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The influence of computer monitor height on head and neck posture[1]

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Abstract

This research describes the influence of "eye level" and "low" monitor locations on the head and neck posture of subjects performing a word processing task. Lowering the monitor to a position 18° below eye level had no significant effect on the position of the neck relative to the trunk, while the mean flexion of the head relative to the neck increased by 5° ($p = 0.024$). In the "eye level" condition the mean gaze angle was 17° below the ear-eye line, and in the "low" condition the average gaze angle was 25° below the ear-eye line. Lowering the monitor thus allows gaze angles closer to that preferred (somewhere between 35° and 44° below the ear-eye line) to be adopted. An examination of head and neck biomechanics suggests that recommendations of the "top of monitor at eye height" type must be questioned.

Relevance to industry

Current recommendations regarding the appropriate height of computer monitors are based more on intuition than empirical evidence. Lower computer monitor placements may be beneficial.

Keywords: VDT; Posture; Head and Neck

The head and neck comprise a complex neuromuscular system which is not well understood. This complexity, combined with the complexity of the visual system, has contributed to controversy regarding the appropriate location of visual display terminals. The conventional view is that the monitor should be located at, or just below, eye level. For example, the Australian Occupational Health and Safety Commission (NOHSC) suggests in a guidance note that "when sitting tall and looking straight ahead, the keyboard user should be looking at the top edge of the screen" (NOHSC, 1989; p. 14). Similar recommendations are prevalent internationally.

Although evidence to the contrary has been gradually accumulating (Kroemer and Hill, 1986;

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Hsiao and Keyserling, 1991; Kumar, 1994), it has only been relatively recently that the "top of monitor at eye level" recommendation has been challenged in literature destined for the user. In particular, Ankrum and Nemeth (1995) have argued that monitors should be located at least 15° below horizontal eye level (see also Leavitt, 1995).

The argument involves inference from the observation that the preferred angle of gaze is quite steeply downwards. Kroemer and Hill (1986) determined the preferred gaze angle to be 35° below the ear-eye line for visual targets at 1 m, and 44 degrees below the ear-eye line for targets at 0.5 m. From these observations, the reasonable conclusion is that locating video monitors at the conventional position requires users to either compromise their preferred gaze angle, or to adopt postures in which one or more of the cervical or atlanto-occipital joints are relatively extended. Ankrum and Nemeth (1995) suggest that adopting postures involving relatively extended head or neck for prolonged periods is likely to lead to discomfort; and that, consequently, lowering the monitor increases the range of comfortable head and neck postures which can be adopted while allowing gaze angles which are comfortable for the visual system.

While consistent with epidemiological research which has found an association between "eye level" monitor heights and neck discomfort (Bergquist et al., 1995), two aspects of this suggestion require further examination. The first is the question of what the consequences of lowering the monitor actually are in terms of the head and neck postures adopted. Kumar (1994) reported head and neck posture, surface electromyography, and subjective discomfort measures of bi-focal wearers using different monitor height placements. For this group of users, head and neck inclination increased with lower monitor placement, while the amplitude of trapezius electromyography and subjective discomfort measures were reduced. One aim of the research reported here is to address this question further by describing the influence of "top of screen at eye level" and "low" monitor locations on the head and neck posture of non-bifocal wearers performing a word processing task.

The second question which requires further examination is the more difficult one of what the consequences of these postures are for discomfort and subsequent injury (assuming that a link between discomfort and injury exists). While there has been considerable work undertaken to assess the biomechanical, electromyographic, and subjective consequences of different degrees of neck flexion (e.g., Chaffin, 1973; Kumar and Scaife, 1979; Moroney et al., 1988), with the exception of some limited work on the electromyographic consequences of extreme postures (Harms-Ringdahl et al., 1986; Schuldt et al., 1986), postures involving head or neck extension have received little attention. There is little understanding of the possible mechanisms involved in causing discomfort, or indeed, the specific postures which are likely to result in discomfort. While a definitive response is not possible at this time, the issues involved will be considered in light of the results reported here.

1. Method

1.1. Subjects

Twelve staff and students from a university population (aged 21–30) volunteered to participate. All were familiar with keyboard/monitor workstations and possessed some word processing experience.

1.2. Procedure

Each subject was provided with a chair, desk, document holder, keyboard, and monitor. The chair, document holder, and monitor were adjustable in height and tilt, and the desk was adjustable in height only. Each subject participated in two experimental conditions which differed only in the location of the computer monitor. In one condition (the "eye level" condition) the monitor was placed such that the screen was vertical, the horizontal distance from the eye to monitor was 0.58 m, and the top of the screen was level with the eyes when sitting in an upright posture. In the other condition (the "low" condition) a monitor location similar to that suggested by Ankrum and Nemeth (1995) was imposed. In this condition the monitor was inclined backwards by 30°, the distance between the eye and monitor increased to 0.7 m, and the top of the screen lowered to 18° below eye level (see Fig. 1 for illustrations of these conditions). All other dimensions were self-selected by each subject. The posture adopted by subjects was necessarily unconstrained and a small amount of variability of actual screen to eye distance and gaze angle relative to the horizontal existed across the duration of the trials. The order of presentation of conditions was randomised and balanced.

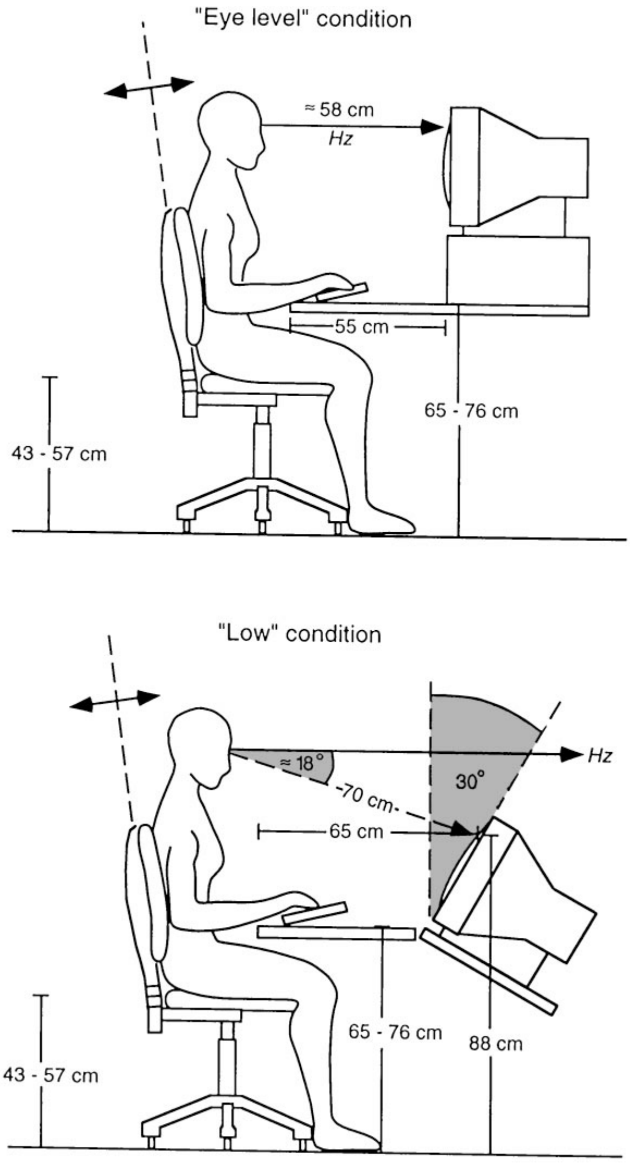

Fig. 1. Workstation layout in "Eye level" and "Low" monitor conditions.

Instruction in the mechanisms of adjustment were provided in a 10 min familiarisation session. After the familiarisation session, spherical reflective markers were attached to the outer canthus of the eye, the mastoid process on a line joining the tragus and outer canthus, the spinous process of the seventh cervical vertebra, and the greater trochanter. These markers were used to define head and neck angles (Fig. 2) which describe the position of the head and neck modelled as three rigid links articulated at pin joints located at the level of atlanto-occipital joint and between C7-T1. The position of the head with respect to the external environment was described by calculating the position of the ear-eye line with respect to the horizontal (Fig. 2).

During the experimental sessions, the reflective markers were illuminated by a 1000 W light placed behind the camera, and the movement of these markers recorded on a Panasonic AG-6300 VHS recorder using a NEC TI-23A CCD camera. The two-dimensional joint angular kinematics were subsequently obtained via automated digitisation (at 30 Hz) of these markers. The tape was replayed through a video processor (VP110, MotionAnalysis Corporation, California, USA) which identifies the pixel coordinates at which transitions occur between light and dark regions and relays these coordinates to PC-based FLEXTRAK software (MotionAnalysis Corporation, California, USA). The two-dimensional coordinates of each marker were obtained by calculating the centroid of each marker outline for each digitised video frame. Standard FLEXTRAK software was used to generate two-dimensional spatial paths as a function of time for each of the four markers.

A 5 min adjustment phase was provided during which subjects were instructed to select a workstation configuration (seat height, back-rest inclination, keyboard position, document holder position and inclination, and desk height) in a manner which felt most comfortable to them. These workstation dimensions were recorded and the configuration maintained for the duration of the work session.

After the adjustment phase, subjects completed a 30 min work phase in which they made corrections to a document displayed on the monitor from

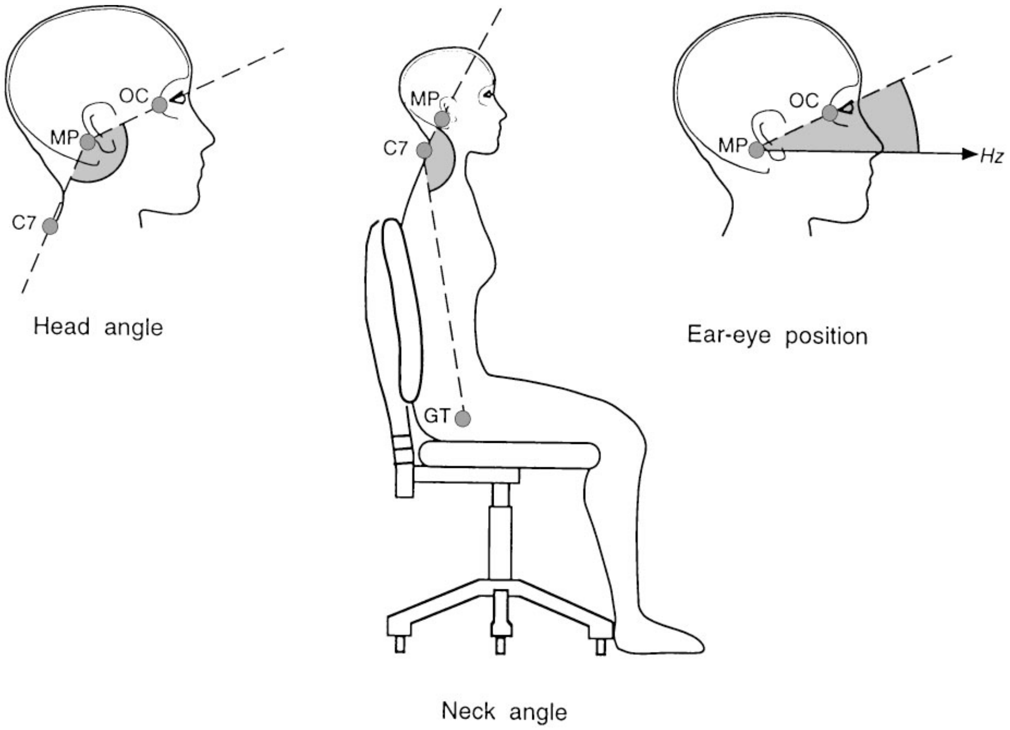

Fig. 2. Placement of markers and definitions of joint angles: OC = outer canthus of the eye, MP = mastoid process on a line joining tragus and outer canthus, C7 = cervical spinous process VII, and GT = greater trochanter. Ear-eye position is defined as the anterior angle subtended between the ear-eye line (a line joining MP and OC markers) and the horizontal. Head angle is defined as the anterior angle subtended by lines joining C7, MP, and OC markers. Neck angle is defined as the anterior included angle subtended between lines joining GT, C7, and MP markers. All angles are defined according to a counterclockwise positive convention, and consequently, increased with neck and head extension. Ear-eye line above the horizontal is positive, and an ear-eye line below the horizontal is negative.

marked hardcopy (font = 14 point Helvetica in both cases). Six, 50 s samples were collected from each 30 min testing period. These samples were extracted during minutes 4–5, 9–10, 14–15, 19–20, 24–25, and 29–30. The position of the ear-eye line with respect to the horizontal, and head and neck angles were calculated for each point, and the data then reduced by extracting every tenth frame yielding an effective frame rate of 3 Hz.

1.3. Analysis

The mean, minimum, and maximum values of each angle were calculated for the 150 data points in each sampled time period. Modal values of each angle for each sample were calculated from a frequency distribution using 2° bin widths. The effect of monitor location on posture was assessed by submitting the average of these values for each subject in each monitor location condition to separate one-way Analysis of Variance (ANOVA).

2. Results

Examination of the summary statistics (Table 1) reveals reliable differences between the "eye height" and "low" monitor conditions in terms of the postures adopted to perform the word processing task. The positions of the neck relative to the trunk did not differ; however, greater flexion of the atlanto-occipital and upper cervical joints was observed in the "low" monitor condition. Specifically, while the "low" monitor was associated with an increase in

Table 1
Summary statistics for measures describing posture as a function of monitor location

Measure	"Eye level" condition Mean (sd)	"Low" condition Mean (sd)	F	p
Neck angle mean (deg)	120.5 (7.0)	118.7 (5.1)	4.59	= 0.058
Neck angle maximum (deg)	129.8 (7.7)	126.2 (5.3)	12.7	= 0.005
Neck angle minimum (deg)	111.8 (7.6)	109.5 (6.1)	1.02	= 0.336
Neck angle mode (deg)	121.8 (7.6)	119.3 (5.8)	2.339	= 0.157
Head angle mean (deg)	147.8 (8.2)	142.8 (9.2)	7.04	= 0.024
Head angle maximum (deg)	159.5 (8.8)	155.8 (11.1)	1.75	= 0.215
Head angle minimum (deg)	132.5 (8.8)	131.0 (9.1)	0.88	= 0.370
Head angle mode (deg)	148.8 (8.8)	140.2 (10.4)	12.5	= 0.005
Ear-eye position mean (deg)	6.9 (7.4)	− 0.8 (7.0)	27.1	< 0.001
Ear-eye position maximum (deg)	18.5 (6.7)	7.9 (8.8)	41.5	< 0.001
Ear-eye position minimum (deg)	− 7.5 (9.7)	− 10.9 (7.5)	2.29	= 0.160
Ear-eye position mode (deg)	9.0 (8.2)	− 0.8 (7.3)	31.94	< 0.001

Note: All degrees of freedom for ANOVA (1,10).

the average maximum flexion of the neck relative to the trunk of 4° ($p = 0.005$), the effect of monitor location on mean, minimum, and modal neck position was smaller and not-significant. The extremes of head position relative to the neck (maximum and minimum head angles) were not significantly influenced by changes in monitor location; however, significant changes in the mean and modal values indicate that the distribution of positions within these extremes was altered. Lowering the monitor increased the mean flexion of the head relative to the neck by 5° ($p = 0.024$), and the average modal value 9° ($p = 0.005$).

These alterations in joint position were reflected in changes in the orientation of the head with respect to the external environment (Table 1). Lowering the monitor reduced the average maximum and modal gaze angle value by 10° and the mean gaze angle by 8°. Combining these values for ear-eye inclination with respect to the horizontal with the location of the centre of the monitor in each condition, allows an estimate of the range of gaze angles relative to the ear-eye line (Fig. 3). In the "eye level" monitor condition, the average gaze angle below the ear-eye line to the centre of the monitor was 17° (10° + 6.9°) below the ear-eye line, with an average range from 2.5° above the ear-eye line to 28.5° below. In the "low" condition, the average gaze angle was 25° below the ear-eye line (26° − 0.8°), and the average range from 15 to 32° below the ear-eye line. Comparison of these values with the preferred gaze angles determined in previous research (between 35° and 44° below the ear-eye line; Kroemer and Hill, 1986) reveals that in both conditions subjects typically adopted a posture which compromised their preferred gaze angle, but in the "low" condition the gaze angle was closer to a preferred angle (by an average of 8°).

3. Discussion

Lowering the monitor did not cause changes in the posture of the neck relative to the trunk, but did increase the flexion of the head relative to the neck. Subjects did not adopt postures in either condition which approximated the previously reported preferred gaze angles, although the gaze angles adopted in the "low" condition were closer.

It is not clear what the functional consequences of the observed postural changes might be. Increases in flexor moment are an inevitable

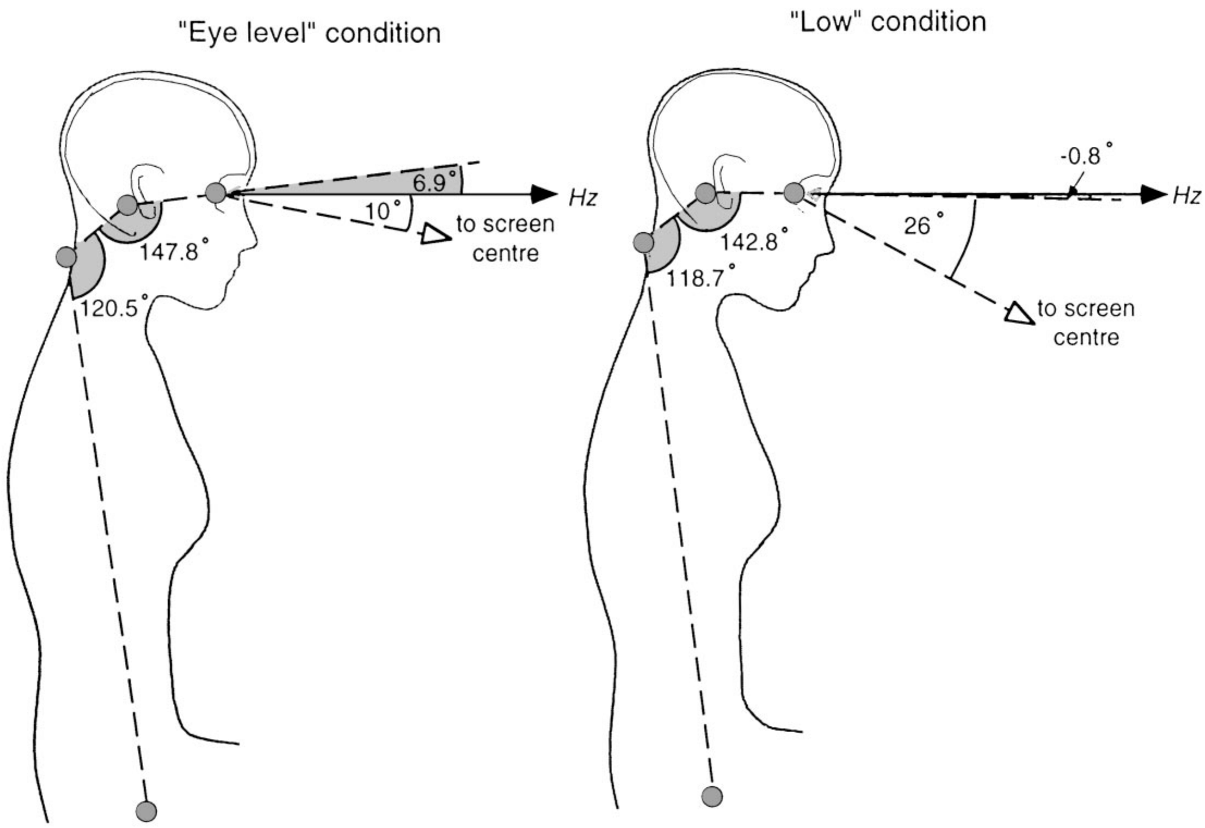

Fig. 3. Average postures adopted in "eye level" and "low" monitor conditions.

consequence of increased head inclination, and hence greater muscle activity might be expected in the extensor musculature. However Kumar (1994) found that while head and neck inclination and flexor moments were increased by lower monitors, the amplitude of trapezius electromyography, and subjective ratings of discomfort, were decreased. An understanding of this previous finding, and of the functional consequences of the postural changes reported here, requires a more detailed consideration of the biomechanics of the head and neck.

The head and neck system comprises a rigid mass of about 4–5 kg (the head) located above a flexible cervical spine. Flexion and extension are possible at the atlanto-occipital and cervical joints. The ligaments and joint capsules are elastic, especially within the mid range, and a large range of movement is possible without significant contribution from passive tissues (Goel et al., 1988).

The centres of mass of the head, and the head and neck combined, are anterior to the neck. Consequently, when the trunk is vertical extensor muscular activity is required to maintain static equilibrium. A large number of muscles with diverse sizes, characteristics, and attachments are capable of contributing to an extensor torque about atlanto-occipital and cervical joints. The suboccipital muscles, which take origin on C1 and C2 and insert on the occiput, are capable of providing extensor torque about the atlanto-occipital joint only; others (such as semispinalis capitis and cervicus) provide extensor torque about cervical as well as atlanto-occipital joints; while others (such as iliocostalis cervicus) provide extensor torque about cervical vertebrae only (Smith et al., 1996). While the sternocleidomastoids have been proposed as extensors of the atlanto-occipital joint and flexors of the cervical spine (Worth, 1994), their attachments on the mastoid processes are very close to the axis of rotation, and consequently, sternocleidomastoid provides no significant extension torque about the atlanto-occipital joint (Winters and Peles, 1990).

Increased flexion at the atlanto-occipital joint increases the horizontal distance of the centre of mass of the head from its axis of rotation (level with the mastoid process). Similarly, with the trunk in a vertical position, an increase in flexion of the cervical spine increases the horizontal distance of the centre of mass of the head and neck combined from the axes of rotation in the vertebral column (and also, all else remaining the same, the horizontal distance of the head from its axis of rotation). Hence, with the trunk in an upright position, both atlanto-occipital and cervical flexion increases the torque required of the extensor musculature to maintain static equilibrium.

Increases in neck flexion beyond 30° are associated with decreased time to fatigue when held isometrically (Chaffin, 1973), presumably a consequence of the increased load moment. According to one model (Snijders et al., 1991), neck *extension* of 30° places the centres of mass approximately over the axes of rotation and reduces the external flexor moment required to resist gravitational acceleration to zero. In contrast to the suggestion made by Ankrum and Nemeth (1995), this logic prompted de Wall et al. (1992) to suggest *increasing* the height of visual targets, such as computer monitors, in order to increase neck extension and (it was assumed) reduce the muscular effort required to maintain this posture.

A number of critical elements are missing from the argument that computer monitors should be located at, or above, eye level to promote a posture involving a relatively extended head and neck, and, hence, reduced muscular effort. The first missing element is a recognition that flexion–extension motion can occur about axes of rotation at different levels, from movement at one level only, to combinations of rotation at different levels of the cervical spine (Worth, 1994). Indeed, flexion may occur at one level, say, about an axis in the lower cervical vertebra while extension occurs at another, say, the atlanto-occipital joint.

The second missing element is a recognition of the inherent instability of the head and neck system, especially in the upright position (Winters and Peles, 1990). The neck muscles must do more than just balance the external forces acting on the system. For the system to be stable, additional co-contraction is required to increase the stiffness of the cervical spine and prevent local buckling. The consequence is that significant muscular activity is probably still required even if the head and neck are positioned such that the flexor torque imposed by gravitational acceleration is minimised. Further, the necessity for muscle activity to stabilise the cervical spine is likely to be greater when it is relatively extended (Winters and Peles, 1990).

The third and fourth missing elements are knowledge of the effect of changes in posture at the atlanto-occipital and cervical joints on both the moment arm, and the average fibre length, of muscles active to provide both the required extensor torque and stiffness. While accurate estimates of moment arm and fibre length changes are available for few of the more than 40 muscles of the neck, it is clear that muscle fibres which produce extensor torque will be shortened to some extent by increased extension of the head and neck. What is open to speculation is the gradient of the length/tension relationship at this point.

The above elements contribute to an argument that postures involving a combination of flexion at cervical joints and extension at the atlanto-occipital joints (a forward head posture, e.g., Cailliet, 1991) may result in discomfort and subsequent injury. While not well quantified (see eg., Dalton and Coutts, 1994), such postures have attracted the ire of therapists, and have previously been associated with physical complaints such as headaches (Watson, 1994).

Maintenance of a forward head posture places the centre of mass of both head, and head and neck combined, anterior to the respective centres of rotation, thus requiring extensor moments about both atlanto-occipital and cervical joints. Such a posture involves a reduction in the average fibre length of the muscles contributing to the necessary extensor torque about the atlanto-occipital joint, and possibly the average fibre lengths of some of the muscle facsicles contributing to the co-contraction necessary to stabilise the cervical spine in this position.

While the length/tension characteristics of individual fascicles are unknown, it is possible that this shortening reduces the tension-generating capabilities of these muscles. The requirement for cervical flexion reduces the possible contribution to atlanto-occipital extensor moment by muscles which extend the cervical vertebrae and, consequently, a contribution to atlanto-occipital extension moment is required of suboccipital muscles. These muscles are relatively short, and even a small change in average fibre length caused by extension of the atlanto-occipital joint is likely to cause significant decrement in their tension generating capabilities. Yet it is precisely these muscles which appear to be primarily responsible for vertical movements about axes high in the cervical spine (Winters and Peles, 1990).

In the light of this line of reasoning, the finding that a "low" monitor location is associated with little change in the position of the neck with respect to the trunk, but is associated with a reduction in the extension of the atlanto-occipital and upper cervical spine, may take on additional significance. The postures observed may well be the consequence of attempting to reach a compromise between the visual discomfort caused by gaze angles higher than preferred, and the musculo–skeletal discomfort caused by maintaining postures involving lower cervical flexion and upper cervical and atlanto-occipital extension.

When the above arguments and the data presented here are considered in conjunction with the characteristics of the visual system and epidemiological data, the weight of evidence is such that recommendations of the "top of monitor at eye height" type must be questioned. Indeed, monitor locations lower than the one investigated in this study may allow the user to achieve preferred gaze angles while adopting a range of postures which do not involve relatively extended upper cervical and atlanto-occipital joints.

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