chairs*

Two types of dynamic chair were used in the experiment (figure 1): chair DA allowed independent sagittal plane rotation of back rest and seat, chair DB allowed rotation in a fixed ratio of the seat-to-back rest rotation (1:2.7). The first chair was also used with the back rest and seat fixed (seat horizontal and back rest at 95° with respect to the seat and this configuration is called chair FA).

The chairs were adjusted for each subject according to a fixed protocol. First, the height of the seat was adjusted to slightly below knee height, resulting in a knee angle of slightly $>90°$ when the feet were in full contact with the floor. This height was measured and reproduced in each of the experimental sessions of the subject. The depth of the seat was standardized across subjects except when using chair DA. In this case seat depth was related to the position of the seat with respect to the axis of rotation. This was adjusted so that the subject was in equilibrium when sitting upright. The height of the arm supports was adjusted so that the forearm was supported when the upper arms were hanging vertically beside the trunk and the elbows were flexed 90°. The horizontal distance between the arm supports was kept constant. The height of the back rest was adjusted so that subjectively optimal support was attained. The resistance of the dynamic chairs to movement was adjusted by one of the researchers, based on feedback from the subject. It was emphasized to the subjects that a minimum resistance should be chosen, while

Figure 1. Chairs used in the experiment (left, DA/FA; right, DB).

maintaining a ‘sense of safety’. Finally the height of the desk surface was aligned with the surface of the arm supports.

2.3. *Experimental task*

Each subject participated in three sessions (each using one of the three chair types) on separate days starting at the same time of day. The chairs were used in a random order. In each session a standardized 3 h task was performed. The task consisted of three activities: word processing, reading a book and computer-aided design (CAD). The word-processing task consisted of reproducing a printed text. The placement of the document varied between subjects but was constant for each subject. The CAD task consisted of reproducing a drawing provided on paper, mainly using the mouse as an input device. Word processing and CAD were performed in three blocks of 45 min each followed by 15 min of reading (figure 2). During the 3 h the subject was not allowed to rise from the chair.

Prior to the experimental task and the stature measurements, at least two maximum isometric trunk extension efforts were performed to obtain an estimate of maximum erector spinae muscle activation. These contractions were elicited by having the subject support the upper body over the edge of a bench, while one of the experimenters pushed the subject’s upper body downward.

2.4 *Measurements*

Markers were attached to the subject at the level of the C7 spinous process, the right hip, the knee and ankle joints, and to the chair over the axis of rotation of the seat (chair marker). Marker positions were recorded on video (sVHS) for 5 min at the periods indicated in figure 2. The camera was positioned to provide a sagittal plane image. Video-frames were digitized and marker locations determined semi-automatically using commercially available software (Winanalyze).

Activity of the back muscle was measured through surface-EMG. Electrodes (Ag/AgCl) were applied bilaterally 3 cm paravertebral at the level of the spinous

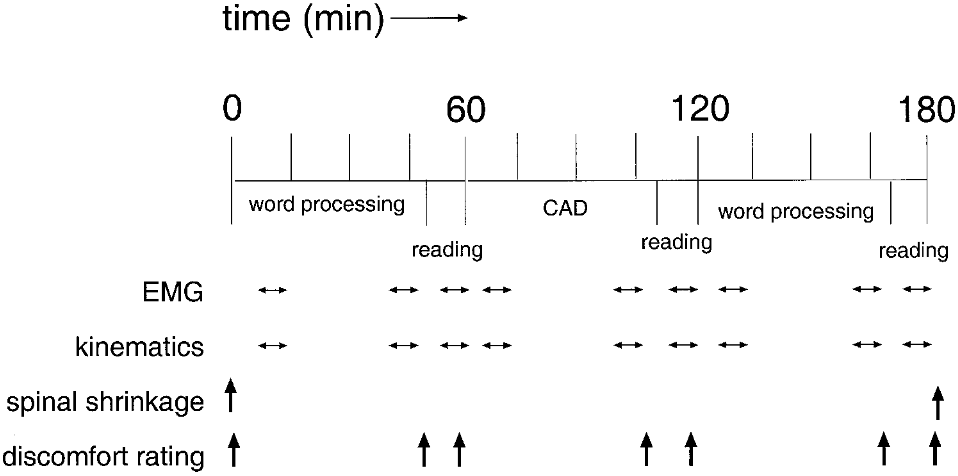

Figure 2. Schematic overview of the experimental procedures. The horizontal line represents a time axis. The experimental tasks are represented below the axis. Arrows indicate the periods during which measurements were taken.

processes of L3 and T10. The signals were amplified (20 times, input impedance $>10^{12}\Omega$, CMRR >90 dB), band-pass filtered (10–400 Hz), 22 bits A/D converted at a rate of 1000 samples per second and stored on disk (Porti 17, TMS, Enschede, The Netherlands). This measurement procedure yielded a resolution of 1.2×10^{-4} mV or about 0.001% MVC. EMG was sampled during the periods in which the video recordings were made.

Spinal shrinkage, the change in length of the spine under the influence of a change in compressive loading, was estimated with a stadiometer (figure 3). Equipment and procedures were similar to those in previous studies (Eklund and Corlett 1984, Dieën *et al.* 1994). In short, the stadiometer allows for reproducible (within 1 mm) measurements of stature. Accurate reproduction of the subject's standing posture from one measurement to another was obtained through mechanically restraining the positions and inclinations of the feet, the pelvis and the head (allowing vertical displacement of the head only), and by requiring the subject to reproduce the distribution of body weight over the left and right forefeet and heels on each measurement. During the measurement subjects kept their arms crossed over their chests and held their breath, without prior deep expiration or inspiration. Each measurement was the average stature measured over 5 s at 20 Hz. Twenty measurements of stature were performed just prior to the experimental task and 20 immediately after the task, with the subjects stepping off the stadiometer between measurements. To avoid confounding of shrinkage results, measurements in each subject always started at the same time of day (either 10.00 or 14.00 hours) and subjects were instructed not to participate in any strenuous physical activity for 24 h prior to the trial.

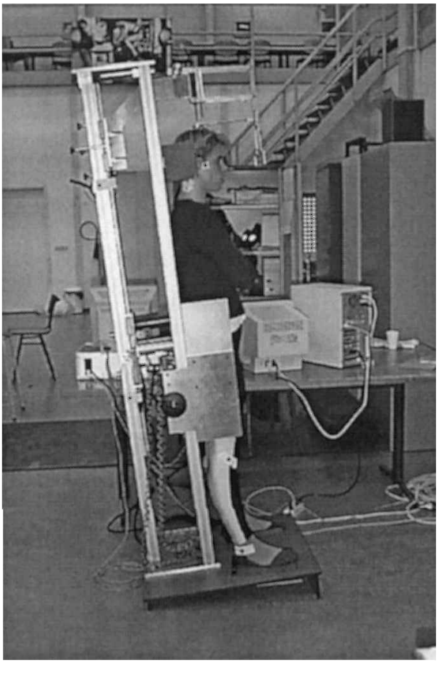

Figure 3. Stadiometer used to estimate spinal shrinkage.

Perceived discomfort was rated at the instants indicated in figure 2 using a 10-point scale, with zero representing no discomfort and 10 being worst imaginable discomfort. Subjects first identified areas where discomfort was experienced using a body chart and subsequently rated the discomfort for those areas separately (Grinten and Smitt 1992).

2.5 *Data analysis*

The analysis of the kinematic data was based on the exposure variance analysis (EVA) as proposed by Mathiassen and Winkel (1991). This method describes the time series of a certain exposure variable by a matrix representing the percentages of measurement time the variable is in between specific levels (intensity bins) for specific lengths of time (repetitiveness bins). Only the C7 marker coordinates were used for further analysis. Trunk angles could not be reliably determined in all instances, since the hip marker was occasionally obscured by the armrests of the chairs. However, careful inspection of the videotapes and analysis of the remaining marker data revealed that subjects did not shift the whole body with respect to the chair. Consequently the other markers do not provide additional information on trunk kinematics.

The coordinates of the C7 marker were referenced to coordinates of the chair marker and subsequently to their own time-averaged position. From the 5 min time-series of coordinate data, EVA matrices were derived with 30 mm bins for position and 30 s bins for the time axis. This resolution was optimal for differentiation between chairs and tasks. Subsequently, two parameters were derived to quantify the extent to which static postures were adopted by the subjects. The first dependent variable was the time the C7 marker was within + /— 15 mm from the calculated average marker position (i.e. in the central bin; figure 4). The second dependent variable was the percentage of the measurement time that a static posture was

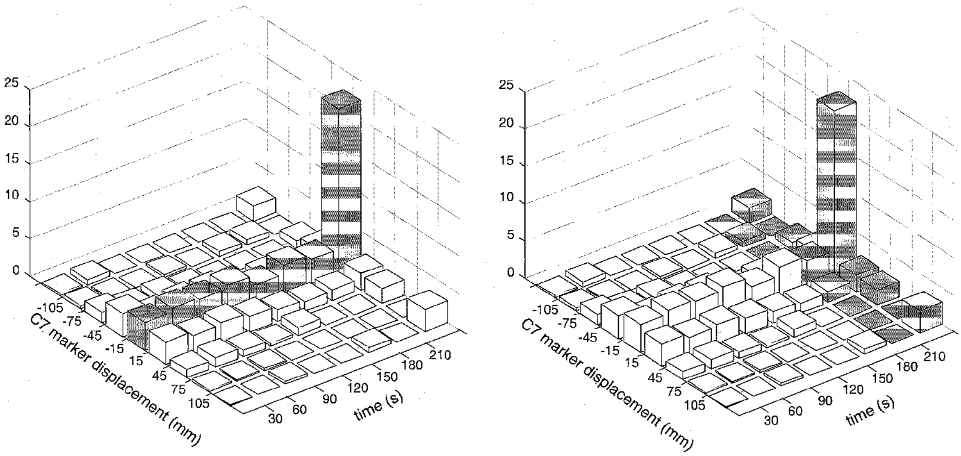

Figure 4. Parameters derived from the EVA of C7 marker displacement. The percentages represented by the grey bars were summed to obtain the proportion of time spent in the average position (left) and to obtain the time spent in postures sustained for >180 s (right). Note that the central bin represents the marker position around the calculated average of each time series. All values along the displacement axis thus represent deviations from the average position not from a predefined neutral position.

adopted, with static defined as the marker remaining within an area with a width of 30 mm for > 180 s uninterrupted (figure 4). Movements within this 30-mm-wide area would correspond to angular excursion of up to about 3.5°.

After storage on disk, EMG data were digitally high-pass filtered at 30 Hz cut-off with a finite impulse response filter to reduce ECG contamination (Redfern *et al.* 1993). Subsequently the signals were rectified and low-pass filtered at 2.5 Hz (Potvin *et al.* 1996). All signals obtained during the experiments were normalized to the peak value obtained from the maximum isometric trunk extension efforts. From the 5 min time-series, the 50th percentile amplitudes and the percentages of the measurement time during which the amplitudes remained below 0.5% MVC were determined, indicating the central tendency of the muscle activity and the percentage of time of rest, respectively.

The final 10 stature measurements taken before and the first 10 after the task were averaged and the differences between these were used to estimate spinal shrinkage. The remaining measurements were used to check the reproducibility. Standard deviations were calculated for measurements 1st – 10th, 2nd – 11th, ..., 11th – 20th. All standard deviations were < 1 mm both before and after the experiment.

Two-way ANOVA for repeated measures was used to test for effects of task (word processing, CAD and reading) and chair (FA, DA, DB) on kinematic variables. Two-way MANOVA (with four muscles), with Wilk's λ as the test statistic, was used to test for the effects on EMG variables. Finally, a non-parametric Friedman test was used to test for effects of chair type on shrinkage and discomfort. In the case of significant effects, chair types were compared one by one using a Wilcoxon matched pairs test. For all tests, results were considered significant at $P < 0.05$.

3. Results

The results for the C7 marker displacement are given in table 1. The percentage of time during which the C7 marker was found to lie within a range of 30 mm around the average position was not affected by chair type, nor by the interaction of chair type and task, whereas the task had a significant effect ($F_{2,16} = 9.5$, $P = 0.002$). Similar results were found for the percentage of measurement time the C7 marker was found to lie within a 30 mm range for > 3 min consecutively. Again only the effect of task was significant ($F_{2,16} = 9.5$, $P = 0.002$). These findings imply that the occurrence of substantial changes in trunk posture was not affected by chair type,

Table 1. Mean (SD) results from the EVA of the C7 marker displacement.

	Chair DA	Chair DB	Chair FA
Percentage of time with a marker within a range of 30 mm around the average position			
CAD	49.8 (18.3)	56.9 (28.5)	67.2 (23.2)
Reading	34.9 (30.6)	23.1 (25.7)	38.13 (32.9)
Word processing	56.4 (26.6)	75.5 (13.9)	55.6 (26.9)
Percentage of time spent in a static posture for > 180 s			
CAD	40.9 (22.0)	64.7 (22.1)	56.9 (30.2)
Reading	48.3 (19.0)	44.7 (22.5)	53.0 (15.7)
Word processing	37.4 (22.9)	39.0 (21.9)	41.0 (30.8)

whereas it was dependent on the task performed. Most postural changes occurred during the reading task compared to word processing and CAD, as illustrated by a typical example of coordinate data shown in figure 5.

Overall EMG activity was very low with means across subjects not exceeding 2% MVC and individual median amplitudes not exceeding 8% MVC. Median amplitudes of erector spine EMG were not significantly affected by chair type or by activity. The percentage of time that muscle activity was $<0.5\%$ MVC was independent of chair type but strongly dependent on the task (Wilk's $\lambda_{4,8} = 0.087$, $P<0.001$). Univariate tests revealed that this was mainly due to an effect on the left thoracic erector spinae muscle ($F_{2,18} = 19$, $P<0.001$), whereas the other muscle showed trends only. Reading showed the largest percentage of observations $<0.5\%$ MVC (in left thoracic erector spinae: 8% of measurement time versus 3% in the other two tasks).

Seated work in the experiment produced on average an increase in stature in all conditions. The gains in stature were significant on the dynamic chairs, averaging 3.3 mm on the chair DA and 4.4 mm on chair DB. On the fixed chair FA the gain in stature averaged 0.06 mm, which was not significantly different from zero. The effect of chair type was significant ($P = 0.018$). Wilcoxon matched pairs tests revealed

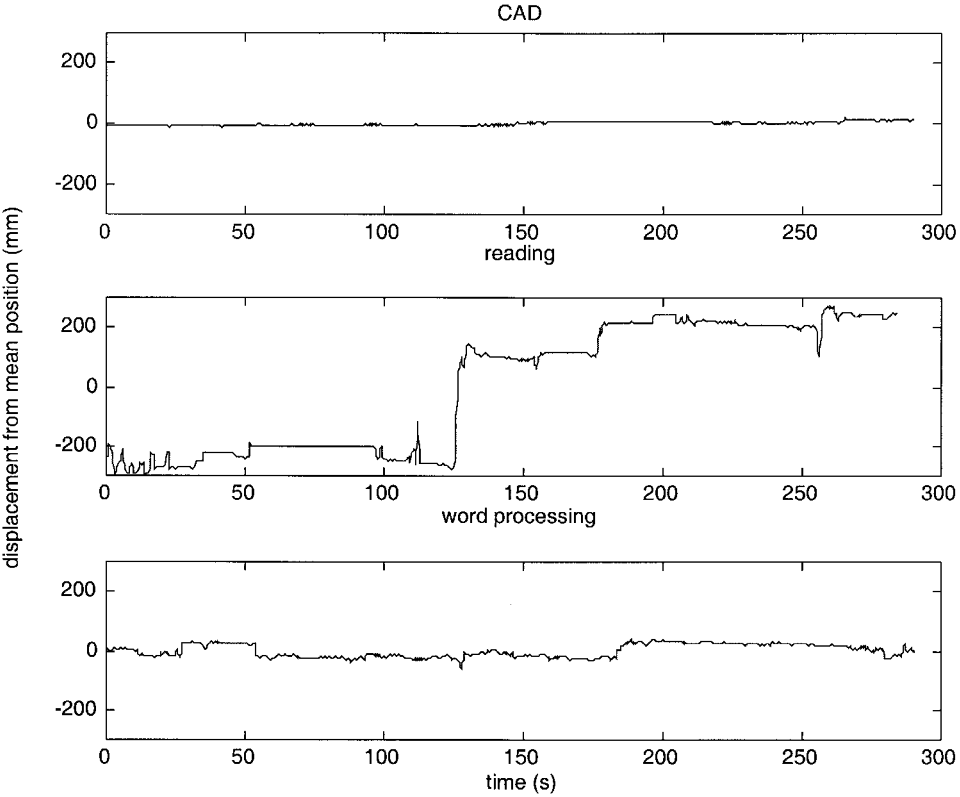

Figure 5. Example of the time histories of the C7 marker displacements in each of the three tasks (each window representing data from the same subject using the same chair).

significant differences between the fixed chair and both dynamic chairs ($P = 0.02$ in both cases), with greater increase in stature when using the dynamic chairs, while the difference between the dynamic chairs was not significant.

No increase in subjective discomfort in any body part was reported during the experimental trials.

4. Discussion

The aim of the present study was to investigate effects of dynamic office chairs on the trunk which might potentially affect low back health. Two dynamic office chairs were compared with one fixed chair. The results revealed a potential advantage of the dynamic chairs. Spinal shrinkage measurements showed an increase in stature when working on the dynamic chairs. The increase in stature is explained by recovery of disc height, which can be accounted for by compression being lower during the experimental trial than during preceding activities. Previous studies have shown similar effects of sitting (e.g. Althoff *et al.* 1992, Leivseth and Drerup 1997). One explanation for the effect of dynamic chairs on spinal shrinkage may therefore be that movements made are tracked by the (spring-loaded) back rest, which might in this way provide more effective support. One would, however, expect this to be reflected also in a lower median EMG amplitude of the extensor muscles on the dynamic chairs. However, this effect may have been masked through pressure exerted by the back rest on the electrodes, which would lead to an increase in amplitude. Though preliminary testing revealed no such effects, this cannot be totally excluded. In addition, movement can contribute to recovery of disc height (Deursen *et al.* 2001). A stronger gain in stature was reported to occur when using a chair, which imposes cyclic rotatory movements on the spine, compared with a conventional chair (Deursen *et al.* 1999). It is debatable whether, in the present study, the difference between the dynamic chairs and the fixed chair is directly attributable to an increase in movement. Kinematic variables studied were not found to be different between chair types, although small sagittal plane movements of the trunk may have been missed with the present analysis technique. However, analysing the data with a higher spatial resolution than the 30 mm bins used did not affect the conclusion and also the cut-off point for static postures (set at 180 s) did not substantially influence the results. The absence of an effect of chair type on trunk kinematics is to some extent supported by Jensen and Bendix (1992). This study, focusing on chairs with more limited dynamic possibilities as compared to the present study, also found no effects on sagittal plane trunk kinematics. It should be kept in mind that movements of the lumbar spine may remain undetected by the measurement method used, especially when occurring primarily in the transversal or frontal plane. Since movements in the transversal plane of small amplitude (0.5° torsion) have an effect on intradiscal pressure and disc height (Deursen *et al.* 2001), the influence of the movement can also not be excluded.

In conclusion, the stronger increase in stature observed after working on the dynamic chairs as compared with the fixed could be due to better trunk support or small effects on trunk kinematics. The increase in stature is to be interpreted as a positive effect, in view of the fact that it reflects an influx of fluids and consequently nutrients into the avascular disc (Urban and McMullin 1988).

A large variety of dynamic chairs are available. Two of these were selected for this study, mainly based on the high frequency of their use. No differences were demonstrated between the two dynamic chairs tested.

Extrapolation of these laboratory results to real life office work should be taken with caution. The finding of a significant effect of chair type on spinal length change might be related to the 'extremely' static test situation (as compared with real life), where people were not allowed to stand during the 3 h. On the other hand, the effect might be even more pronounced in real life, as the testing period was quite short in comparison to an 8 h working day. Another issue to be mentioned is that the subjects were not familiarized with sitting on dynamic chairs. In addition, the period to become accustomed to the chairs was short in this study. Therefore it remains unknown whether a longer period to get used to the chairs would have led to other results.

The effect on stature change might lead to the conclusion that dynamic chairs, like the ones used in this study, should be advocated. However, it is the authors' experience that many of the dynamic chairs used in practice are not used in the proper way. It is not uncommon to see dynamic chairs being used while locked in one position. The introduction of dynamic chairs probably needs to be accompanied by careful instruction or even training of the future user. Another option in this respect might be offered by chairs promoting passive movement such as described by Deursen *et al.* (1999). Potential health effects of dynamic chairs or chairs providing passive motion need to be confirmed in field studies.

An important finding in the present study was the pronounced effect of task on kinematic and EMG variables as compared with the effects of chair type. It should be realized that the present study compared three chairs which each fulfilled most ergonomic criteria, and subjects were not specifically instructed or trained to use the dynamic possibilities of the chairs. Nevertheless, these results point in the direction that ergonomic measures in the office environment should address the design of functions maybe more than the design of the workplace. It is in this respect worrying that the physical characteristics of many tasks become more similar as more tasks are performed through interaction with a computer. It should be kept in mind though that the present study focused on one aspect of workplace design only.

5. Conclusions

When performing word-processing, reading and CAD work on two dynamic chairs, spinal shrinkage measurements showed a larger stature gain, as compared with when working on a chair with a fixed seat and back rest. Trunk kinematics and erector spinae EMG were strongly affected by the task performed but not by the chair type. These results imply that dynamic office chairs offer a potential advantage over fixed chairs with respect to trunk loading, but the effects of task design may be more pronounced.

Acknowledgements

The authors acknowledge the support of ASPA Kantoorinrichting. They also thank Frank Heijligers and Eva Janssen (student in Human Movement Technology, The Hague) for their assistance in performing the experiments.

References

Althoff, I., Brinckmann, P., Frobin W., Sandover, J. and Burton, K. 1992. An improved method of stature measurement for quantitative determination of spinal loading, *Spine*, **17,** 682–693.

ANDERSSON, G. B. J., ÖRTENGREN, R., NACHEMSON, A. and ELFSTRÖM, G. 1974. Lumbar disc pressure and myo-electric back muscle activity during sitting, *Scandinavian Journal of Rehabilitation Medicine*, **6,** 101 – 121.

DEURSEN, D. L. v., GOOSSENS, R. H. M., EVERS, J. J. M., HELM, F. C. T. v. D. and DEURSEN, L. L. J. M. 1999. Length of the spine while sitting on a new concept for an office chair, *Applied Ergonomics*, **31,** 95 – 98.

DEURSEN, D. L. v., SNIJDERS, C. J., DIEËN, J. H. v., KINGMA, I. and DEURSEN, L. L. J. M. v. 2001, Passive vertebral rotation causes instantaneous depressurization of the nucleus pulposus, *Journal of Biomechanics*, **34,** 405 – 408.

DIEËN, J. H. v., CREEMERS, M., DRAISMA, I., TOUSSAINT, H. M. and KINGMAD, I. 1994, Repetitive lifting and spinal shrinkage, effects of age and lifting technique, *Clinical Biomechanics*, **9,** 367 – 374.

DIEËN, J. H. v., OUDE VRIELINK, H. H. E. and TOUSSAINT, H. M. 1993, An investigation into the relevance of the pattern of temporal activation with respect to erector spinae muscle endurance, *European Journal of Applied Physiology*, **66,** 70 – 75.

EKLUND, J. A. E. and CORLETT, N. 1984, Shrinkage as a measure of the effect of load on the spine, *Spine*, **9,** 189 – 194.

EKLUND, J. A. E. and CORLETT, E. N. 1987, Evaluation of spinal loads and chair design in seated work tasks, *Clinical Biomechanics*, **2,** 27 – 33.

EVANS, W., JOBE, W. and SEIBERT, C. 1989, A cross-sectional prevalence study of lumbar disc degeneration in a working population, *Spine*, **14,** 60 – 64.

GRINTEN, M. P. v. d. and SMITT, P. 1992, Development of a practical model for measuring body part discomfort, in S. Kumar (ed.), *Advances in Industrial Ergonomics and Safety IV* (London: Taylor & Francis), 311 – 318.

HÄGG, G. 1991, Static work loads and occupational myalgia — a new explanation model, in P. A. Anderson, D. J. Hobart and J. V. Danoff (eds), *Electromyographical kinesiology* (Amsterdam: Elsevier), 141 – 143.

HALES, T. R. and BERNARD, B. P. 1996, Epidemiology of work-related musculoskeletal disorder, *Orthopedic Clinics of North America*, **27,** 679 – 709.

HOLM, S., MAROUDAS, A., URBAN, J. P., SELSTAM, G. and NACHEMSON, A. 1981, Nutrition of the intervertebral disc: solute transport and metabolism, *Connective Tissue Research*, **8,** 101 – 119.

JENSEN, C. V. and BENDIX, T. 1992, Spontaneous movements with various seated workplace adjustments, *Clinical Biomechanics*, **7,** 87 – 90.

KINGMA, I., DIEËN, J. H. v., NICOLAY, K., MAAT, J. J. and WEINANS, H. 2000, Monitoring water content in deforming intervertebral disc tissue by finite element analysis of MRI data, *Magnetic Resonance Imaging in Medicine*, **44,** 650 – 654.

KRAEMER, J., KOLDITZ, D. and GOWIN, R. 1985, Water and electrolyte content of human intervertebral discs under variable load, *Spine*, **10,** 69 – 71.

KROEMER, K. H. E. 1994, Sitting (or standing?) at the computer workplace, in R. Leuder and K. Noro (eds), *Hard Facts about Soft Machines* (London: Taylor & Francis), 181 – 191.

LEIVSETH, T. and DRERUP, B. 1997, Spinal shrinkage during work in a sitting posture compared to work in a standing posture, *Clinical Biomechanics*, **12,** 409 – 418.

MAROUDAS, A., STOCKWELL, R. A., NACHEMSON, A. and URBAN, J. P. G. 1975, Factors involved in the nutrition of the human lumbar intervertebral disc: cellularity and diffusion of glucose *in vitro*, *Journal of Anatomy*, **120,** 113 – 130.

MATHIASSEN, S. E. and WINKEL, J. 1991, Quantifying variation in physical load using exposure vs time data, *Ergonomics*, **34,** 1455 – 1468.

MCGILL, S. M., HUGHSON, R. L. and PARKS, K. 2000, Lumbar erector spinae oxygenation during prolonged contractions: implications for prolonged work, *Ergonomics*, **43,** 486 – 493.

MIEDEMA, M. C., EIKHOUT, S. and DELLEMAN, N. J. 1999, Dynamiek in kantoorstoelen, *Tijdschrift voor Ergonomie*, **24,** 2 – 8.

POTVIN, J. R., NORMAN, R. W. and MCGILL, S. M. 1996, Mechanically corrected EMG for the continuous estimation of erector spinae muscle loading during repetitive lifting, *European Journal of Applied Physiology*, **74,** 119 – 132.

REDFERN, M. S., HUGHES, R. E. and CHAFFIN, D. B. 1993, High-pass filtering to remove electrocardiographic interference from torso EMG recordings, *Clinical Biomechanics*, **8,** 44 – 48.

ROBERTS, N., HOGG, D., WHITEHOUSE, G. H. and DANGERFIELD, P. 1998, Quantitative analysis of diurnal variation in volume and water content of lumbar intervertebral discs, *Clinical Anatomy*, **11,** 1 – 8.

SALEWYTSCH, A. J. and CALLAGHAN, J. P. 1999, Can quantified lumbar spine postures and trunk muscle activation levels predict discomfort during prolonged sitting, *in 31st Annual Conference of ACE, Ergonomics and Safety* (Hull: Association of Canadian Ergonomists).

SERBER, H. 1994, The study of lumbar motion in seating, in R. Leuder and K. Noro (eds), *Hard Facts about Soft Machines* (London: Taylor & Francis), 423 – 431.

SUZUKI, Y., SUGANO, T. and KATO, T. 1994, An ergonomic study of dynamic sitting, in R. Lueder and K. Noro (eds), *Hard Facts about Soft Machines* (London: Taylor & Francis), 347 – 373.

URBAN, J. P. G. and MCMULLIN, J. F. 1998, Swelling pressure of the lumbar intervertabral discs: Influence of age, spinal level, composition and degeneration, *Spine*, **13,** 179 – 187.

VIDEMAN, T., NURMINEN, M. and TTROUP, J. D. G. 1990, Lumbar spinal pathology in cadaveric material in relation to history of back pain, occupation, and physical loading, *Spine*, **15,** 728 – 740.

WESTGAARD, R. H. and DELUCA, C. J. 1999, Motor unit substitution in long-duration contractions of the human trapezius muscle, *Journal of Neurphysiology*, **82,** 501 – 504.