Eur J Appl Physiol (2002) 86: 492–497
DOI 10.1007/s00421-002-0576-6

ORIGINAL ARTICLE

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"Occupational backache" – surface electromyography demonstrates the advantage of an ergonomic versus a standard microscope workstation

Accepted: 21 December 2001 / Published online: 19 February 2002

Abstract Musculoskeletal symptoms such as low back pain, neck pain, and tension headache are reported by up to 80% of professional personnel involved in daily microscope work. Yet, in striking contrast to the high prevalence of complaints, there is a general unawareness of this issue both in those suffering, and those ordering and designing microscopes. We intend to call attention to this underestimated work-related health hazard and to demonstrate a potential means of prevention. We obtained repeated surface electromyographic (EMG) recordings from the most strained neck, upper limb, and back muscles in 12 healthy volunteers while they were operating a near-to-ergonomic prototype workstation and a conventional microscope, respectively. Mean EMG activity was reduced in all recorded muscles when operating the ergonomic workstation compared to the standard microscope. This improvement became more distinct with sustained work, and was most pronounced in those muscles displaying the highest degree of activity while using the standard microscope. We demonstrate the usefulness of surface EMG recordings to show the advantage of an ergonomically tailored and individually adjustable microscope workstation over a standard microscope. The former allows the operator to maintain a more physiological posture, and may thus prevent the development of cumulative musculoskeletal disorders during prolonged microscope-related work.

Keywords Electromyography · Ergonomics · Microscope workstation · Occupational medicine

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Introduction

Numerous studies of a variety of occupational groups report the prevalence of work-related musculoskeletal complaints and discuss the pathophysiological basis of cumulative trauma disorders (Hagberg and Wegman 1987; Harber et al. 1992; Vanderpool et al. 1993; Hunting et al. 1994; Luttmann et al. 1998; Wærsted 2000). We have found, however, only little information about work-related physical disorders of professionals operating conventional microscopes for a prolonged time (Krueger et al. 1986; Haines and McAtamney 1993; Kalavar and Hunting 1996). A survey of cytotechnologists disclosed that 60–80% experienced headache or neck pain, up to 75% suffered shoulder and back pain, and up to 75% complained about eye strain (Haines and McAtamney 1993). Similar numbers were obtained by Kalavar and Hunting (1996). While eye strain can be partially reduced by optimization of peripheral contrast and choice of optimal wavelength of light, constant eye movements while screening slides are inevitable. It is possible that skeletal-muscle-related complaints may be resolved by a more ergonomic design of the microscope workstation.

One of the authors (A.K.) suffered from progressive tension neck syndrome with subsequent tension headache over a period of 7 years. The suspected cause of his symptoms was the non-physiological posture he maintained when operating his standard microscope workstation as a pathologist for several hours each day. However, representatives of different microscope manufacturers ensured him that there was no demand for a microscope more ergonomic than they considered their products already were. In an endeavor to improve his condition, he designed a prototype ergonomic microscope workstation according to his personal ideas and experience. The aim of this study was to establish that operating an ergonomic versus a conventional microscope results in markedly reduced muscle activity and less muscle strain, and thus may prevent the development of cumulative musculoskeletal disorders during prolonged microscope-related work. This was achieved by making surface electromyographic (EMG) recordings from various muscle groups in 12 subjects while they operated each of the two types of microscope workstation.

Methods

Twelve healthy volunteers (8 males, 4 females; age 24–50 years, mean 35 years; body height 160–192 cm) served as subjects after giving their informed consent to participate. The subjects were either advanced medical students, residents, or senior doctors who utilized microscopes professionally and were involved in pathological or microbiological research or routine diagnostics. We recorded surface EMG activity using a standard eight-channel electrodiagnostic system (Nicolet Viking IV) with a sampling rate of 125,000 Hz and filters set at 10 Hz and 10 kHz. Recordings were obtained with the subject sitting on a standard office chair and operating a standard microscope ("standard condition"), and on a special ergonomic chair with support for the lower back and operating a prototype ergonomic microscope ("ergonomic condition"). Pairs of gold cup electrodes (diameter 1 cm) were attached unilaterally over the paramedian upper and lower neck (3rd and 7th vertebral level) and mid and lower back (8th thoracic and 3rd lumbar level) with an inter-electrode distance of 3 cm, and in a belly-tendon fashion over the biceps brachii, brachioradialis, flexor carpi radialis, extensor digitorum communis, trapezius (upper part), and sternocleidomastoid muscles. Muscle selection was based on the location of previously diagnosed fibromyalgia in axial muscles in one subject (A.K.), and the rational concept of upper extremity muscle involvement during microscope operation. To obtain recordings from ten muscles with an eight-channel device, we randomly interchanged the connections of electrode pairs several times throughout a 40-min recording period (20 min for each microscope workstation), yielding four to ten traces with sweeps of 20 s duration each per muscle and per condition. There were no rest periods other than the time needed to take position at the other microscope.

In the standard condition, subjects operated a commercially available standard-type microscope (the brand is unimportant since it is representative for what is generally offered on the market). This "standard microscope" was set on top of a pile of books to improve the sitting posture on a standard office chair that is also regularly used in the same laboratory – as was previously practiced by A.K., and is still practiced routinely by others (e.g., A.G.).

In the ergonomic condition, subjects operated a commercially available microscope stand (Olympus type BX50), which was originally adapted by A.K. according to his personal needs and individual anthropometric measures. This stand is equipped with a narrow bottom front piece of 8 cm, and focusing knobs positioned sufficiently deep and the handle of the mechanical stage long enough to allow the operator's hands to rest on the surface of the table. To accommodate a 180-cm tall person, the table was fitted with unique adjustable slanting "wings", also allowing the forearms to be angled at 90° at the elbow and to rest on the surface while operating the control knobs. This stand was fitted with double-headed discussion equipment and – against the manufacturer's advice – two distance rings and an ergonomic observation tube on top. This particular microscope workstation was equipped with a special ergonomic chair (Hagas, Capisco, 8005) with support for the lower back, allowing an upright physiological sitting posture with an open angle between thigh and abdominal wall, rendering the spine in a natural flexure. To compensate for the other subjects' body heights and leg lengths, it was necessary to adjust for each individual the elevation and slope of the chair, the level of the back support, the height of the table, and the slope of the slanting wings. Despite a slightly reduced optical quality and the inclined armrests, this arrangement represents our close-to-optimal prototype of an ergonomic microscope workstation (Fig. 1).

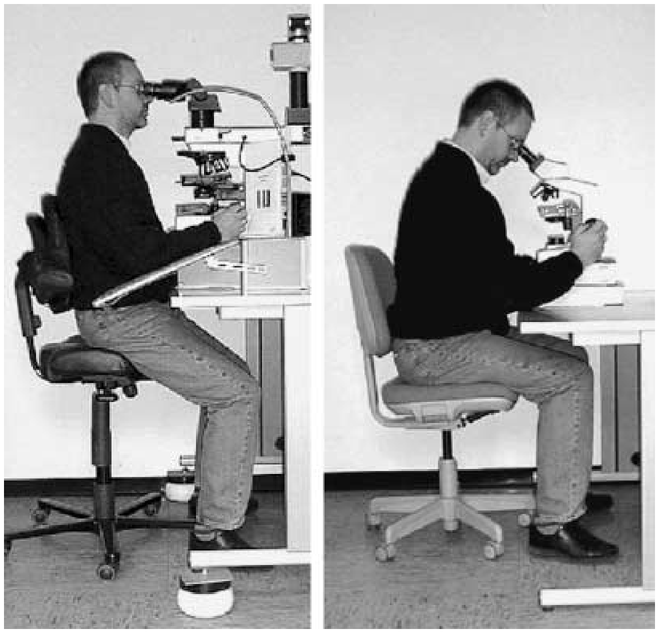

Fig. 1 Photograph showing the prototype near-to-ergonomic microscope workstation on the left, and the standard microscope on the right. Note the different sitting postures assumed by the operator at each of the microscopes

Seven subjects were studied in the standard condition first, five subjects started with the ergonomic condition. Data were stored on floppy disk and analyzed off-line. Artifact-free windows of 10 s duration were selected and the area under the curve was measured. Data are presented as the mean (SD) for each muscle in each condition. To analyze the effect of prolonged sitting and operating the microscope, we compared the first two recordings in each condition with the last two recordings in each condition. Analysis of variance for repeated measures was used to assess statistical significance. Correlation between individual age, body height or microscope experience and the amount of EMG activity in each muscle were calculated with the Spearman's rank order correlation test.

Results

Sitting on a standard office chair and operating a conventional microscope resulted in extensive EMG activity in all recorded muscles. Group average EMG activity was largest in the finger extensors, trapezius and mid-thoracic paraspinal muscles, and subsequently less in the lumbar and upper cervical paraspinal muscles, biceps brachii, brachioradialis, sternocleidomastoid, lower cervical paraspinal, and wrist flexor muscles. In the ergonomic condition, a profound reduction of mean EMG activity was noted in all recorded muscles (Fig. 2). Across all subjects, the most attenuation was observed in the trapezius, biceps brachii, upper and lower cervical paraspinal muscles. EMG activity was even largely reduced in the forearm muscles involved in operating the knobs and handles of the mechanical stage, due to the support of the forearms on the slanting wings. All 12 subjects showed statistically significant attenuation of EMG activity in the upper and lower cervical paraspinal and trapezius muscles, 10 subjects in the wrist flexor, 9 subjects in the sternocleidomastoid, biceps brachii, and brachioradialis muscles, 8 subjects in the mid-thoracic muscles, and 7 subjects in the lumbar paraspinal and finger extensor muscles (Fig. 3).

Although there were different individual patterns of the most strained muscles, there was no correlation with individual age, body height or microscope experience. In addition, the results were not altered according to whether subjects were first enrolled in the standard or the ergonomic condition.

In each muscle, the difference between the ergonomic and standard condition was significantly correlated with the level of EMG activity in the standard condition. Individual muscles displaying the most extensive activity while operating a conventional microscope were apt to manifest the largest EMG signal reduction, hence the highest degree of improvement observed when operating the ergonomic microscope workstation ("gain" in Fig. 3; Spearman's correlation: lumbar and mid-thoracic paraspinal, trapezius, and biceps brachii: each $P < 0.001$; upper and lower cervical paraspinal, sternocleidomastoid, brachioradialis, and finger extensor muscles: each $P < 0.01$; wrist flexors: not significant). In contrast, in the ergonomic condition, EMG activity increased significantly only in single muscles of four subjects (one subject in the lumbar and mid-thoracic paraspinal muscles, one each in the lumbar, biceps brachii and brachioradialis, respectively). Each of them, however, had very low EMG activity in the standard condition, hence, even the increases resulted in low absolute values (Fig. 3).

With sustained work, EMG activity decreased further while operating the ergonomic microscope ($P < 0.001$ in all muscles combined; $P < 0.05$ in the upper cervical paraspinal and trapezius muscles, each). In contrast, EMG activity did not significantly change over time in the "non-physiological" posture in front of the conventional workstation when combining all muscles, but rather tended to increase in the sternocleidomastoid, trapezius, thoracic and lumbar paraspinal, and wrist flexor muscles (Fig. 4).

When questioned about their subjective experience, all volunteers found the ergonomic sitting position relaxing, and some were impressed with the difference in comfort between the two workstations. This is particularly remarkable as the sitting posture in front of the ergonomic microscope was unfamiliar for all subjects except A.K., who was the only one with long-term experience. We did not, however, implement a formal psychophysical rating scale at the time of the study.

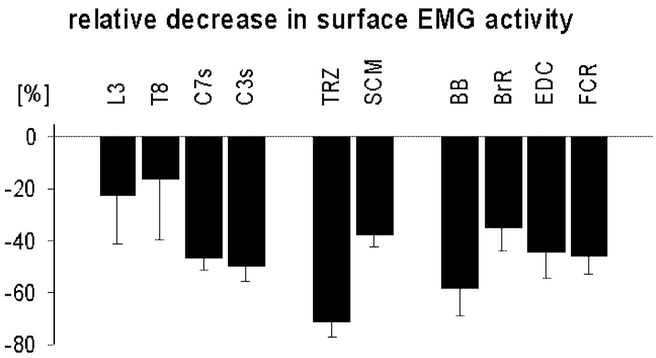

Fig. 2 Relative decrease of mean surface electromyographic activity across all 12 subjects while operating an ergonomic versus a standard microscope. (*L3* Paraspinal muscles at the level of the third lumbar vertebra, *T8* eighth thoracic vertebra, *C7s* seventh cervical vertebra, *C3s* third cervical vertebra, *TRZ* trapezius muscle, *SCM* sternocleidomastoid muscle, *BB* biceps brachii muscle, *BrR* brachioradialis muscle, *EDC* extensor digitorum communis muscle, *FCR* flexor carpi radialis muscle)

Discussion

To our knowledge, this is the first neurophysiological study that demonstrates in a large number of subjects the advantage of an ergonomic versus a conventional microscope workstation with regard to musculoskeletal symptoms. We have shown that the assumption of a more relaxed and "physiological" posture while operating an ergonomic microscope results in much lower levels of continuous muscle activity. Of note is that despite differences in the individual pattern of muscle activity, the most strained muscles were usually those that experienced the largest benefit in the ergonomic condition. Furthermore, we confirm the feasibility of surface EMG recordings in neurophysiological research issues related to occupational medicine.

Present standard microscope workstations

Present microscope workstations are not designed to be operated while assuming a physiological posture. Large numbers of professionals complain about work-related musculoskeletal symptoms as they are regularly forced to work at ordinary tables, often within a restricted space, and with suboptimal illumination and insufficient air supply at the workbench (Krueger et al. 1986, 1989; Haines and McAtamney 1993; Kalavar and Hunting 1996). Commercially available microscope workstations usually lack features that would allow easy adjustments for the considerable difference of anthropometric measures in various individuals. The market offers only three main sizes of microscope, differing in quality and price rather than in dimensions. The smallest and most inexpensive microscopes are designed for students. The typical microscope that is designed to be used routinely by professionals is usually of medium size and price, while the most sophisticated devices are designated as photo-, video-, or research microscopes for the mature and most experienced operator. Common to all models is a fixed distance between the focus control and eyepieces, which was actually too short for all individuals studied (body height 160–192 cm). As a consequence, the back and neck have to be considerably bent to enable the user to look through the eyepieces. Furthermore,

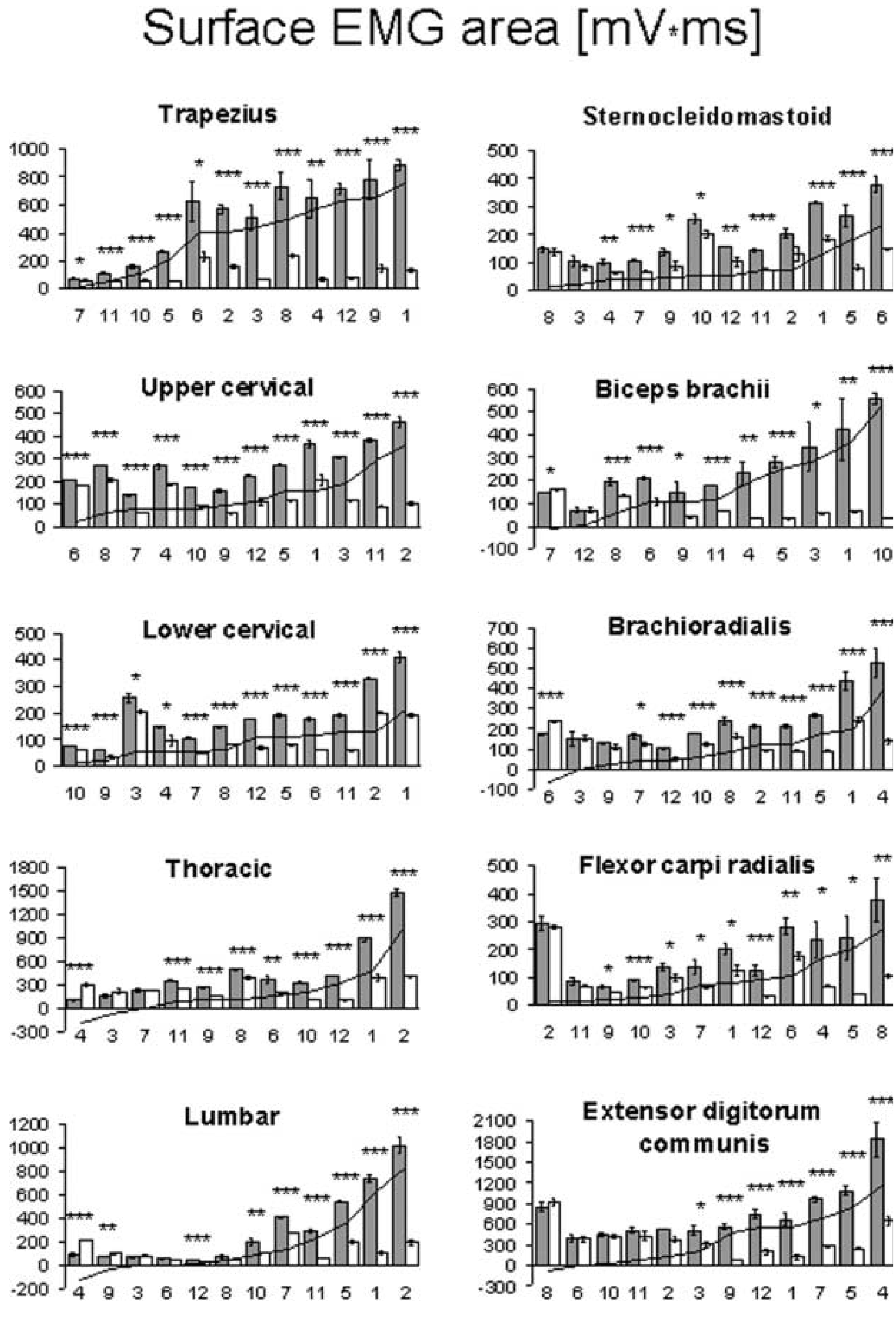

Fig. 3 Surface electromyographic area (mV·ms) recorded in individual muscles of 12 subjects while operating a standard microscope (condition 1, *gray columns*) and a prototype ergonomic microscope (condition 2, *white columns*). The numbers on the x-axis represent individual subjects. For each muscle, subjects are arranged according to incremental improvement (*black line*) from the standard to the ergonomic condition. Note the larger "gain" in those muscles with greater electromyographic activity in the standard condition ($*P < 0.05$; $**P < 0.01$; $***P < 0.001$)

the usual eyepiece inclination of 30–45° requires the operator to assume an awkward neck anteflexion, a rigid posture that has to be maintained for the whole working time – often for hours. This may cause high levels of strain in the erector spinae and shoulder muscles, and may explain cumulative neck, shoulder, and low back pain, as well as tension headache (Lewit 1977; Harms-Ringdahl and Ekholm 1986). As a countermeasure, many microscopists place their equipment on a pile of books, or a reversed drawer (Kalavar and Hunting 1996). The necessity of bending forward is thus reduced, which may alleviate some of the tension in the lumbar erector spinae muscles. Using a box with a slanting surface to correct for the inadequate angle of the eyepieces further helps to elude the neck anteflexion. In return, however, adjustment knobs including those for coarse and fine focus control are then lifted from the surface of the table, resulting in an arduous posture of

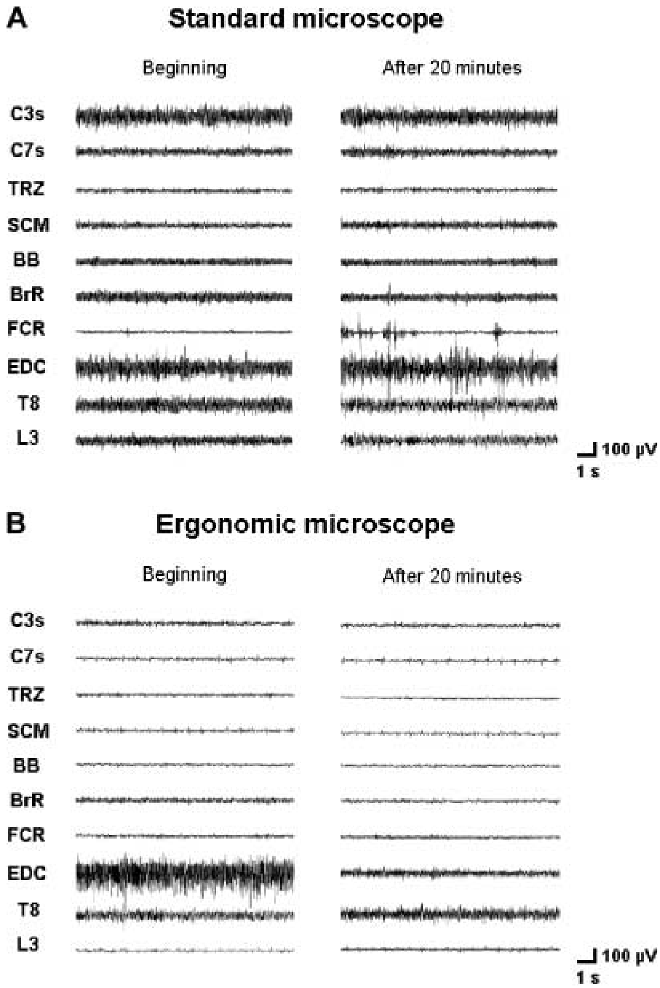

Fig. 4A, B Representative surface electromyographic recordings of one subject. **A** Operating a standard microscope, at the beginning (*left column*) and end (*right column*) of the recording session. **B** Operating a prototype ergonomic microscope, at the beginning (*left column*) and end (*right column*) of the recording session. Recordings were made from the muscles indicated to the left of the figure. Note the tendency toward deterioration over time in the "standard condition", and toward improvement in the "ergonomic condition"

the arms, and hence painful muscle tensions in, for example the biceps brachii, brachioradialis, and shoulder girdle muscles, in particular the rhomboidei, levator scapulae and trapezius muscles, as has been the personal experience of all of the microscopists who participated in our study.

The ideal ergonomic microscope workstation

An ideal ergonomic microscope workstation must provide ample facilities to accommodate individual anthropometric measures in different subjects. The microscopist must be allowed to assume an upright sitting posture with a down-gaze of about 5° below the horizontal plane, preventing excessive tension in the neck muscles. The shoulder girdle must be relaxed with the elbows flexed at 90° and the forearms supported by arm rests in a horizontal plane (e.g., on "wings" placed on both sides of the microscope stand. These wings have to be cushioned to avoid ulnar nerve pressure palsies at the sulcus or Guyon's loge (Kalavar and Hunting 1996). To compensate for individual trunk and arm lengths, the wings should be slightly tiltable with the hinge close to frequently operated control knobs for stage position and focus, to keep their vertical distance from the plane constant. Thus, the forearms and hands may remain on their designated rests even throughout long periods of microscope use. This also implies a continuously adjustable distance between the eyepieces and focus controls (Fig. 1), which to our knowledge is not offered by any of the major microscope manufacturers to date.

An ergonomic seat with ample flexibility to compensate for body size and thigh length is inevitable for obtaining an ideal sitting posture. Provided an open angle exists between the thigh and abdominal wall, the spine assumes a natural flexure, one that occurs physiologically while standing upright (Bendix 1987). The height of the workstation should permit the operator to sit in an upright position and must also be adjustable to individual needs, which will usually require a surface considerably higher than an ordinary office table.

Finally, a point that was not addressed specifically by our study. The feet must rest flat on the floor to provide adequate proprioceptive input from the soles for postural control adjustments (Haines and McAtamney 1993; Kavounoudias et al. 1998). To enable this, the foot-operated switch of a dictating system has to be either built ultra-flat, or partially submerged into the floor. Most older models, however, measure up to 5 cm in height, which may lead to substantial muscle strain in the lower leg.

Our near-to-ergonomic microscope workstation

The microscope workstation presented here was not designed especially for this paper, but has rather been in constant use by one of the authors (A. K.) for the past 4 years. Although our near-to-ergonomic microscope workstation did not sufficiently meet all of the aforementioned criteria, EMG activity was substantially reduced in all muscles, in particular in the trapezius, biceps brachii, upper cervical and lumbar paraspinal muscles, as compared to the standard microscope. This reduction in EMG activity should, in theory, prevent cumulative shoulder and neck pain and tension headache (Lewit 1977; Harms-Ringdahl and Ekholm 1986). In fact, since operating the ergonomic microscope exclusively, A.K. no longer suffers upper cervical syndrome and tension headache. The least overall relative improvement in mid-thoracic and lumbar paraspinal muscles was due largely to an actual increase in EMG activity – although low in absolute values – in three subjects. We believe that in these individuals in particular, our seat did not provide enough support for their back, and the fixed table height was not adequate for their needs (Fig. 3). The observed significant reduction of EMG activity in the upper extremity muscles underlines the importance of amply adjustable rests to support the arms while working.

We are aware of the ongoing and controversial discussion about a potential correlation between surface EMG signals and pain syndromes in cumulative trauma disorders (Lofland et al. 2000; Pullman et al. 2000). We do not intend to become involved in the discussion about terminology and the variety of additional psychological and psychophysical factors contributing to this highly complex issue. There is, however, general agreement and supporting literature (Yassi 1997) stating that repetitive strain injuries or cumulative trauma disorders may result from prolonged maintenance of awkward postures, or repetitive and forceful motions. The latter in turn are associated with increased surface EMG activity.

A methodological point of concern in our study is the lack of EMG calibration, which is generally considered necessary for a valid interpretation of surface EMG signals. It is common practice to present muscle activity as a percentage of maximum voluntary contraction. To the best of our knowledge, however, maximum contraction cannot convincingly be obtained from axial muscles, which are highly relevant in our study. We tried to avoid this drawback by comparing two conditions in each subject, thereby yielding relative changes that should result in meaningful and comparable values across different subjects. Because of the relatively short recording periods, we decided not to formally assess muscle fatigue and performance, but we were surprised to learn from our volunteers that they found the ergonomic sitting position relaxing. Therefore, we may well have found indicators of muscle fatigue (Luttmann et al. 1996), but as our equipment does not allow for analysis of signal amplitude versus frequency, this has to remain speculative at this point.

Notwithstanding these limitations of our study, we have demonstrated the benefit of an ergonomic over a conventional microscope workstation with respect to reduced overall muscle activity. This is in line with previous reports in which it was postulated that improvements in work-related disorders could be achieved by changing workplace designs according to ergonomic recommendations (Garb and Dockery 1995; Aaras et al. 1998; Luttmann et al. 1998).

Acknowledgements The authors are grateful to Mrs. M. Hoch, Hochzirl, and Mrs. K. Jeller, Innsbruck, Austria, for their expert technical assistance.

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