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The Influence of Eye Solutions on Blinking and Ocular Comfort at Rest and During Work at Video Display Terminals

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The aim of this work was to study blink frequency changes and levels of ocular discomfort during work at a video display terminal, and the effects on these parameters of augmented or reduced humidification of the ocular surface.

Blink rate was measured from recordings of the electrical signal evoked by the contraction of the orbicularis oculi muscle. Blink rate and interblink intervals were analyzed at rest and during performance of a task with a computer (playing a card game) for 10 or 30 min in steady environmental conditions and during application of a continuous stream of air to the face. In two separate sessions, the effect of pretreatment with humidifying ocular solutions of different elastoviscosity (balanced salt solution or elastoviscous 0·1% Hylan A solution) was assayed. At the end of each experimental period, the subjects marked the level of ocular discomfort experienced on a 0–10 cm visual analogue scale.

The blink frequency at rest ($12{\cdot}4 \pm 1{\cdot}2$ blinks min^{-1}) was reduced significantly (to $10{\cdot}3 \pm 1{\cdot}1$ blinks min^{-1}) by pretreatment with elastoviscous eyedrops both with and without air applied to the face. This effect was not obtained with balanced salt solution. During performance of the visual task for 10 or 30 min, basal blink rate decreased significantly, to about 40% of the control value. Neither application of an air jet on the face nor application of eye solutions of different viscosity modified this reduced blink rate.

A low degree of ocular discomfort developed after performance of the visual task that was enhanced by air application to the face. This discomfort was reduced by pretreatment with ocular solutions, the elastoviscous eye solution being more efficient than the balanced salt solution. Interblink interval duration was also more regular after treatment with the elastoviscous solution.

These data suggest that blink rate at rest is maintained in part by activation of sensory receptors of the cornea and conjunctiva, which are stimulated by desiccation of the ocular surface. Reduction of eye blink frequency elicited by the performance of a visual task with a computer appears to depend on central neural mechanisms that are quite independent of peripheral sensory inputs. The reduction of blink frequency consecutive to computer use was associated with a sensation of discomfort that was attenuated more effectively by elastoviscous eyedrops than by regular balanced salt solution.

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Key words: blink frequency; ocular discomfort; computer use; elastoviscous solution; viscoelastic solution.

1. Introduction

Blinking plays an important role in the maintenance of the integrity of the ocular surface because it contributes to the maintenance of eye surface humidity and favours drainage of tears, expression of lipids from Meibomian glands and spreading of tear lipids across the precorneal film (Holly, 1980; Doane, 1981; Korb et al., 1994).

The mean values of blink frequency at rest reported in the literature vary widely (12–19 blinks min^{-1}, for review, see Karson et al., 1981). Various physical factors, such as ocular irritation or precorneal tear film condition may modify this value (Ponder and Kennedy 1928; Tsubota et al., 1996; Nakamori et al., 1997). Cognitive processes also have a marked influence on blink rate. The performance of simple behavioural tasks such as listening, talking, arithmetical exercises or silent rehearsal, significantly increase basal blink rate (Karson et al., 1981; Tanaka and Yamaoka, 1993). Conversely, tasks that require visual information processing like reading, reduce basal spontaneous blinking (Karson et al., 1981; Goldstein, Bauer and Stern, 1992). The data suggest that blink frequency depends on the type and difficulty of the task and on the degree of attention and fatigue (Stern, 1994).

While working with computers, blink rate falls below resting conditions (Yaginuma, Yamada and Nagai, 1990; Patel et al., 1991; Tsubota and Nakamori, 1993). This is usually combined with an increase of the exposed ocular surface, due to the opening of the eye to watch the video display unit. Both circumstances increase tear evaporation (Tsubota and Nakamori, 1995). The ensuing dryness of the ocular surface has been proposed as the origin

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of the ocular discomfort signs reported by computer users (Rolando, Refojo and Kenyon, 1983; Tsubota and Nakamori, 1993). These include burning or itching, foreign body sensation, lacrimation, photophobia, ocular or orbital pain and headache. However a defined relationship between blink rate changes, humidification and ocular discomfort during work at video display units has not been established; neither has the preventive effect of humidifying solutions been determined experimentally.

2. Materials and Methods

Subjects

Twenty healthy volunteers (12 males, 8 females) with ages ranging from 19 to 26 years (mean: 21·1 ± 0·5 years) participated in this study. None of them had ocular pathologies. One wore eyeglasses (+2D). Subjects gave informed consent to a protocol approved by our Institute and were free to interrupt their participation at any time. They received financial compensation for their contribution to the study.

Measurement of Blink Frequency

Subjects were seated comfortably in front of a 12″ video display unit provided with a screen filter (Glare/guard Professional Plus, Misco, Spain). The viewing distance was 53 ± 2 cm. The height of the screen was adjusted to have its center at the level of the subject's eyes. The subject wore earphones connected to a music source (a Mendelssohn compilation) and chose to handle the mouse of the computer either with the right or the left hand. During the computer task sessions, the subject continuously played the game Solitaire (Windows 3.11, Microsoft Corp., Seattle, WA, U.S.A.) (Patel et al., 1991).

To record electromyographic activity of extraocular muscles, EEG recording disc electrodes (10-mm diameter, Harvard Apparatus, South Natick, MA, U.S.A.) were placed in the external angle of the eye and in the lower eyelid. The skin surface under the electrodes was cleaned with alcohol and covered with a thin layer of conducting EEG paste. A ground electrode was placed in the center of the forehead. The electrodes were maintained in place with a small piece of hypoallergenic adhesive band and connected to a DC amplifier (DAM 50, WPI, New Haven, CT, U.S.A.) without apparent discomfort for the subject. The output of the amplifier was connected to one of the channels of a chart recorder (San-Ei 8K, San-Ei Instruments Co. Ltd., Japan) while a second channel was used to mark events. In a part of the experiments, an air convector, placed in front of the subject at the height of the head at a distance of 69 ± 2 cm, was used to direct an air stream at room temperature (24 ± 0·1 °C) to the face of the subject (air speed at the face: 0·8–1·0 m s^{-1}).

The temperature and relative humidity of the air in the room were monitored throughout the experiment and maintained stable (mean values: 23·8 ± 0·1°C and 51·8 ± 0·8%, respectively).

Subjects reported an average time of computer use of 0·6 ± 0·2 hr day^{-1} (range: 0–3 hr) and 1·3 ± 0·2 hr day^{-1} of TV watching (range: 0–3·5 hr).

Solutions

Two types of solution were used: balanced salt solution, (B.S.S.®, Alcon-Iberhis SA, Madrid, Spain) and an elastoviscous solution of 0·1% Hylan A (Hy-A) dissolved in phosphate buffered physiological solution (Hylashield®, Biomatrix Inc., Ridgefield, NJ, U.S.A.). Hy-A is an elastoviscous high molecular weight derivative of hyaluronan.

Procedure

Prior to the experiment, a general description of the goals and procedures was given to the subject, followed

TABLE I

Experimental protocols

	Session	Treatment	Period 1	Period 2	Period 3	Period 4
Protocol A	1st	No treatment				
	2nd	Balanced salt solution	Rest,	Game,	Game + air,	Recovery,
	3rd	Elastoviscous solution	10 min	10 min	10 min	10 min
Protocol B	1st	No treatment				
	2nd	Balanced salt solution	Rest,	Game,	Game + air,	Recovery,
	3rd	Elastoviscous solution	10 min	30 min	30 min	10 min
Protocol C	1st	Non treatment				
	2nd	Balanced salt solution	Rest,	Rest + air,	Game + air,	Recovery + air,
	3rd	Elastoviscous solution	10 min	10 min	10 min	10 min

Rest = Subject resting, looking at the infinite. Game: Subject performing the computer task. Air: A current of air is applied to the face (see methods). A 4 minute pause was allowed between periods. Treatments were applied during these pauses.

by a session in which he/she became familiar with placement of the electrodes, recording procedures and use of the computer.

Three separate protocols (A, B and C) were established, each of them with different duration of computer use (Table I). Each protocol included three sessions: no treatment, treatment with B.S.S. and treatment with Hy-A, performed on different days (1–7 days apart). The sessions were in turn divided into variable duration periods of rest, computer game playing and recovery, performed consecutively with a 4 min pause between them. In the treatment sessions, a drop of B.S.S. or of Hy-A was instilled bilaterally, just before the beginning of each of the periods of the session. Thus, four drops were applied to each eye throughout the experiment, with a 10–30 min pause between applications. Electrical signals generated by orbicularis oculi muscle contractions during blinking were recorded throughout the experiment. At the end of the various periods, the subjects were asked to mark the degree of discomfort experienced in a visual analogue scale (V.A.S.) drawn on a paper sheet and divided in 10 steps (from 0, no discomfort, to 10, maximum imaginable discomfort). At this point, they were also asked to report in their own words any observation or comment considered relevant.

Data Analysis

The number of blinks min^{-1} during the various phases of the experiment was obtained from the paper traces. The interblink periods were also measured from the paper recordings and expressed in seconds. Numerical data were fed into a computer and analyzed using SigmaStat for Windows. Data were expressed as mean $\pm$ S.E.M. and compared using paired and unpaired Student t test, Wilcoxon and Mann-Whitney test, One Way ANOVA or ANOVA on Ranks and Dunn's method for multiple comparisons.

3. Results

Direct Effects of Eye Drops

Three subjects complained of a mild unpleasant sensation immediately after B.S.S. was applied whereas the rest did not attribute an affective quality to the sensation produced by the eye drop. Three individuals reported blurred vision immediately after application of Hy-A; this disturbance disappeared after a few blinks; the remaining subjects reported a sensation of comfort after application of Hy-A.

Blink Rate

No treatment Average frequency of blinking in basal conditions (Session 1: at rest when no solution was instilled into the eye) varied widely among individuals (range 1·1–31·8 blinks min^{-1}), with a mean value around 12 blinks min^{-1} [12·4 $\pm$ 1·2 blinks min^{-1}, $n = 39$; Fig. 1(A)]. Applying air to the face, slightly increased the mean blink rate during the resting period (15·2 $\pm$ 3·6 blinks min^{-1}, $n = 12$) but differences with basal frequency were not significant. Mean blink rate was significantly reduced to about 42% of control during the performance of an attentive computer task [Fig. 1(A)]. Low blink frequency values during the computer playing period were similar for 10 min play (7·3 $\pm$ 1·4 blinks min^{-1}, $n = 15$) and 30 min play (6·1 $\pm$ 1·2 blinks min^{-1}, $n = 12$). Application of an air stream to the eyes during the computer game did not modify the reduced blink frequency that accompanied the performance of the attentive task (10 min: 7·2 $\pm$ 1·1 blinks min^{-1}, $n = 27$; 30 min: 5·9 $\pm$ 1·1 blinks min^{-1}, $n = 12$). Blink frequency recovered its initial values after return to resting conditions (12·7 $\pm$ 1·7 blinks min^{-1}, $n = 27$).

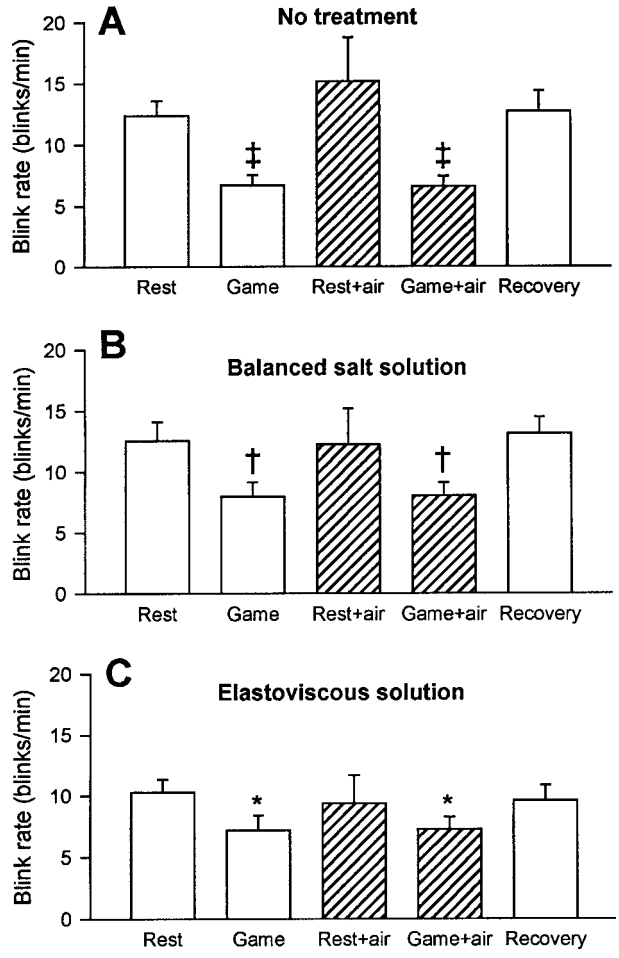

FIG. 1. Blink frequency at rest and during performance of a computer task, without (A) and after treatment with balanced saline solution (B) and elastoviscous, 0·1% Hylan A solution (C). Striped columns correspond to sessions in which an air stream was applied continuously to the face of the subject. Data from 10 min and 30 min periods have been pooled. $^*P < 0{\cdot}05$; $\dagger P < 0{\cdot}01$; $\ddagger P < 0{\cdot}001$, Student t test. Comparisons were made with blink frequency at rest during the same session.

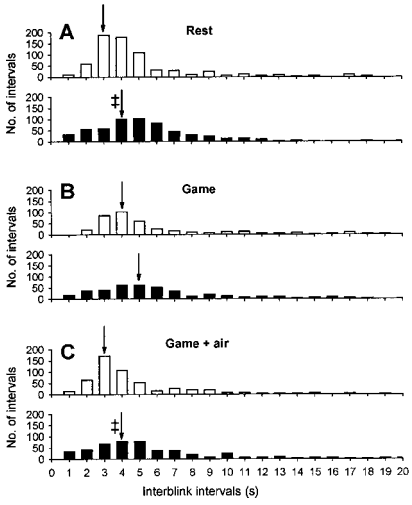

FIG. 2. Distribution of interblink interval duration at rest (A) and during performance of a computer task (B, C). In each panel, the upper interval histogram (□) correspond to data obtained when no treatment was applied, and the lower interval histogram (■) to the data of treatment with 0·1% Hylan A solution. Bin width: 1 sec. ‡$P < 0{\cdot}001$, Mann-Whitney Rank Sum Test. Comparisons were made between no treatment and after the application of the elastoviscous solution.

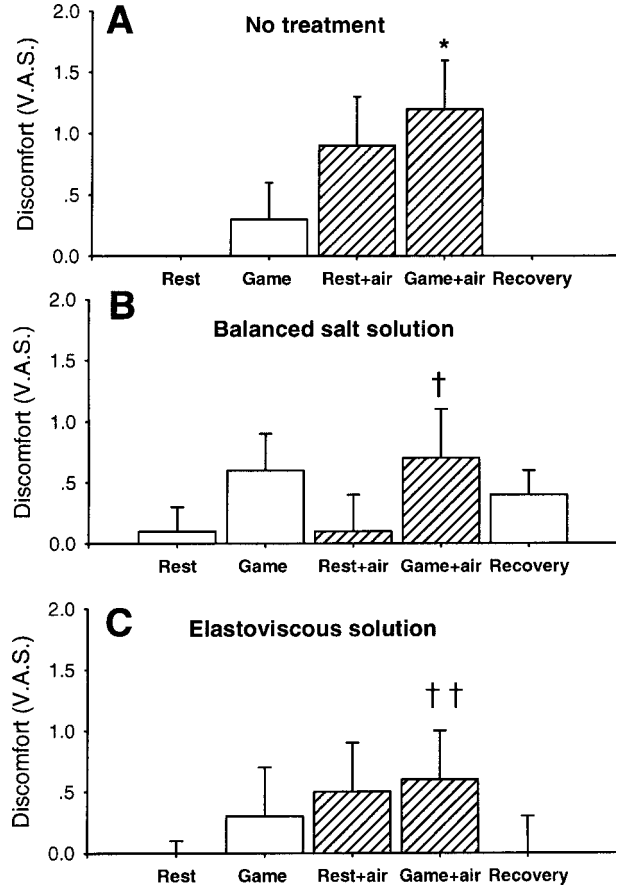

FIG. 3. Discomfort values at rest and during performance of a computer task. V.A.S.: visual analogue scale units. (A) When no treatment was applied. (B) After ocular application of balanced salt solution. (C) After application of 0·1% Hylan A solution. The stripped columns correspond to sessions in which an air stream was applied continuously to the face of the subject. Data from 10 min and 30 min have been pooled. *$P = 0{\cdot}007$, Wilcoxon Signed Rank Test, difference with 'Game' [(A) □]. †$P = 0{\cdot}048$ and ††$P = 0{\cdot}021$, paired t test, differences with 'Game + air' column in A.

Figure 2 shows that the distribution of blink intervals duration during rest and computer play did not follow a normal distribution curve. The significantly lower blink rate observed during the performance of the video game task was reflected in significantly longer interblink intervals (mean: $7{\cdot}5 \pm 0{\cdot}5$ s) in comparison with the rest period (mean: $4{\cdot}8 \pm 0{\cdot}3$ s, $P < 0{\cdot}05$ Dunn's method). The duration and distribution of intervals during the computer use with air applied in the face presented an intermediate situation (mean: $5{\cdot}9 \pm 0{\cdot}4$ s).

Effect of balanced salt solution B.S.S. instilled at rest and before computer playing did not modify basal blink frequency ($12{\cdot}6 \pm 1{\cdot}5$ blinks min^{-1}, $n = 39$) or the magnitude of the decrease evoked by computer playing during 10 min ($9{\cdot}6 \pm 1{\cdot}8$ blinks min^{-1}, $n = 15$) and during 30 min ($6{\cdot}0 \pm 1{\cdot}3$ blinks min^{-1}, $n = 12$). Results were similar when air was applied to the face (10 min: $9{\cdot}1 \pm 1{\cdot}4$ blinks min^{-1}, $n = 27$; 30 min: $7{\cdot}3 \pm 1{\cdot}8$ blinks min^{-1}, $n = 15$). Blink frequency returned to basal values during the recovery period ($12{\cdot}3 \pm 2{\cdot}9$ blinks min^{-1}, $n = 12$). The mean values of blink frequency of the different experimental periods with B.S.S. treatment are illustrated in Fig. 1(B).

Effect of elastoviscous solution Eyes pretreated with Hy-A [Fig. 1(C)] exhibited a blink rate at rest that was lower than for eyes without treatment or treated with B.S.S. ($10{\cdot}3 \pm 1{\cdot}1$ blinks min^{-1}, $n = 39$; $P < 0{\cdot}05$ in comparison with no treatment value). This frequency value was not altered by application of air to the face ($9{\cdot}4 \pm 2{\cdot}3$ blinks min^{-1}, $n = 12$). Following Hy-A, computer playing still decreased significantly the blink frequency ($7{\cdot}5 \pm 1{\cdot}7$ blinks min^{-1}, $n = 15$ and $6{\cdot}4 \pm 1{\cdot}8$ blinks min^{-1}, $n = 12$ for 10 and 30 min respectively) [Fig. 1(C)]. Blink rate during the recovery period returned to the initial values ($9{\cdot}6 \pm 1{\cdot}3$ blinks min^{-1}, $n = 39$).

Treatment with Hy-A significantly modified the distribution of interblink intervals both at rest [mean: $5{\cdot}6 \pm 0{\cdot}2$ s, Fig. 2(A)] and during computer use with the air stream [mean: $7{\cdot}0 \pm 0{\cdot}4$ s, Fig. 2(C)], moving the median towards longer interblink interval values. This did not occur during computer use [mean: $7{\cdot}7 \pm 0{\cdot}4$ s, Fig. 2(B)].

Ocular Discomfort

No treatment The development and magnitude of discomfort varied widely between individuals. No discomfort was reported during the initial resting

period or during recovery. Playing with the computer produced a mild sensation of ocular discomfort ($0{\cdot}3 \pm 0{\cdot}3$ V.A.S. units). This sensation was significantly enhanced by application of air onto the face while playing ($1{\cdot}2 \pm 0{\cdot}4$ V.A.S. units). When air was applied during the initial rest period, discomfort was also reported [$0{\cdot}9 \pm 0{\cdot}4$ V.A.S. units; Fig. 3(A)].

Effect of balanced salt solution Application of B.S.S. [Fig. 3(B)] during the rest period produced a slight discomfort sensation ($0{\cdot}1 \pm 0{\cdot}2$ V.A.S. units) but differences with untreated subjects were not significant. Discomfort produced by computer playing was not modified by pretreatment with B.S.S. ($0{\cdot}6 \pm 0{\cdot}3$ V.A.S. units). However, B.S.S. treatment reduced the discomfort felt when air was applied during the computer playing period ($0{\cdot}7 \pm 0{\cdot}4$ V.A.S. units), the difference from the corresponding no treatment period being significant ($P = 0{\cdot}048$, paired t test).

Effect of elastoviscous solution Application of Hy-A solution did not evoke discomfort at rest or during the recovery period. The discomfort reported after computer playing was similar to that obtained during no treatment [$0{\cdot}3 \pm 0{\cdot}4$ V.A.S. units; Fig. 3(C)]. Hy-A prevented more effectively than B.S.S., the discomfort caused by the performance of the computer task with air in the face [$0{\cdot}6 \pm 0{\cdot}4$ V.A.S. units; $P = 0{\cdot}021$ paired t test compared with no treatment; Fig. 3(C)].

4. Discussion

There is ample evidence that various mental activities including reading, memory use, or emotions modify blink rate (Karson et al., 1981; Tanaka and Yamaoka, 1993). Confirming previous work (Patel et al., 1991; Tsubota and Nakamori, 1993), the present paper shows that during performance of a computer task, the basal blink rate of about 12 blinks min^{-1} found in normal young subjects decreased by about half. This reduced blink frequency was not changed by enhanced corneal desiccation evoked by a current of air or by longer times of computer work, neither was it modified when ocular humidification was increased with various eye drops. In contrast, blink frequency at rest augmented nearly 20% by application of an air stream to the face and was reduced significantly by instillation of an elastoviscous solution.

Blinking may be classified as reflex, spontaneous or voluntary (Evinger, Manning and Sibony, 1991) and involves a complex neural network extending from the medulla to the cerebral cortex. Lid movements during the reflex and spontaneous blinking exhibit different latencies, velocities, durations, amplitudes and strength, suggesting that neural circuits controlling them may differ in part (Manning and Evinger, 1986; Jääskeläinen, 1995). Ponder and Kennedy (1928) suggested that the periodic or spontaneous blink was independent of afferent impulses arising from the retina, cornea, conjunctiva or extrinsic eye muscles. More recently, other authors have speculated that spontaneous blinking is governed in part by a corneal reflex evoked by desiccation of the corneal surface (Holly, 1973) or by reduction of corneal temperature (Efron, Young and Brennan, 1989). Dry spots of the precorneal tear film begin to appear 15–30 s after a blink (Doane, 1980) while corneal temperature drops at a rate of 0·033°C/s when the eyes are open (Efron et al., 1989). These changes are far too slow to explain the normal adult blink rate as being produced by a blink reflex evoked by stimulation of thermal and polymodal nociceptors innervating the anterior ocular surface (Belmonte and Gallar, 1996).

Nevertheless, our results suggest that stimuli that modify neural activity in sensory fibers of the cornea and conjunctiva, such as enhanced evaporation or additional humidification of the ocular surface, change basal blink rate. This observation supports the hypothesis that sensory input from corneal and conjunctival sensory fibers evoked by desiccation normally modulates the excitability of the neural circuits involved in spontaneous blinking. This interpretation is favoured by the observation that moderate discomfort at the end of the computer playing period was enhanced when air was applied to the face, whereas elastoviscous solutions attenuated this ocular discomfort. It seems conceivable that both the temperature reduction and the thinning of the tear film that take place during eye opening act as stimuli for ocular sensory afferents. Firing of nociceptive sensory fibers is associated with sensations of discomfort or overt pain, depending on nerve impulse frequency (Meyer, Campbell and Raja, 1994; Chen et al., 1995). Hypertonic saline and cooling, activate respectively polymodal and cold fibers of the cornea (Belmonte et al., 1991; Gallar et al., 1993), whereas humidification of the corneal surface transiently stops spontaneous firing of corneal sensory afferents. In the present experiments, Hy-A elastoviscous solution was more effective than B.S.S. in reducing basal blink rate and discomfort evoked by computer playing and by air application to the face. This is presumably due to a more prolonged humidifying action of the ocular surface by Hy-A, possibly because its elastoviscous physical properties prevent the removal by lid movements of the moisturizing film formed on the cornea and conjunctiva.

The results of this work confirm that during a performance task that requires strong visual attention, blink frequency drops. The influence of visual attention on blinking has been interpreted as the result of a cortical influence on the pontine reticular formation neurons that elicit spontaneous blinking (Karson, 1989). This effect may be due in part to suppression of the facilitatory input from peripheral afferents.

Wallace, Meredith and Stein (1993) described converging influences from visual, auditory and somatosensory cortices onto output neurons of the superior colliculus, which project into the tecto-reticulo-spinal tract, perhaps mediating inhibitory influences on motor neurons involved in blinking. The inhibition of blinking was not counteracted by an enhanced peripheral sensory stimulus such as air or application of solutions to the eye. These results favor the interpretation that during the performance of a visual task, facilitatory inputs from the periphery are largely inhibited by cortical influences and blink frequency is determined by a 'central pacemaker'. Interestingly, the peripheral afferent sensory information seems nonetheless to produce a low level of 'wind up' in central trigeminal sensory neurons that would be responsible for the discomfort reported by the subjects at the end of computer use.

According to this work, blink rate at rest is partially influenced by extrinsic factors like ocular surface conditions (Tsubota and Nakamori, 1995; Tsubota et al., 1996) whereas low blinking induced by the performance of an attentive task is mainly governed by intrinsic neural mechanisms. The use of computers for prolonged periods of time is often accompanied by complaints of ocular discomfort (Bergqvist, 1989). The observations reported here suggest that the main cause of these symptoms is the increased activity of sensory nociceptive terminals in the exposed eye surface elicited by the reduced blinking. Nevertheless, the present data indicate that this increased sensory input from the cornea and conjunctiva causing discomfort is unable to overcome the strong inhibition of neural blinking mechanisms during the performance of a computer task. Therefore, reduction of this sensory input with long-lasting humidifying solutions seems to be an effective means of dealing with the consequences of reduced blinking caused by prolonged work in front of the computer screen.

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