Using Eye Blinks as a Tool for Augmented Cognition

Ric Heishman and Zoran Duric

4400 University Drive
Fairfax, Virginia 22030
{rheishman,zduric}@cs.gmu.edu

Abstract. The human face comprises a complex system integrated from tissue, bone and electricity. Biometrics associated with this region provide useful information for a wide range of research disciplines. For those interested in augmented cognition, the metrics and behaviors inherent to eye blinks are particularly valuable in the interpretation and understanding of an individual's affective and cognitive states. Our work involves a novel integration of computer vision techniques for observing and interpreting the biometric information flow inherent in human eye blinks, and using these behavioral patterns to gain insight into the cognitive engagement and fatigue levels of individual subjects. Of particular interest are behavioral ambiguities – both across multiple subjects and in individual subjects across various scenarios – that present problems to both the observation and interpretation processes. Our work is pertinent to system development efforts across a wide range of applications, including driver fatigue, medical patient monitoring and critical system operator vigilance.

Keywords: Eye, blink, cognition, affective computing, motion.

1 Introduction

The human face comprises a complex system integrated from tissue, bone and electricity. Biometrics associated with this region provide useful information for a wide range of research disciplines. For those interested in the general field of augmented cognition, the metrics and behaviors surrounding eye blinks can be particularly valuable in the understanding and interpretation of an individual's affective and cognitive states. Our work involves a novel integration of computer vision techniques for observing and interpreting the biometric information flow inherent in human eye blinks, and using these behavioral patterns to gain insight into the cognitive engagement and fatigue levels of individual subjects. Metrics such as blink frequency and blink transition time or blink closure duration can serve to characterize particular states in individual subjects. Of particular interest are behavioral ambiguities – both across multiple subjects and in individual subjects across various scenarios – that present problems to both the observation and interpretation processes. These ambiguities, such as incomplete or erratic eye closure, asymmetrical blink behavior, and minimal motion during transition, are present in one or more forms in a significant percentage of groups of random individuals.

D.D. Schmorrow, L.M. Reeves (Eds.): Augmented Cognition, HCII 2007, LNAI 4565, pp. 84–93, 2007.

2 Experimental Framework

Our basic experimental design methodology engages random subjects with specific cognitive activities under contrasting conditions of mental and physical fatigue. The subjects were digitally videotaped from a frontal parallel view while participating in each of four experimental sessions: FD – Fatigued/Disengaged, FE – Fatigued/Engaged, ND – Non-Fatigued/Disengaged, NE – Non-Fatigued/Engaged. The FE/FD (fatigued) sessions were held late in the evening after a normal work day and the NE/ND (non-fatigued) sessions were held early in the morning after a full night's rest (minimum of eight hours). In the FD/ND (disengaged) sessions, the subject maintained continuous eye contact with the computer screen and was instructed to clear their minds (defocus) or "daydream". The length of these sessions averaged 15-20 minutes each. The FE/NE (engaged) sessions involved the subjects exercising problem-solving skills on a specific graphical puzzle activity. The length of these sessions averaged 20-25 minutes each.

The data processing and analysis stage involves five phases. In the manual *initialization* phase, the user chooses open and closed eye sample frames and sets the Region-Of-Interest (ROI) for each eye in these frames. The system then processes an initial frameset (1000 video frames) to gather a working set of eye transition ROIs. The *reduction* phase reduces this working set to a small number (~50) and the *clustering* phase uses k-means clustering to create a minimal eye transition alphabet (~12). The *classification* phase processes the remaining frames using a combination of static histogram analysis and dynamic image flow analysis to generate the eye state matrix. Finally, the *determination* phase employs a deterministic finite state machine to process the eye state matrix and generate the final blink behavior data.

Preliminary testing involved seven random volunteer subjects. Structured testing was then performed using five additional random volunteer subjects. Collectively, these experiments provided approximately 1.5 million color video frames for processing and analysis. For additional detail on these processes and techniques, please refer to prior publications by the authors and others [1,2,4].

3 Ambiguous Blink Behaviors

Figure 1 depicts an example of optimal eye biometric monitoring conditions, where there is clear definition of the open and closed eye states, sufficient transition range, and symmetry between the left and right eye regions.

Fig. 1. Example of optimal eye biometric monitoring conditions

Fig. 2. Examples of ambiguous eye biometric monitoring conditions. Top – narrow eye openings and asymmetrical open states, Middle – incomplete closed state, Bottom – asymmetrical and incomplete closed state.

Figure 2 depicts three examples of ambiguous eye region behaviors. The *top* subject exhibits narrow eye openings and asymmetrical open states, which provide limited transition range and problematic correlation between the left and right eye regions. The *middle* subject exhibits an incomplete closed state, which provides a limited transition range. The *bottom* subject exhibits both an asymmetric and incomplete closed state, which causes problematic state correlation between the left and right eye regions.

Fig. 3. Three different closed states for a single subject within a single HCI scenario

Figure 3 depicts three examples of differing blink behaviors exhibited by a single subject within a single HCI scenario testing session. This volatile behavior provides differing transition range metrics that cause problems with blink definition parameters. Our initial approach for eye ROI analysis involved the use of static frame-by-frame histogram analysis. However, given the frequency and breadth of the aforementioned blink behavior ambiguities, we shifted our subsequent analyses to a more dynamic approach using flow analysis across contiguous series of frames.

4 Comparison of Analysis Techniques

To compensate for the inadequacies inherent to static computer vision monitoring techniques, flow analysis can be used to enhance interpretation by compensating for processing anomalies that arise in problematic data streams. Flow analysis provides crisp parsing of the blink transition stages and is significantly more effective in delineation and classification when used in conjunction with or in lieu of static computer vision techniques such as histogram analysis using Euclidean Distances. Again, for detailed discussion of these techniques, refer to prior publications by the authors [2,4].

Table 1 provides a comparison of results from two of the processing extremes – subject CD (previously cited as an example of optimal eye biometric monitoring conditions (refer to Fig. 1) and subject SG (previously cited as an example of eye biometric pattern inconsistencies (refer to Fig. 3). The subject data was processed through three testing phases: *Manual* – manually counted while viewing video sequence at reduced speed, *Histogram* – (automatically processed using static histogram analysis techniques, and *Flow* – hybrid process using both histogram and flow analysis techniques. Note that the *Manual* and *Flow* data are consistent across both subjects, with some differences due to inconsistencies inherent to manual objective dispositioning. Conversely, the *Histogram* results are consistent in the

Table 1. Comparison between a subject exhibiting optimal eye biometric monitoring conditions (CD) and ambiguous eye biometric behavior (SG). Subject SG exhibited multiple completely-closed eye blink states (as depicted in Fig. 3).

	CD-FD			SG-ND		
	Manual	Histogram	Flow	Manual	Histogram	Flow
Blinks						
- total blinks in scenario	237	235	237	350	292	351
- blink frequency (seconds)	3.79	3.82	3.79	3.07	3.68	3.06
Steady-State (time between blinks)						
- min (seconds)	0.00	0.00	0.00	0.00	0.03	0.00
- max (seconds)	16.30	16.47	16.97	15.13	20.47	15.40
- mean (seconds)	3.39	3.47	3.43	2.76	3.15	2.66
- std dev (seconds)	2.57	2.65	2.97	2.55	2.55	2.28
Transition (blink duration – open/closed/open)						
- min (seconds)	0.30	0.07	0.10	0.10	0.10	0.10
- max (seconds)	0.77	4.23	0.53	0.43	0.43	0.63
- mean (seconds)	0.38	0.39	0.30	0.22	0.23	0.28
- std dev (seconds)	0.06	0.43	0.09	0.08	0.05	0.08

ideal subject but quite erratic in the problematic subject. Table 2 provides a sample data set of a single subject across all four HCI testing scenarios.

Table 2. Complete example data set for single subject using three techniques (M – manual, H – static histogram, F – dynamic hybrid histogram/flow) across all four HCI scenarios

Scenario	Method	Total Blinks	Blink Freq	Period (max)	Period (min)	Period (mean)	Period (sd)	Tran (max)	Tran (min)	Tran (mean)	Tran (sd)
FD	M	677	*	*	*	*	*	*	*	*	*
	H	638	1.97	8.57	0.00	1.66	1.30	5.00	0.10	0.36	0.35
	F	678	1.85	8.73	0.00	1.55	1.25	0.76	0.10	0.28	0.07
FE	M	511	*	*	*	*	*	*	*	*	*
	H	483	2.68	13.27	0.00	2.38	1.85	19.30	0.10	0.36	1.19
	F	510	2.54	8.27	0.00	2.28	1.61	0.60	0.10	0.24	0.05
ND	M	350	3.07	15.13	0.00	2.76	2.55	0.43	0.10	0.22	0.08
	H	292	3.68	20.47	0.03	3.48	3.15	0.43	0.10	0.23	0.05
	F	351	3.06	15.40	0.00	2.66	2.28	0.63	0.10	0.28	0.08
NE	M	267	*	*	*	*	*	*	*	*	*
	H	286	5.58	24.33	0.00	4.67	4.87	19.73	0.07	1.93	3.56
	F	266	6.00	31.60	0.07	5.71	5.04	0.06	0.10	0.26	0.06

5 Affective and Cognitive State Classification

Recent studies focused in areas relevant to eye blinks involving cognitive engagement and fatigue provide the following general assertions [3,6]:

- *blink rate* (BR) tends to increase as a function of cognitive workload, fatigue and time-on-task
- *blink closure duration* (BCD) tends to decrease as a function of cognitive work-load and increases as a function of fatigue

Fig. 4 provides the layout of our adaptation of Russell's conceptual framework – the Pleasure-Arousal psychological judgment space for affected feelings[5], which we refer to as the Fatigued, Engaged, Non-Fatigued, Disengaged (FEND) Condition Space. The horizontal plane represents the Fatigue state spectrum from Fatigued to Non-Fatigued. The vertical plane represents the Engagement state spectrum from Engaged to Disengaged. The quadrants formed by the integration of the two state dimensions provide the behavioral context for each of the four unique HCI scenarios. Each quadrant displays the corresponding Blink Rate (BR) and Blink Closure Duration (BCD) behaviors, based on historical empirical data from previous studies, for that particular state context.

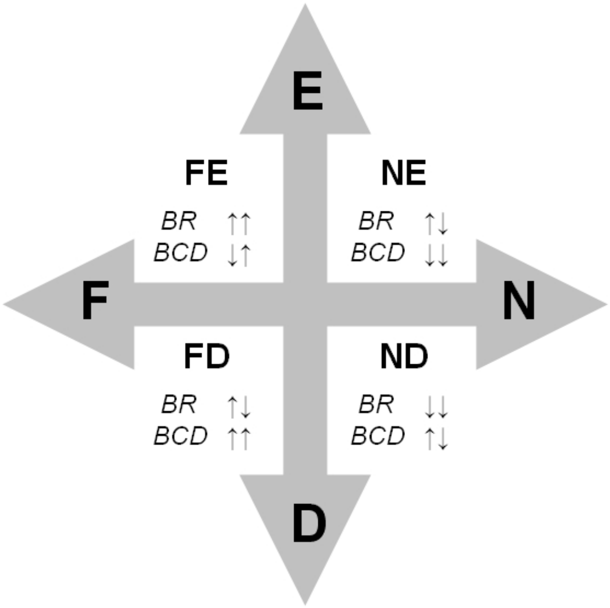

Fig. 4. Examples Fatigued, Engaged, Non-Fatigued, Disengaged (FEND) Condition Space – framework for the experimental domain

Given the aforementioned impact of fatigue and cognitive engagement on each scenario context, the following expectations regarding the Blink Rate (BR) and Blink Closure Duration (BCD) behaviors are implied. The magnitude of the impact of each state is assumed to be relatively equal for framework development purposes.

- *FE scenario* – elevated BR with moderate BCD
- *NE scenario* – moderate BR with suppressed BCD
- *ND scenario* – suppressed BR with moderate BCD
- *FD scenario* – moderate BR with elevated BCD

Figs. 5 & 6 provide the Blink frequency (blink rate – BR) and transition duration (blink closure duration – BCD) for all five subjects across the four HCI scenarios. In each plot, the dashed line represents the relative expected behavioral trend, as outlined in the FEND Condition Space (refer to Fig. 4). For blink frequency, the general expectation gleaned from cognitive psychology is that the highest blink rate should be exhibited by subjects in the FE state; the lowest blink rate should be exhibited by subjects in the ND state; and the subject's blink rates for the FD and NE states should fall somewhere between FE and ND. For transition duration, the general expectation is that the longest blink closure duration should be exhibited by subjects in the FD state; the lowest closure duration should be exhibited by subjects in the NE state; and the subject's blink closure duration for the FE and ND states should fall somewhere between FD and NE.

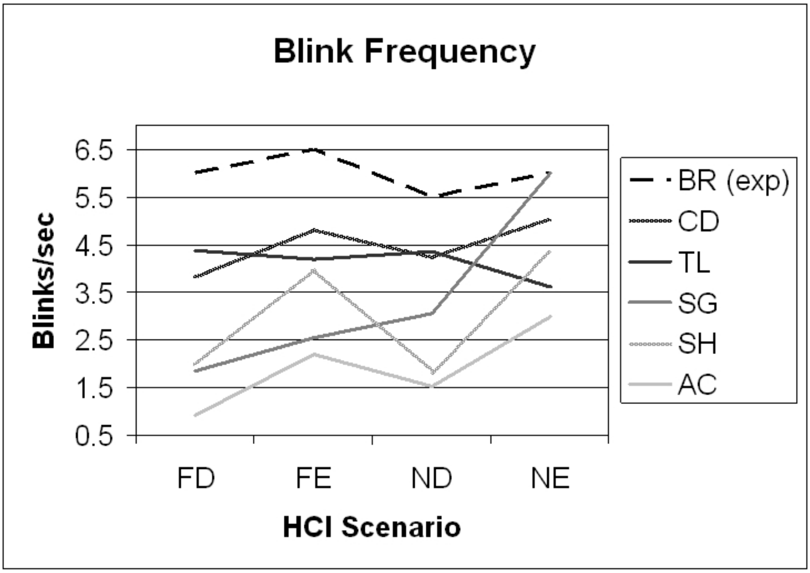

Fig. 5. Blink frequency (blink rate – BR) for all five subjects across the four HCI scenarios

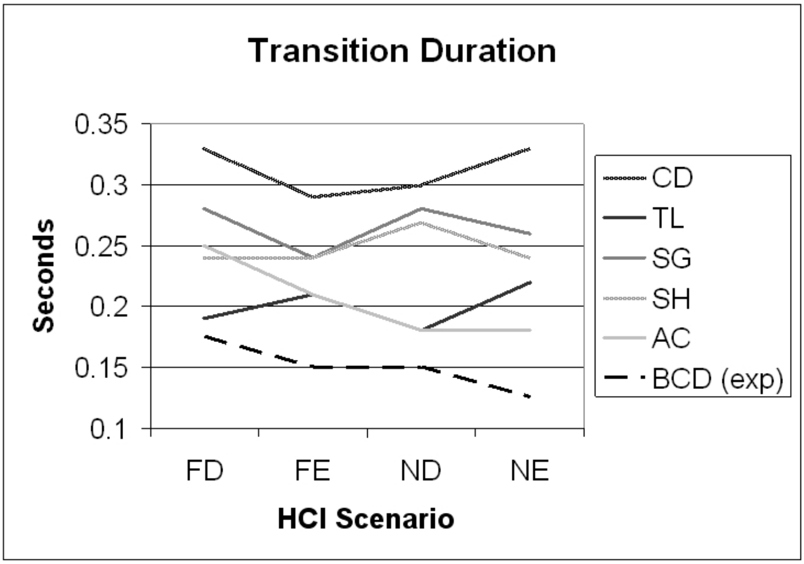

Fig. 6. Transition duration (blink closure duration – BCD) for all five subjects across the four HCI scenarios

This side-by-side comparison clearly illustrates one important fact – that there is no universal blink rate or blink closure duration that can be assumed for a generalized group of subjects. Another interesting thing to note here is that there was very little overlap in the results for each individual subject, thus each subject's behavioral range was unique on the relative magnitude scale. Finally, while the individual ranges of the transition durations projected by all subjects were relatively similar, some subjects expressed double (and in one case quadruple) the range of other subjects in the blink frequency data. We next present a more detailed examination of each individual subject.

Subject CD exhibits deviation from the expected behavior for blink rate. The NE and FD scenarios constitute the highest and lowest (respectively) blink rates while the FE and ND scenarios fall toward the middle of the range. The data does show elevated blink rates for the engaged versus disengaged sessions, however the fatigued versus non-fatigued sessions cover a similar, slightly translated trend. This subject's blink closure duration data tracks well with the expected trend, with the exception of the NE scenario – which is similar in value to the FD scenario. The summary for this subject is as follows:

- *FE scenario* – moderately elevated BR with moderate BCD
- *NE scenario* – elevated BR with elevated BCD
- *ND scenario* – moderately suppressed BR with moderate BCD
- *FD scenario* – suppressed BR with elevated BCD

Subject SG exhibits significant deviation from the expected behavior for blink rate in all scenarios. As with subject CD, the NE and FD scenarios constitute the highest and lowest (respectively) blink rates while the FE and ND scenarios fall toward the middle of the range. The data here show elevated blink rates for the non-fatigued versus fatigued sessions, however the engaged versus disengaged sessions provide little useful distinction. This subject's blink closure duration data is relatively flat, with minimal tracking with the expected trend. The summary for this subject is as follows:

- *FE scenario* – slightly suppressed BR with slightly suppressed BCD
- *NE scenario* – significantly elevated BR with moderate BCD
- *ND scenario* – slightly elevated BR with moderate BCD
- *FD scenario* – suppressed BR with moderate BCD

Subject TL exhibits nearly completely opposing trends to the expected behavior for blink rate in all scenarios. Additionally, there is significantly less variation in the data across scenarios compared to the other subjects. The only significant blink rate behavior is expressed in the NE scenario. As with the blink rate data, this subject's blink closure duration tracks nearly opposite to the expected trend. The data does reflect, however a distinction between the engaged versus disengaged sessions. The summary for this subject is as follows:

- *FE scenario* – slightly suppressed BR with slightly elevated BCD
- *NE scenario* – suppressed BR with elevated BCD
- *ND scenario* – slightly elevated BR with moderate BCD
- *FD scenario* – slightly elevated BR with slightly suppressed BCD

The subject SH blink rate data shows clear distinction between the engaged and disengaged sessions but no distinction between the fatigued and non-fatigued sessions. The blink closure duration data provides only slight distinction in the ND scenario. These biometric behaviors taken together provide the following general classification for this individual subject. As reflected in the classification rules, distinguishing between the FE and NE scenarios is problematic. The summary for this subject is as follows:

- *FE scenario* – significantly elevated BR with suppressed BCD ***
- *NE scenario* – significantly elevated BR with suppressed BCD ***
- *ND scenario* – significantly suppressed BR with slightly elevated BCD
- *FD scenario* – significantly suppressed BR with suppressed BCD

Subject AC exhibits deviation from the expected behavior similar to subject CD for blink rate, however with an exaggerated data spread. The NE and FD scenarios constitute the highest and lowest (respectively) blink rates while the FE and ND scenarios fall toward the middle of the range. The data does show elevated blink rates for the engaged versus disengaged sessions, however the fatigued versus non-fatigued sessions cover a similar, slightly translated trend. This subject's blink closure duration data generally tracks with the expected trend, except for the ND scenario, which is similar in value to the NE scenario. The summary for this subject is as follows:

- *FE scenario* – moderately elevated BR with moderate BCD
- *NE scenario* – significantly elevated BR with suppressed BCD
- *ND scenario* – moderately suppressed BR with suppressed BCD
- *FD scenario* – significantly suppressed BR with elevated BCD

Overall, none of the subjects tracked exactly with the expected behaviors, however, most provided adequate information for inferring a state from the blink rate and blink closure duration biometrics.

6 Conclusions

The experimental results of our study indicate that there are sufficient measurable behaviors inherent in the human eye blink for the reasonable determination of affective states (i.e., physical and/or mental fatigue) and cognitive states (i.e., task engagement) in individual subjects. However, this determination requires a priori knowledge of each individual gained through the learning process described above. Interestingly, six of the twelve subjects involved in our study exhibited one or more eye biometric ambiguities. These ambiguities can cause problems for static analysis techniques such as thresholding, but such anomalies can be interpreted effectively using techniques such as dynamic image flow analysis.

Finally, it has been suggested by some in the cognitive psychological community and others in HCI that blink frequency increases with cognitive workload and fatigue (or time-on-task) while blink closure duration decreases as a function of workload and increases as a function of fatigue. While we found this general assertion to largely hold true, in certain individuals the exact opposite was shown to be the reality. This understanding, coupled with other observations during the experimental phase, prevents us from generalizing the determination capability to a wider range of subjects.

References

1. Bhaskar, T.N., Keat, F.T., Ranganath, S., Venkatesh, Y.V.: Blink detection and eye tracking for eye localization. In: Proc. Conference on Convergent Technologies for Asia-Pacific Region, vol. 2, pp. 821–824 (2003)
2. Duric, Z., Li, F., Sun, Y., Wechsler, H.: Using normal flow for detection and tracking of limbs in color images. In: Proc. 15th International Conference on Pattern Recognition, vol. 4, pp. 40268–40271 (2002)
3. Fukuda, K., Stern, J.A., Brown, T.B., Russo, M.B.: Cognition, blinks, eye-movements, and pupillary movements during performance of a running memory task. Aviation, Space, and Environmental Medicine 76, C75–C85 (2005)
4. Heishman, R., Powers, W., Duric, Z.: Techniques for tracking and analyzing eye region biometrics in HCI Scenarios. In: Proceedings of the 19th British HCI Group Annual Conference, Edinburgh, Scotland, vol. 2, pp. 229–231 (2005)
5. Russell, J.A.: Reading emotions from and into faces: Resurrecting a dimensional-contextual perspective. In: Russell, J.A., Fernandez, J.M. (eds.) The Psychology of Facial Expression (chapter 13), pp. 295–320. Cambridge University Press, Paris (1997)
6. Stern, J.A.: The eye blink: Affective and cognitive influences. In: Forgays, D.G., Sosnowski, T., Wrzesniewski, K. (eds.) Anxiety: Recent Developments in Cognitive, Psychophysiological, and Health Research (chapter 8), pp. 109–128. Hemisphere Publishing, Washington (1992)