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Factors Regulating Eye Blink Rate in Young Infants

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Abstract

Purpose—The purpose of the present work was to investigate whether individual differences in eye surface area are related to the rate of spontaneous eye blinking (SB) in young infants. Rate of SB was also compared to the rate of gaze shifts.

Methods—Forty-four 4-month-old infants were observed under controlled conditions for 4–6 minutes. SB, eye surface area, gaze shifts and various background variables were measured.

Results—Individual differences in the rate of SB and in eye surface area were wide. Neither the eye surface area nor the rate of gaze shifting was related to the rate of SB in young infants. However, when SB do occur, they are more likely to coincide with a shift in gaze than immediately precede or follow a shift in gaze.

Conclusions—Eye surface area does not explain individual differences in the rate of SB in infancy. This and other recent work suggests that central factors may play a more prominent role in the mechanisms of SB early in human development than previously reported and that the mechanisms regulating the rate of SB appear to be developmentally continuous with those of adults. To the extent that the rate and timing of SB reflects developing neurological systems, SB may be useful clinically.

Keywords

spontaneous eye blinking; palpebral fissure; eye surface area; gaze shifts; infants

Human infants exhibit low rates (<4 per min) of spontaneous eye blinking (SB).^{1, 2} From this low rate of SB in infancy, the rate increases gradually to about 15–30 per min in adulthood^{3–5}. Current explanations of the low rate of SB in infants compared to adults have focused primarily on the precorneal tear film. The lipid layer of the tear film has been a focal point because it retards evaporation and stabilizes the tear film⁶. In infants, the lipid layer of the tear film is thicker and more stable than in adults^{7,8} and the amount of exposed eye surface area is smaller. Following a blink, it is believed that evaporation leads to eye surface cooling which triggers a blink that in turn restores the tear film^{9,10}. Because adults and infants show similar levels of corneal sensitivity to cooling of the eye surface¹⁰, the lower SB rate in infants is not due to reduced sensitivity to surface cooling that results when the tear film breaks up. These facts have led to the hypothesis that the low rate of SB in infants is due to the combination of thicker lipid layer and relatively small palpebral aperture and so, as children develop, a thinner tear film is less effective in reducing evaporation and SB are triggered more frequently which is manifested as a developmental increase in SB.^{8,10}

In contrast, research on adults has identified central as well as peripheral mechanisms that regulate the rate of SB. Peripheral factors that are believed to affect rate of SB include: tear film stability, thickness of the lipid layer, and rate of eye drying^{6, 9}. Environmental factors

such as relative humidity, temperature and pollutants affect the rate of SB indirectly through changing the conditions at the eye surface¹¹.

With respect to central mechanisms of SB, investigations in adult human and non-human primates have identified a role for dopamine (DA) systems^{12–15}. Although a few researchers have failed to demonstrate a relationship between SB and DA function¹⁶, converging evidence in adults for a role for DA involvement in SB rate comes from a range of fields including psychopathology^{17–20}, biological bases of personality^{21–23}, and cognitive research^{24–26}. The specific components of the DA system contribute to SB regulation have not been identified, and furthermore, it is not known whether the mechanisms underlying SB are the same for infants and adults.

The present study addresses two objectives in order to identify factors that contribute to the rate of SB early in human development. The first objective was to test whether eye surface area is linked to the rate of SB in young infants. Others have asserted that the combination of a smaller palpebral fissure and thicker tear film of infants contribute to less rapid eye drying and thus a slower rate of SB among infants^{8,10}. However, for infants between 3–6 mos, the tear film has a uniform thickness⁸. Therefore, the present study tests the relationship of eye surface area and SB in 4 mo-old infants when tear film thickness is constant.

The second objective was to examine the relationship between the rate and timing of shifts in gaze with respect to SB. Current studies in infants have not adequately described the dynamic relationship between eye movement and SB. Shifts in gaze might be related to SB by central mechanisms or by changes at the surface of the eye. For example, shifts in gaze might disrupt tear film stability and so contribute to surface cooling, thus increasing the rate of SB for infants who express more shifts in gaze. Previous work in adults^{27, 28} shows reductions in tear film stability with changes in vertical direction of gaze. Other work, however, presents evidence that the tear film remains stable between blinks even during changes in gaze direction⁶. Given the potential for developmental differences, the analysis in infants is warranted.

This study investigates several potential sources of individual differences in the rate of SB early in human development. The presence or absence of relationships between SB and eye surface area and gaze shifting addresses the contributions of peripheral and central sources of SB regulation. Understanding the relative contributions of peripheral and central mechanisms of SB in human infants is important most basically for helping maintain a healthy eye surface. Additionally, to the extent that the rate and timing of SB reflects nascent neurological systems, SB may be useful clinically³². For example, researchers have examined patterns of SB and attention in early childhood to help understand the neural deficits of autism³³.

METHODS

Participants

Forty-four, healthy and full term infants participated (19 females, 25 males) ($M=118.5 \pm 6.5$ days). Infants, from a variety of socio-economic backgrounds, were recruited through brochures, visits to the local hospital maternity ward, well-baby visits to the local OB-GYN, and letters sent to parents found in the birth announcements. Our procedures adhered to the tenets of the Declaration of Helsinki. Procedures were reviewed and approved by the University's institutional review board, and informed consent was obtained from every parent.

Procedure

After obtaining consent, the infant was placed on a scale to estimate body weight (clothes on), and was seated in a modified infant car seat facing a three-sided arena. Two concealed cameras (one digital, one CCD) were positioned at 140 cm to the infant's face, with 99 cm distance

between the two lenses. (Further details of equipment and configuration have been reported³⁴).

The observation consisted of 2 primary phases (quiet baseline and stimulus presentation) that were designed as part of a larger, psychological study³⁴. Measures reported here are taken from the baseline period with the exception that some samples of eye surface area were taken from the stimulus presentation period in order to find the best images. Each phase lasted 3–6 min. The infant was not directly addressed or touched unless s/he became fussy. All periods of infant fussiness were excluded from analyses. During the visit, each parent was asked a series of questions about her or his infant's health and caregiving practices.

Measures

Spontaneous Eye Blinking—Briefly, trained coders reviewed video records in slow motion and frame-by-frame to identify valid SB. Eye closures associated with the following were not included in the analysis: yawns, sneezes, startles, coughs, grimaces, fussiness, or hand movements toward face or mouth. Also, asymmetrical and slow ($> 1/3$ sec) blinks were not included. The infant must also have had at least 3 min of continuous data (or two, 2 minute segments of data) to be included in analyses. To assess inter-rater reliability in identifying valid blinks, two people coded 27% of the cases and were blind to each other's codes. A version of percent agreement was used. The estimate of inter-rater reliability was 87%. This value may underestimate agreement between coders because it was based on two coders agreeing to both the time (within 1 sec) of the eye closure and the type of eye closure. This method for reliably identifying spontaneous eye blinks in infants has been reported^{2,34}.

The time between successive blinks (sec) during the baseline period was averaged to gain each infant's mean inter-blink-interval (IBI). These values were base-10 log transformed to correct a strong skew.

Eye Surface Area—Because infants' heads were not restrained, digital images were reviewed to select images for analysis in which the infant's face was turned toward the camera. Digital images were analyzed using LabVIEW (v. 7.1) image analysis routines (National Instruments, 6504 Bridge Point Pkwy, Austin, TX, USA (203) 720-0031; www.ni.com). To measure the planar area of the eye surface exposed, the user traced the outline of the eye surface along the inside edges of the lids using the computer's mouse. This method slightly underestimates the eye surface area given that the lids are curved and the edges drawn using the mouse are a series of short, straight lines. Image enhancement routines allowed the user to adjust images to maximize the detection of the edges. Four measurements from each infant were averaged. Measurements were highly similar, $r(44) = .91$. Reasons for slight variations include changes in eye position, head position and degree of eyelid opening.

Rate of Gaze Shifts—Trained assistants analyzed the first two minutes of the baseline phase using a combination of slow motion and frame-by-frame analysis of the analog video recordings. The first two minutes was sufficient to analyze the typical rate of changes in gaze for infants given that many such movements may be sampled during that period of time. Also, although patterns of attention fluctuate over time and transient patterns occur in new environments³⁵, a two min period of observation in a stable environment extends well beyond the period of these fluctuations. A time sampling approach was used to estimate the frequency of gaze shifts. Presence or absence of any detectable change in gaze was noted for each 1-sec bin (inter-rater reliability estimate was 92%). The rate of eye movement is indicated by the number of bins per min with a change in gaze.

During baseline, no specific stimulus objects were presented. The three-sided arena (183 cm high) was covered in fabric of uniform, light color. Infants could turn their heads sharply to their right to see their parent (seated next to the infant, or holding the infant)).

RESULTS

Preliminary Analyses

Samples of eye surface area were examined to confirm that no systematic differences in measures occurred when those measurements were taken further apart in time. The standard deviation of the four area measures and the time (minutes) between the measurements were not related, $r(44) = -.022$, $p = .89$.

Preliminary analyses were conducted on a set of variables that could represent potential confounds. No sex differences were found in eye surface area, IBI, rate of eye movement, or current body weight. The results for these one-way ANOVAs were as follows: eye surface area $F(1,42) = .88$, $p = .35$; IBI, $F(1,42) = 2.61$, $p = .14$; eye movement $F(1,42) = .07$, $p = .80$; body weight $F(1,42) = 1.37$, $p = .25$. None of the following variables were significantly correlated to eye surface area: weight at 4 months, time of day, age in days, hours since last feeding, and hours since last sleeping (all r 's were .26 to .03). Birth weight exhibited a marginally significant, negative correlation with eye surface area: $r = -.29$, $p = .054$. (Figure 2 includes birth weight data.)

One-way ANOVAs were used to test whether the eye surface area was related to the following: use of medications (yes, no), type of caregiving (in home, out of home), and method of feeding (breast, bottle, both). None of the categorical variables were related to eye surface area (p 's were between .53 and .64). Method of feeding approached statistical significance with eye surface area: $F(2,43) = 2.9$, $p = .07$.

Individual Differences

Individual differences in surface area were wide: range of 117.4 to 739.6 mm² ($M = 390.7 \pm 116.9$). Wide individual differences were also found in IBI (Figure 1). The average eye surface area of the 25% of infants with the greatest values ($M = 532.3$ mm²) was twice as large as that of the 25% of infants with the smallest eye surface area ($M = 247.4$ mm²). For IBI, the fastest 25% of infants blinked just over 2.5 times faster than infants with the slowest rate of SB. These SB rates are consistent with those observed in previous studies of infants^{10,35,36}.

Relationship between IBI and Eye Surface Area

Infants were divided into three groups based on length of IBI during the baseline phase. This was done by identifying the lower third ($N = 14$, fast rate of SB), middle third ($N = 16$) and upper third ($N = 14$, slow) of IBIs. All subsequent analyses of IBI use the log transformed values from the baseline phase.

One way ANOVA was used to test whether differences in eye surface area were apparent for infants who blinked at different rates (slow, intermediate, fast). Infants' eye surface area was not related to IBI, $F(2,41) = 1.25$, $p = .30$. The scatterplot of eye surface area and IBI (birth weight data are indicated by the size of the symbols) clearly illustrates the absence of relationships among these variables (Figure 2).

Relationship between IBI and Rate of Gaze Shifts

One potential source of influence on the rate of SB is the rate of gaze shifts. As in the previous analysis, infant data from the baseline period were grouped by rate of SB by identifying the

upper, middle and lower thirds of the range of IBIs. One-way ANOVA showed that IBI (slow, intermediate, fast) was not related to rate of gaze shifts, $F(2,41)=1.8$, $p=.17$ (Figure 3).

One way ANOVA also showed that the rate of gaze shifts (slow $N=14$, intermediate $N=16$, fast $N=14$) was not related to eye surface area, $F(2,41)=.044$, $p=.96$. Infants were grouped following the same pattern as used for creating groups based on IBI.

The sample size did not permit a between subjects ANOVA of the effects of gaze shift rate (slow, medium, fast) and IBI (slow, intermediate, fast) on eye surface area. However, a one-way ANOVA using area as the dependent variable, IBI groups as the independent variable and gaze shift rate as a covariate yielded no significant effects: IBI, $F(2,40)=1.2$, $p=.32$, and gaze shifts, $F(1,40)=.01$, $p=.93$.

Temporal Relationship between SB and Shifts in Gaze

To investigate the timing of SB with respect to shifts in gaze, a repeated measures ANOVA for successive 1-sec intervals before and after SB was conducted. For an infant's data to be included, at least three SB with 5 intervals before and 5 after an SB was required. Of the 44 infants, 35 infants met this criterion. From each infant, three, or four if available, SB were analyzed. For the selected SBs, the number of shifts in gaze for each 1-sec interval before and after the SB were tallied. (Recall that a time sampling method was used to record shifts in gaze so that each 1-sec bin has a binary value of 1 or 0 depending on whether a shift in gaze was observed.) For the interval in which the SB occurred, a gaze shift was tallied only if it co-occurred with the SB (i.e., gaze at the start of the eyelid closure for a valid SB was shifted by the time the eyelids were parted at the end of the SB). The variable, therefore, is the number of gaze shifts noted for each 1-sec bin before, during, and after the SB. The maximum number of shifts per bin for each infant is 4 and the minimum is zero. The eye movements investigated here are large amplitude shifts that result in a new direction of gaze, not small adjustments or individual saccades that may occur during eye closure.³⁷

The ANOVA revealed significant variation over the seconds surrounding an SB, $F(10, 340)=12.6$, $p<.001$ with significant linear and higher order trends. Paired t-tests were conducted to determine which intervals differed from the interval in which the SB occurred (Figure 4). The paired comparisons showed that every interval differed substantially from the interval containing the SB (all $p<.001$). In the 10 sec window surrounding an SB, gaze shifts most often were coincident with the SB. Additionally, the interval immediately preceding the SB contained significantly fewer eye movements than all subsequent intervals plus the -5 sec interval. Intervals -2, -3 and -4 were not statistically different from interval -1 (p 's respectively: .083, .057, .068).

DISCUSSION

Results from the present study demonstrate no relationship between the rate of spontaneous eye blinking eye and surface area in 4-month-old infants despite wide individual differences in both. The test conducted here, with young infants of the same age, tests the unique contribution of eye surface area to the rate of SB. Previous work with infants suggested that both surface area and tear film thickness may contribute to the relatively low rate of SB in infants¹⁰. However, in infants at this age the tear film thickness is uniform⁸, so this test of the relationship between eye surface area and SB is not confounded with tear film thickness differences. Similar results have been obtained with adults³⁸. Furthermore, given the evidence that infants between 3–6 mos have similar tear film thicknesses⁸, the wide individual differences in SB at 4 mos can not be explained by tear film thickness either. Nevertheless, given that tear film thickness was not measured in this study; further investigation is needed to confirm the implication regarding the role of tear film thickness of the present study.

A second primary finding was that infants who expressed different rates of gaze shifting did not show systematically different rates of SB. Absence of a tight relationship between the rate of gaze shifts and SB argues against a hypothesis that the frequency of eye movements might disrupt the tear film and in turn promote more rapid surface cooling and thus trigger more SB. Although the rates of gaze shifting and SB were unrelated, the timing of SB indicated some coordination with gaze shifts. In the seconds preceding and following a spontaneous eye blink, the relative number of shifts in gaze was greatest during the blink. This temporal coordination observed between gaze shifts and SB has been demonstrated in adults^{30–31}. Such coordination may shorten the loss of visual information compared to when these eye movements occur in succession³⁹. In adults, this coordination has been attributed to higher order mechanisms^{31, 40} rather than mechanical features³⁰ or stimulus features³¹ and also affects eye movement⁴¹ and visual processing.⁴⁰

Three implications of these results are offered. First, they address the contributions of peripheral and central mechanisms underlying individual differences in rate of SB in infants. The absence of effects on SB by two prominent components of the eye surface (i.e., eye surface area, tear film thickness) in combination with evidence that the rate of SB in infants can be manipulated experimentally^{2,34}, indicates that central mechanisms may play a more prominent role in the regulation of SB during early infancy than previously believed.

A second implication is that the neural systems for coordinating SB and ongoing patterns of visual attention are present early in the first year of human maturation. A third implication of these results is that the mechanisms regulating SB in infants appear to be similar to that of adults. Taken together, the results for infants and adults show the following parallels: (a) similar sensitivity to eye surface cooling¹⁰, (b) wide individual differences in rate of SB,^{2,10,34,36} (c) eye surface area unrelated to SB rate³⁸ (d) temporal coordination between SB and gaze shifts,^{30–31} and (e) malleability of the rate of SB through experimental manipulation.^{26,34,42} These similarities provide evidence for developmental continuity in the mechanisms that regulate SB.

Although these results do not speak directly to the causes of the developmental increase in rate of SB, the results of the present study appear inconsistent with a cross-sectional study that showed a positive correlation between rate of SB and eye surface area for infants between birth and one year¹⁰. It is possible that the positive correlation between eye surface area and SB rate is expected because SB rate increases along with eye surface area in human maturation. While a role for tear film thickness in explaining the developmental increase in rate of SB has not been ruled out, if it were true, it would mean that the mechanisms driving developmental change are different from those explaining the wide individual differences at a given age (apparently not eye surface area or tear film thickness). This issue of the potential causal relationship between rate of SB and tear film thickness and quality would best be addressed using a longitudinal design in which direct measures of the tear film are used.

Despite progress in elucidating mechanisms of SB, major questions remain about the source (s) of individual differences and the cause(s) of developmental change. Clearly, eye surface features such as the precorneal tear film have a unique and essential role in regulating SB throughout the lifespan^{6,43}. Recent work, however, has sought to more fully explain the respective roles of peripheral and central nervous system factors. To-date, no comprehensive model has been offered that links explanations of individual differences, developmental change and transient changes in the rate of SB.

Understanding the mechanisms and development of SB has potential to expand our understanding of (a) normative development with respect to eye movement and features of the eye surface, (b) the interaction of peripheral and central factors in maintaining a healthy eye surface, and (c) the possibility that SB could serve as an index to central nervous system

function early in ontogeny. To the extent that SB rate or timing reflects central mechanisms, it may be useful in understanding early neurological development and may also be useful diagnostically.⁴⁴

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Figure 1. Histograms illustrate individual differences in the log inter-blink-interval (IBI) and eye surface area (mm²) for the sample (N=44). Inset shows untransformed IBI data.

Figure 2.
Log IBI by eye surface area (mm²); symbols reflect quartiles of infant birth weight (larger bubbles indicate larger birth weight).

Figure 3. Left panel: Scatterplot of gaze shift rate (movements per min) by log IBI. Right: Mean (SD) gaze shift rate for three groups of infants who blinked at different rates.

Figure 4.

Mean (SE) number of intervals with eye movement across successive 1-sec intervals before and after a spontaneous eye blink (SB) (blinks sampled from 35 infants). Asterisks indicate differences in the number of eye movements for intervals compared to the number of movements coinciding with the SB.