Visual Display Height

Robin Burgess-Limerick, Mark Mon-Williams, and **Vanessa L. Coppard,** University of Queensland, Queensland, Australia

We examined the influence of backrest inclination and vergence demand on the posture and gaze angle that workers adopt to view visual targets placed in different vertical locations. In the study, 12 participants viewed a small video monitor placed in 7 locations around a 0.65-m radius arc (from 65° below to 30° above horizontal eye height). Trunk posture was manipulated by changing the backrest inclination of an adjustable chair. Vergence demand was manipulated by using ophthalmic lenses and prisms to mimic the visual consequences of varying target distance. Changes in vertical target location caused large changes in atlanto-occipital posture and gaze angle. Cervical posture was altered to a lesser extent by changes in vertical target location. Participants compensated for changes in backrest inclination by changing cervical posture, though they did not significantly alter atlanto-occipital posture and gaze angle. The posture adopted to view any target represents a compromise between visual and musculoskeletal demands. These results provide support for the argument that the optimal location of visual targets is at least 15° below horizontal eye level. Actual or potential applications of this work include the layout of computer workstations and the viewing of displays from a seated posture.

INTRODUCTION

Many occupations require employees to fixate visual targets (e.g., computer monitors or other visual displays). Although some people perform such tasks with no adverse consequences, others can experience visual and postural discomfort (e.g., Bergqvist, Wolgast, Nilsson, & Voss, 1995; Jackson et al., 1997). One aspect of workstation design that influences the incidence of discomfort is the vertical location of the visual display (Bergqvist et al., 1995). Conventional recommendations regarding computer monitors advocate locating the monitor even with or just below horizontal eye level (e.g., National Occupational Health and Safety Commission, 1989). A recent *Human Factors Design Guide* sponsored by the U.S. Federal Aviation Authority (Wagner, Birt, Snyder, & Duncanson, 1996) suggested that the optimal location for visual displays is in an arc extending from horizontal eye height down to 30° below horizontal eye height (see exhibits 7.2.1.6.3 and 7.2.1.6.8).

Such recommendations are not based on empirical findings, and a number of authors have argued that the optimal location of visual targets is somewhat lower. Ankrum and Nemeth (1995) suggested that visual targets should be located at least 15° below horizontal eye height. Kroemer, Kroemer, and Kroemer-Elbert (1994) suggested that visual targets should be 30° or more below horizontal eye height. The argument for lower visual targets is based on the observation that there is a subjective preference for targets to be positioned such that the eyes rotate downward relative to the head (Bergqvist & Knave, 1994; Heuer, Bruewer, Roemer, Kroeger, & Knapp, 1991; Hill & Kroemer, 1986; Hsiao & Keyserling, 1991; Mon-Williams, Burgess-Limerick, Plooy, & Wann, 1999). Kroemer and Hill (1986), for example, measured the average preferred gaze angle as 35° below the ear-eye line (a line joining

Address correspondence to Robin Burgess-Limerick, School of Human Movement Studies, University of Queensland, QLD 4072, Australia; robin@hms.uq.edu.au. **HUMAN FACTORS**, Vol. 42, No. 1, Spring 2000, pp. 140–150.

the external auditory meatus and the outer canthus) for visual targets at 1 m and 44° below the ear-eye line for targets at 0.5 m. Mon-Williams et al. (1999) found that the preferred gaze angle of 12 participants ranged from 19° to 36° below the ear-eye line (mean = 27°) for a target at 0.65 m.

Mon-Williams et al. (1999) proposed a mechanical mechanism for this phenomenon based on the knowledge that an observer's eyes must converge to maintain single vision of near visual targets. The activation of the medial recti muscles of the eye produces this ocular vergence. However, the extraocular muscles that raise the eyes (the superior recti and inferior obliques) also create a horizontal divergent force. Thus raising the eyes increases the activation required of the medial recti, which causes visual discomfort. This simple mechanical model explains why observers prefer to look downward to view near targets and why the preferred vertical gaze angle gets progressively lower for closer objects. Measurements of open-loop heterophoria (an indirect measure of vergence effort) as a function of vertical gaze angle are consistent with these conclusions (Mon-Williams et al., 1999; Mon-Williams, Plooy, Burgess-Limerick, & Wann, 1998).

In a normal erect posture, the ear-eye line is typically about 15° above horizontal eye height (Jampel & Shi 1992). Consequently, for seated observers to fixate a visual target placed at horizontal eye height, they must either compromise their preferred gaze angles (leading to increased vergence effort) or rotate their heads posteriorly by some combination of atlanto-occipital or cervical extension. In previous experiments we have established that both gaze angle and head orientation are altered by changes in the vertical location of visual targets (Burgess-Limerick, Plooy, & Ankrum, 1998; Burgess-Limerick, Plooy, Fraser, & Ankrum, 1999). In addition, we observed that participants adopted gaze angles that were higher than preferred when the visual target was higher than 15° below horizontal eye level (Mon-Williams et al., 1999). On the basis of these data we have argued that visual targets should be located at least 15° below horizontal eye level.

In these previous experiments, however, the inclination of the trunk was held constant or uncontrolled. In addition to attempting to replicate these results, one of our aims in this experiment is to determine whether trunk inclination influences the posture adopted and hence the gaze angle adopted to view any given visual target location. If trunk inclination influences vertical gaze angle, then recommendations regarding the appropriate location of visual displays must encompass consideration of the trunk posture adopted at any particular workstation.

Closer visual targets increase vergence demand. However, it is not known whether these changes in vergence demand cause changes in the posture adopted to view visual targets. A further aim of this experiment is to determine whether changes in vergence demands cause changes in the gaze angles that are adopted. Increased vergence demands might cause participants to adopt a posture that involves greater posterior rotation of the head (achieved by some combination of atlanto-occipital and cervical extension) and thus might reduce vergence effort by allowing lower gaze angles. If posture is altered by vergence demands, then recommendations regarding the appropriate location of visual displays must encompass consideration of the display distance. If posture is not altered by increased vergence demands, then the consequences of placing visual displays in locations that are viewed using gaze angles that are higher than preferred will be exacerbated as the distance to the display decreases.

In previous experiments we have noted that the changes in head orientation associated with changes in vertical target location are achieved predominantly by changes in atlanto-occipital posture, whereas cervical posture remains relatively unaltered. The final aim of this experiment is to determine the relative contribution of atlanto-occipital and cervical changes to any changes in posture induced by alterations in backrest inclination or vergence demand and to determine the potential musculoskeletal consequences of the postural responses.

METHOD

Participants

The participants consisted of 12 students (6 women and 6 men aged 20–28) who volunteered to participate in the experiments. They did not receive any reward.

Procedure

Participants were seated and viewed a small color video monitor (4.5-cm high × 5.5-cm wide) on which a cartoon was continuously displayed. The screen was placed at varying locations on a 0.65-m-radius arc so that the video monitor remained 0.65 m from the eye. The center of the arc was placed at the same height as the outer canthus of the eye in the midsagittal plane. For each trial the monitor was placed in one of the following seven locations: +30°, +15°, 0°, –15°, –30°, –45°, and –60° with respect to a virtual horizontal line passing from the eye through the center of the arc. Positive values indicate target locations above horizontal eye height. We manipulated trunk inclination by changing the backrest inclination of an adjustable chair (Monarch; Posture Seating Inc., Brisbane, Australia) to either an upright position, in which the trunk angle was 100°, or a reclined position, in which the trunk angle was 110° (see Analysis section for definition).

Participants wore a standard ophthalmic trial frame (a pair of spectacles with interchangeable lenses and prisms) throughout the experiment. A combination of ophthalmic lenses and ophthalmic prisms was used to manipulate vergence demand. The prisms were designed to minimize unwanted optical aberrations: They had no refractive power but had a curved front and rear surface. This type of prism is called a *meniscus plano* prism. The use of lenses and prisms allowed precise manipulation of vergence effort while all other aspects of the experimental setup (e.g., the visual appearance and size of the target) remained constant (see Tresilian, Mon-Williams, & Kelly, 1999). It was important to use a combination of lenses and prisms in order to avoid a conflict between accommodation and vergence (these ocular-motor responses are neurally cross-linked). Three different vergence demands were created: (a) plano meniscus lenses were used so that vergence demand was equal to that normally present for a target at 0.65 m, (b) a combination of lenses and prisms was used to create the normal accommodation and vergence demands for a target at 0.50 m, and (c) a combination of lenses and prisms was used to create the oculomotor demands for a target at 0.33 m.

The experimental manipulations resulted in 42 conditions (7 Target Locations × 3 Vergence Demands × 2 Backrest Angles); one trial was performed in each condition. The backrest inclination and vergence demand conditions were presented in blocks; the order of blocks was balanced across participants. The seven target locations were presented in random order within each block. Each trial required the participant to view the video monitor for 1 min while the positions of infrared-emitting diodes (IREDs) placed on the participant were recorded at 1 Hz. The participants completed all the experimental trials in one session (lasting approximately 2 hr).

Analysis

The head, neck, and trunk were modeled as three rigid links articulated at pin joints located at the level of the atlanto-occipital joint and between the seventh cervical vertebra and first thoracic vertebra. Infrared emitting diodes (IREDs) were placed adjacent to the outer canthus (OC), on the mastoid process (MP) on a line joining the tragus and the outer canthus, on the spinous process of C7, and at the greater trochanter (GT). The three-dimensional coordinate of each IRED was recorded using an optoelectronic movement recording system (Optotrak, Northern Digital, Waterloo, Ontario, Canada). Optotrak is factory precalibrated and has a static positional resolution of within 0.2 mm. The projection of these IREDs in the sagittal plane was used to define the sagittal postures of the trunk, neck, and head (Figure 1).

The orientation of the trunk relative to the environment was described as the anterior angle subtended between a line joining the C7 and GT markers and the horizontal. The sagittal posture of the cervical spine was described by the anterior angle subtended by the MP, C7, and GT markers (neck angle). Sagittal posture of the skull relative to the atlas was described by the anterior angle subtended between the C7, MP, and OC markers (head angle).

The sagittal orientation of the eyes required to fixate the visual target from a particular head orientation (gaze angle) was calculated from the measured trunk, neck, and head angles. It

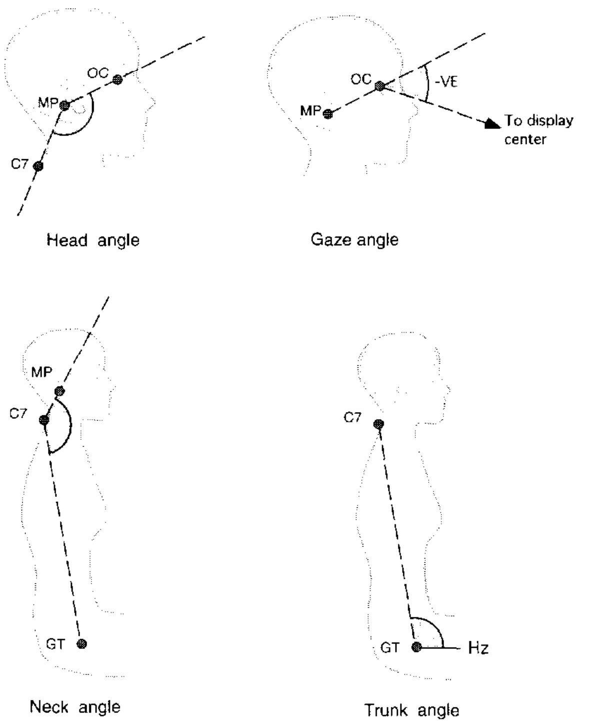

Figure 1. Definition of angles used to describe the adopted postures.

was expressed as the anterior angle subtending a line joining (a) the outer canthus and the target and (b) the line joining MP and OC markers (the ear-eye line). A negative value indicates that the gaze angle was below the ear-eye line.

The measured trunk, head, and neck angles and calculated gaze angles were averaged across the 60 samples from each trial. The means were submitted to three-way (2 × 3 × 7) fully-repeated-measures factorial analysis of variance (ANOVA) for each of the four dependent variables. A Bonferroni correction was employed to maintain the experiment-wise error rate below .05. As a consequence, only those main effects or interactions with probability values of less than .002 were considered statistically reliable. Multiple ANOVAs with appropriate Bonferroni correction were preferable to multivariate analysis of variance (MANOVA) in this situation because Type 1 error rate is not fully controlled by MANOVAs (Huberty & Morris, 1989). We calculated 95% confidence intervals for all group mean values.

RESULTS

Summary statistics for the ANOVA are presented in Table 1. Neither the three-way interaction nor the two-way interaction was statistically significant, indicating that the effects of backrest inclination, vergence demand, and target location on posture were independent. The manipulation of trunk inclination was effective: The mean (95% confidence interval) trunk inclination was 100° (±0.05°) and 110° (±0.09°) in the upright and inclined backrest conditions, respectively. Trunk orientation was otherwise unaffected by the independent variables and did not differ across changes in vergence demand or target location.

The effects of backrest inclination and target location on the head and neck angle are illustrated in Figure 2. A 90° change in vertical target location was associated with an average 41° change in head angle, from 176° (±2.9°) when the target was 30° above the horizontal eye height to 135° (±2.4°) when the visual target was 60° below the horizontal. The effect of target location on neck angle was also statistically reliable, but the effect was smaller than that observed with head angle. It changed only 14° from an average of 121° (±2.4°) in the 30° target location to 107° (±1.7°) in the –60° target location. The effect of target location on neck angle was restricted to target locations lower than –15°, in that the neck angle adopted for higher target locations was not reliably different from the neck angle adopted at –15°. A 10° increase in backrest inclination caused an average 7° decrease in neck angle (from 122° ±1.2° to 115° ±1.1°), suggesting that participants compensated for the resulting posterior trunk rotation primarily by an increase in cervical flexion. In contrast, head angle was not significantly influenced by changes in backrest inclination, suggesting that the posture of the atlanto-occipital joint was not sensitive to changes in backrest inclination.

The effect of target location and backrest inclination on the calculated gaze angle is illustrated in Figure 3. Gaze angle was significantly influenced by the manipulation of target location (from –12° ±2.6° when the target was 30° above horizontal eye height to –48° ±2.5° when the target was 60° below horizontal eye height). This result indicates that the change in target location caused participants to change the orientation of their eyes 36° relative to the head in order to maintain target fixation through the 90° target range.

TABLE 1: Summary Statistics for the Three-Way (2 × 3 × 7) Fully-Repeated-Measures Factorial ANOVA Performed for Each of the Four Dependent Variables.

	Trunk Angle		Neck Angle		Head Angle		Gaze Angle	
Dependent Variable	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*
				Main Effect				
Backrest *df* = (1,11)	2600	<.0001	28.4	<.0001	0.2	.668	13.8	.003
Vergence *df* = (2,22)	0.1	.887	0.3	.712	0.6	.674	0.5	.629
Target *df* = (6,66)	1.3	.234	42.9	.0001	87.5	.0001	70.6	.0001
				Two-Way Interactions				
Backrest × Vergence *df* = (2,22)	0.6	.544	0.8	.475	0.3	.766	0.8	.462
Backrest × Target *df* = (6,66)	0.3	.913	1.5	.186	1.5	.200	.99	.443
Vergence × Target *df* = (12,132)	1.2	.269	2.2	.014	1.5	.131	2.7	.003
				Three-Way Interaction				
Backrest × Vergence × Target *df* = (12,132)	0.9	.588	1.7	.074	1.0	.412	1.5	.122

Note: A Bonferroni correction was employed to maintain the experiment-wise error rate below .05. As a consequence, only those main effects or interactions with probability values less than .002 were considered to be statistically significant.

There was no reliable effect of vergence demand. As the means and confidence intervals represented in Figure 4 illustrate, the posture of the head and neck (and consequently the calculated orientation of the eyes with respect to the head) were virtually identical regardless of the vergence demand induced by the prism manipulation. The use of the opthalmic trial frame to manipulate vergence demand provides a potential confound to this result. Comparison of these data with previous results (Mon-Williams et al., 1999) indicates that the trial frames altered the gaze angles adopted at the extremes of target locations. This alteration created a lower gaze angle at extremely high target locations and a higher gaze angle at extremely low target locations. However, the same frames were worn in all conditions, and the overall pattern of results was consistent with previous results. Consequently, although it is not possible to completely exclude the possibility of a confounding effect, the observed differences in gaze angle in response to changes in target location suggest that it is not likely that the trial frames caused the absence of changes in gaze angle in response to changes in vergence demands.

DISCUSSION

The results demonstrate a strong relationship among visual target location, gaze angle, and atlanto-occipital posture. For a constant backrest inclination, changes in vertical target location were accommodated by changes in

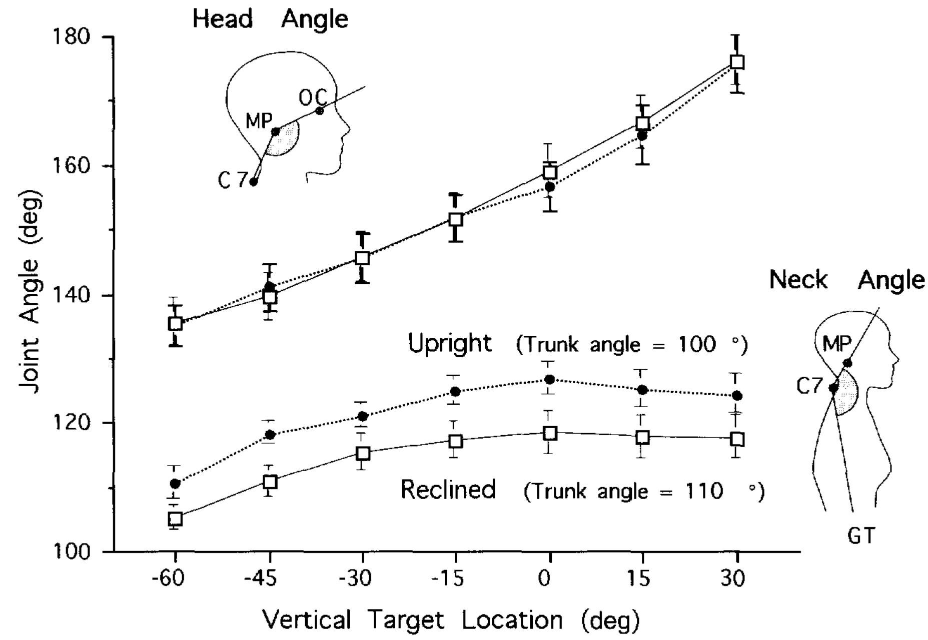

Figure 2. Mean sagittal atlanto-occipital posture (head angle) and cervical posture (neck angle) adopted as a function of vertical target location and backrest inclination. Error bars indicate 95% confidence intervals.

both gaze angle and atlanto-occipital posture, whereas cervical posture was altered to a much lesser extent. Participants adopted gaze angles that were higher than preferred (based on previous reports) for target locations higher than −15°. These observations are consistent with our previous experiments (Burgess-Limerick et al., 1998; Burgess-Limerick et al., 1999; Mon-Williams et al., 1999).

There was also a strong relationship between backrest inclination and cervical flexion. Increases in trunk angle induced by changes in

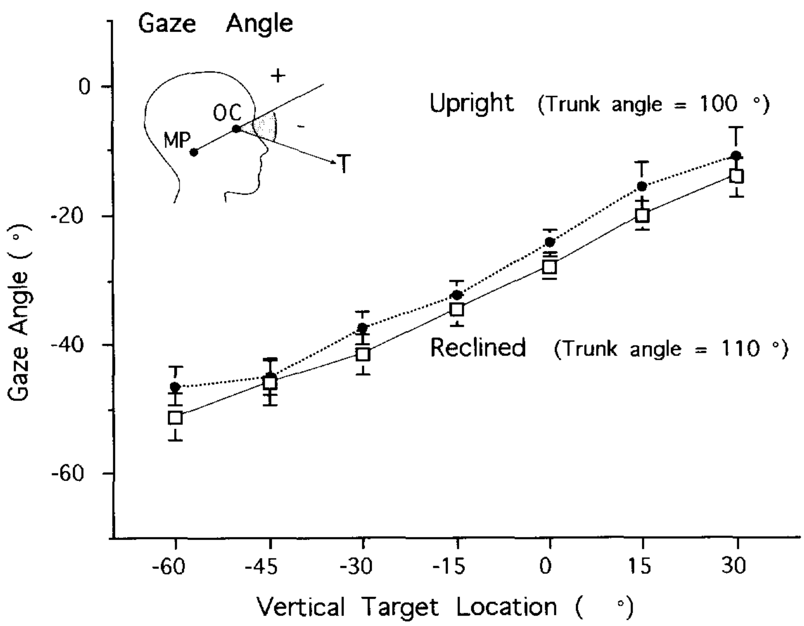

Figure 3. Mean calculated gaze angle relative to the head (gaze angle) as a function of vertical target location and backrest inclination. Error bars indicate 95% confidence intervals.

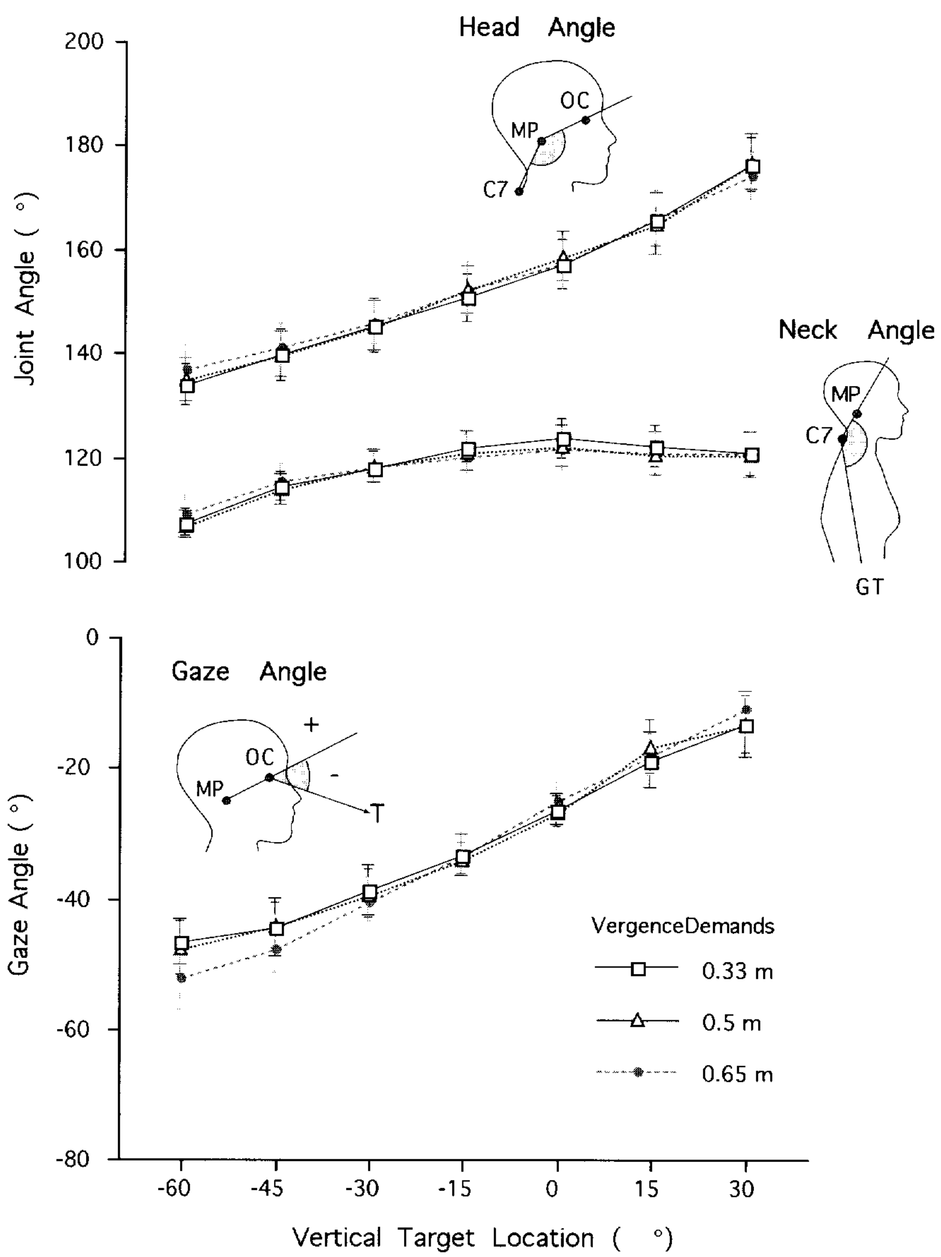

Figure 4. Mean atlanto-occipital posture (head angle), cervical posture (neck angle), and gaze angle relative to the head as a function of vergence demands and backrest inclination.

back-rest inclination were associated with corresponding decreases in neck angle, indicating increased cervical flexion. Thus the orientation of the head relative to the external environment (and hence the gaze angle) was relatively unaffected by changes in backrest inclination of the magnitude investigated in this study.

The finding that backrest inclination did not significantly influence gaze angle suggests that the conclusions drawn from previous experiments regarding the optimal placement of visual displays can be generalized to workstations in which the trunk is approximately vertical without consideration for the precise backrest inclination of the seat. The generalized nature of this conclusion is consistent with epidemiological research that has found an association between eye-level computer monitor heights and neck discomfort (Bergqvist et al., 1995).

The change in vergence demands induced by the prism manipulations was substantial in optical terms, corresponding to changes in target distance from 0.65 m to 0.33 m. The absence of any influence of these changes on the posture that participants adopted to view the visual targets, despite the assumed effect of a preference for a lower gaze angle, suggests that participants placed greater weight on musculoskeletal demands than on vergence demands, at least in this situation (when the duration of continuous fixation was short [60 s]). Such a situation is typical of that frequently encountered, for example, in the situation of a nontouch typist who shifts fixation repeatedly between monitor, hard copy, and keyboard. Given that vergence demands increase with reduced target distance, the potential for visual fatigue associated with placing visual displays at a level higher than optimal is increased for closer displays. This conclusion is consistent with subjective data on eye strain obtained in a field study (see Jaschinski, Heuer, & Kylian, 1998).

Interpretation of the consequences of the observed postural responses requires consideration of the biomechanics of the head and neck. The head and neck system comprises a rigid head located above a relatively flexible cervical spine. Flexion and extension are possible at the atlanto-occipital and cervical joints. The ligaments and joint capsules are relatively elastic, especially within the midrange, and a large range of movement is possible without significant contribution from passive tissues (Goel, Clark, Gallaes, & King Liu, 1988).

The centers of mass of the head and the head and neck combined are anterior to the atlanto-occipital and cervical joints. Consequently, extensor torques about the atlanto-occipital and cervical joints are required to maintain static equilibrium when the trunk is vertical. A large number of muscles with diverse sizes, morphology, and attachments can contribute to these torques. The suboccipital muscles, which origininate on C1 and C2 and are inserted on the occipital bone, can provide extensor torque only about the atlanto-occipital joint. Others (such as semispinalis capitis) provide extensor torque about cervical as well as atlanto-occipital joints. Still others provide extensor torque only about cervical vertebrae (Mayoux-Benhamou, Revel, & Vallee, 1997).

Increased flexion at the atlanto-occipital joint increases the horizontal distance of the center of mass of the head from its axis of rotation (level with the mastoid process). Similarly, when the trunk is approximately vertical, an increase in flexion of the cervical spine increases the horizontal distance of the center of mass of the head and neck combined from the axes of rotation in the vertebral column (and, assuming the position of the atlanto-occipital joint remains constant, the horizontal distance of the center of mass of the head from its axis of rotation also increases). Hence with the trunk approximately vertical, both atlanto-occipital and cervical flexion increases the torque required of the extensor musculature to maintain static equilibrium. The conventional view, based on the aforementioned analysis, is that an erect head and neck posture that reduces the flexor moment of the head is preferred. According to one model (Snijders, Hoek van Dijke, & Roosch, 1991), a neck extension of 30° places the centers of mass approximately over the axes of rotation and reduces the external flexor moment required to resist gravitational acceleration to 0. This logic has prompted recommendations to increase the height of visual targets such as computer monitors in order to increase neck extension and reduce muscular effort (de Wall, Van Riel, Aghina, Burdorf, & Snijders, 1992).

Although such a simplified model of the situation is intuitively attractive, the cervical spine is particularly complex. Thus there is no definitive answer to the question of the optimal posture (or range of postures) for the head and neck. In the paragraphs that follow we provide an analysis of the available empirical data related to this question to assist readers in interpreting the results reported here.

The recommendation to avoid static postures involving extreme neck flexion can be justified by an experiment conducted by Chaffin (1973). In that study the time taken to reach significant muscle fatigue decreased from 5 hr to 2 hr when neck flexion increased from 30° to 60°. The consequences of flexion of a lesser degree are less certain, however. Electromyographic (EMG) evaluations of different neck postures have yielded varied results. Schuldt, Ekholm, Harms-Ringdahl, Nemeth, and Arborelius (1986), for example, demonstrated that there was elevated EMG activity in posterior neck musculature during maximal flexion but that there were no significant differences for intermediate postures. Harms-Ringdahl, Ekholm, Schuldt, Nemeth, and Arborelius (1986) did not detect EMG differences between neutral and extreme flexion. Kumar (1994) reported decreased trapezius EMG and subjective discomfort associated with increased neck inclination and flexor moment. Turville, Psihogios, Ulmer, and Mirka (1998) also reported a decrease in mean trapezius activity when participants worked at a computer monitor that was lowered by 25°, but they found an increase in mean cervical erector spinae activity.

These apparent anomalies exist because the external flexor moment is only one factor contributing to the demands placed on neck musculature. Other factors that are involved include the muscle tension required to maintain stability of the flexible cervical spine and the influence of muscle length on tension-generating capability. The complexity of these competing demands make it difficult to determine an optimal posture. There are probably substantial individual differences in the consequences of any particular posture.

The head and neck system is inherently unstable, especially in the upright position (Winters & Peles, 1990). Consequently, the neck muscles must do more than just balance the external forces acting on the system. For the system to be stable, additional cocontraction is required to increase the stiffness of the cervical spine and prevent buckling. Thus significant muscular activity is probably required to stiffen the cervical spine, even if the head and neck are positioned to minimize the flexor torque imposed by gravitational acceleration. There is probably a greater necessity for muscle activity to stabilize the cervical spine when the spine is relatively extended (Winters & Peles, 1990).

Another contributing factor is that the tension-generating capability of a muscle is highly dependent on its length. In general, changes in posture at the atlanto-occipital and cervical joints alter both the moment arm and the average fiber length of muscles that actively provide the required extensor torque and stiffness. Although accurate measurements of moment arm and fiber length changes are not available, the muscle fibers that produce extensor torque are shortened to some extent by increased extension of the head and neck. The suboccipital muscles in particular are relatively short, and even a small change in average fiber length caused by extension of the atlanto-occipital joint is likely to cause significant decrement in their tension-generating capabilities. However, it is precisely these muscles that appear to be primarily responsible for vertical movements about axes high in the cervical spine (Winters & Peles, 1990). The best available estimates (Figure 5) suggest that extension of the atlanto-occipital joint beyond a neutral position rapidly leads to a decrease in the force-generating capability of the small suboccipital muscles. This is also true of muscles that cross both cervical and atlanto-occipital joints (such as semispinalis capitis), unless the cervical spine is in a markedly flexed posture.

In a normal erect posture the ear-eye line is typically 15° above horizontal eye height (Jampel & Shi, 1992). This provides the best available definition of the neutral posture of the atlanto-occipital joint. In the current experiment (consistent with previous research; Burgess-Limerick, Plooy, & Mon-Williams, 1998) the head was, on average, held in this erect posture when the visual target was 15° below horizontal eye height, regardless of trunk inclination or vergence demands. Searching for visual displays higher than 15° below horizontal eye height caused extension of the atlanto-occipital joint from the neutral position and led to gaze angles that were higher than preferred. Even a small amount of extension of the atlanto-occipital joint is likely to cause a decrement in the tension-generating capabilities of both the suboccipital muscles and the cervical muscles that are inserted on the occiput (although the gradient of the relationship for the latter muscle groups depends on the cervical posture). This description of the biomechanical consequences provides an explanation of why participants do not rotate their heads sufficiently posteriorly to adopt preferred gaze angles for viewing high targets. This description also supports the conclusion that the posture adopted to view any target represents a compromise between visual and musculoskeletal demands.

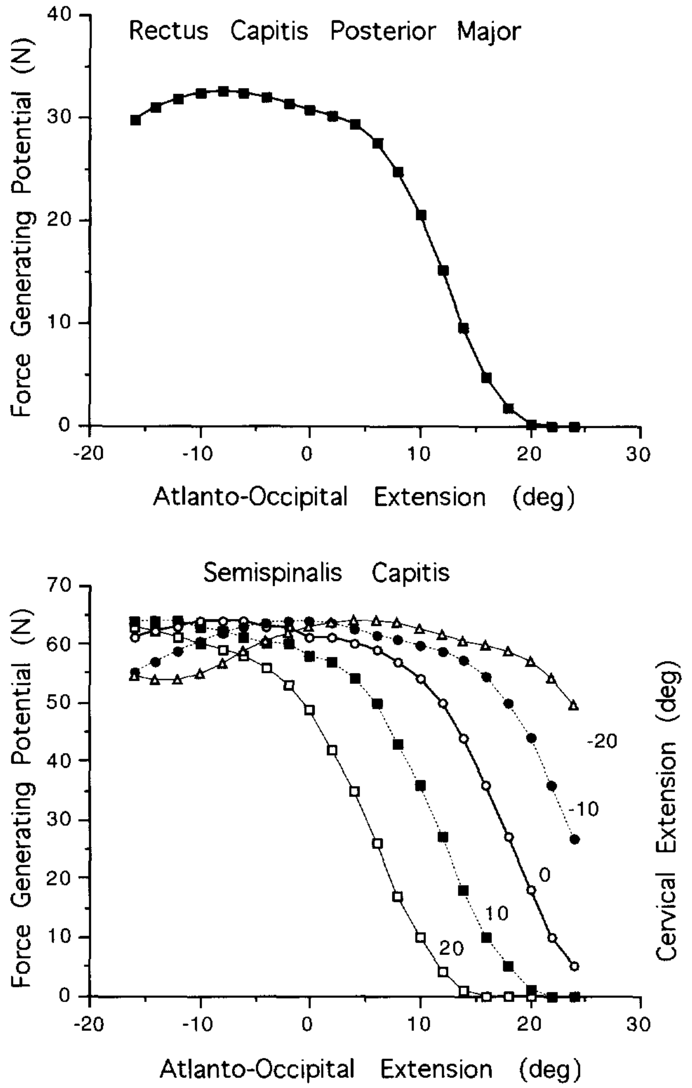

Figure 5. Estimated changes in the tension-generating capacity of rectus capitis posterior major as a function of atlanto-occipital extension and semispinalis capitis as a function of cervical and atlanto-occipital extension. This represents unpublished data supplied by Anita Vasavada, Rehabilitation Institute of Chicago. See Vasavada, Li, and Delp (1998) for model details. Neutral posture corresponds approximately to the posture adopted when visual targets were located 15° below horizontal eye height.

ACKNOWLEDGMENTS

This research was supported by Australian Research Council grant 99/ARCS306G.

REFERENCES

Ankrum, D. R., & Nemeth, K. J. (1995, April). Posture, comfort, and monitor placement. *Ergonomics in Design*, 7–9.

Bergqvist, U., & Knave, B. (1994). Eye discomfort and work with visual display terminals. *Scandinavian Journal of Work, Environment and Health, 20*, 27–33.

Bergqvist, U., Wolgast, E., Nilsson, B., & Voss, M. (1995). Musculoskeletal disorders among visual display terminal workers: Individual, ergonomic, and work organizational factors. *Ergonomics, 38*, 763–776.

Burgess-Limerick, R., Plooy, A., & Ankrum, D. (1998). The effect of imposed and self-selected computer monitor height on posture and gaze angle. *Clinical Biomechanics, 13*, 584–592.

Burgess-Limerick, R., Plooy, A., Fraser, K., & Ankrum, D. R. (1999). The influence of computer monitor height on head and neck posture. *International Journal of Industrial Ergonomics, 23*, 171–179.

Burgess-Limerick, R., Plooy, A., & Mon-Williams, M. (1998). The effect of vertical visual target location on head and neck posture. In M. A. Hanson (Ed.), *Contemporary ergonomics 1998* (pp. 123–127). London: Taylor & Francis.

Chaffin, D. B. (1973). Localized muscle fatigue: Definition and measurement. *Journal of Occupational Medicine, 15*, 346–354.

de Wall, M., Van Riel, M. P. J. M., Aghina, J. C. F. M., Burdorf, A., & Snijders, C. J. (1992). Improving the sitting posture of CAD/CAM workers by increasing VDU monitor working height. *Ergonomics, 35*, 427–436.

Goel, V. K., Clark, C. R., Gallaes, K., & King Liu, Y. (1988). Moment-rotation relationships of the ligamentous occipito-atlanto-axial complex. *Journal of Biomechanics, 21*, 673–680.

Harms-Ringdahl, K., Ekholm, J., Schuldt, K., Nemeth, G., & Arborelius, U. P. (1986). Load moments and myoelectric activity when the cervical spine is held in full flexion and extension. *Ergonomics, 29,* 1539–1552.

Heuer, H., Bruewer, M., Roemer, T., Kroeger, T., & Knapp, H. (1991). Preferred vertical gaze direction and observation distance. *Ergonomics, 34,* 379–392.

Hill, S. G., & Kroemer, K. H. E. (1986). Preferred declination and the line of sight. *Human Factors, 28,* 127–134.

Hsiao, H., & Keyserling, W. M. (1991). Evaluating posture behavior during seated tasks. *International Journal of Industrial Ergonomics, 8,* 313–334.

Huberty, C. J., & Morris, J. D. (1989). Multivariate analysis versus multiple univariate analyses. *Psychological Bulletin, 105,* 302–308.

Jackson, A. J., Barnett, E. S., Stevens, A. B., McClure, M., Patterson, C., & McReynolds, M. J. (1997). Vision screening, eye examinations and risk assessment of display screen users in a large regional hospital. *Ophthalmic and Physiological Optics, 17,* 187–195.

Jampel, R. S., & Shi, D. X. (1992). The primary position of the eyes, the resetting saccade, and the transverse visual head plane. *Investigative Ophthalmology and Visual Science, 33,* 2501–2510.

Jaschinski, W., Heuer, H., & Kylian, H. (1998). Preferred position of visual displays relative to the eyes: A field study of visual strain and individual differences. *Ergonomics, 41,* 1034–1049.

Kroemer, K. H. E., & Hill, S. G. (1986). Preferred line of sight angle. *Ergonomics, 29,* 1129–1134.

Kroemer, K. H. E., Kroemer, H. B., & Kroemer-Elbert, K. E. (1994). *Ergonomics: How to design for ease and efficiency.* Englewood Cliffs, NJ: Prentice-Hall.

Kumar, S. (1994). A computer desk for bifocal lens wearers, with special emphasis on selected telecommunication tasks. *Ergonomics, 37,* 1669–1678.

Mayoux-Benhamou, M. A., Revel, M., & Vallee, C. (1997). Selective electromyography of dorsal neck muscles in humans. *Experimental Brain Research, 113,* 353–360.

Mon-Williams, M., Burgess-Limerick, R, Plooy, A., & Wann, J. (1999). Vertical gaze direction and postural adjustment: An extension of the Heuer model. *Journal of Experimental Psychology: Applied, 5,* 35–53.

Mon-Williams, M., Plooy, A., Burgess-Limerick, R., & Wann, J. (1998). Gaze angle: A possible mechanism of visual stress in virtual reality headsets. *Ergonomics, 41,* 280–285.

National Occupational Health and Safety Commission. (NOHSC). (1989). *Guidance note for the prevention of occupational overuse syndrome in keyboard employment.* Canberra, Autralia: Australian Government Publishing Service.

Schuldt, K., Ekholm, J., Harms-Ringdahl, K., Nemeth, G., & Arborelius, U. P. (1986). Effects of changes in sitting work posture on neck and shoulder muscle activity. *Ergonomics, 29,* 1525–1537.

Snijders, C. J., Hoek van Dijke, G. A., & Roosch, E. R. (1991). A biomechanical model for the analysis of the cervical spine in static posture. *Journal of Biomechanics, 24,* 783–792.

Tresilian, J. R., Mon-Williams, M., & Kelly, B. M. (1999). Increasing confidence in vergence as a cue to distance. *Proceedings of the Royal Society: Biological Sciences, 266,* 39–44.

Turville, K. L., Psihogios, J. P., Ulmer, T. R., & Mirka, G. A. (1998). The effects of video display terminal height on the operator: A comparison of the 15° and 40° recommendations. *Applied Ergonomics, 29,* 239–246.

Vasavada, A. N., Li, C., & Delp, S. L. (1998). Influence of muscle morphometry and moment arms on the moment-generating capacity of human neck muscles. *Spine, 23,* 412–422.

Wagner, D., Birt, J. A., Snyder, M., & Duncanson, J. P. (1996). Human factors design guide. Springfield, CA: National Technical Information Service. (NTIS No. DOT/FAA/CT-96/1) Springfield, CA: National Technical Information Service.

Winters, J. M., & Peles, J. D. (1990). Neck muscle activity and 3-D head kinematics during quasi-static and dynamic tracking movements. In J. M. Winters & S. L.-Y. Woo (Eds.), *Multiple muscle systems: Biomechanics and movement organisation* (pp. 461–480). New York: Springer-Verlag.

Robin Burgess-Limerick is senior lecturer in occupational biomechanics at the University of Queensland. He received his Ph.D. in biomechanics from the University of Queensland in 1994.

Mark Mon-Williams received his Ph.D. in psychology from Glasgow Caledonian University in 1994. He is lecturer in the School of Psychology, University of St. Andrews, Scotland.

Vanessa Coppard is a research assistant at the University of Queensland. She received a B.Sc. (Applied) from the University of Queensland in 1997.

Date received: January 4, 1999
Date accepted: July 27, 1999