Title
Insomniacs Misidentify Angry Faces as Fearful Faces Because of Missing the Eyes: An Eye-Tracking Study

Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 39(0)

Authors
Zhang, Jinxiao
Chan, Antoni B.
Lau, Esther Y.Y.
et al.

Publication Date
2017

Peer reviewed

Insomniacs Misidentify Angry Faces as Fearful Faces Because of Missing the Eyes: An Eye-Tracking Study

Jinxiao Zhang (tepzhang@hku.hk)
Department of Psychology, The University of Hong Kong, Pok Fu Lam, Hong Kong
Antoni B. Chan (abchan@cityu.edu.hk)
Department of Computer Science, The City University of Hong Kong, Kowloon Tong, Hong Kong
Esther Y.Y. Lau (laueyy@eduhk.hk)
Department of Psychology, The Education University of Hong Kong, Tai Po, Hong Kong
Janet H. Hsiao (jhsiao@hku.hk)
Department of Psychology, The University of Hong Kong, Pok Fu Lam, Hong Kong

Abstract

Insomniacs were found to have compromised perception of facial expressions. Through eye movement examinations, here we test the hypothesis that this effect is due to impaired visual attention functions for retrieving diagnostic features in facial expression judgments. 23 individuals with insomnia symptoms and 23 non-insomniac controls completed a task to categorize happy, sad, fearful, and angry faces. The insomniacs were less accurate to recognize angry faces and made more "fearful" mistakes than controls. A hidden Markov modeling approach for eye movement data analysis revealed that when recognizing angry faces, more insomniacs adopted an eye movement pattern focusing on the mouth while more controls adopted a pattern attending to both the eyes and the mouth. This result is consistent with previous findings that the primary diagnostic feature for recognizing angry faces is the eyes suggesting that impaired information selection through visual attention control may account for the compromised emotion perception in insomniac individuals.

Keywords: insomnia; eye-tracking; hidden Markov model; facial expression

Introduction

Insomnia is closely related to emotional disorders such as anxiety and depression (see Baglioni et al., 2010 for a review). In particular, compromised perception of emotional facial expressions, which has an important role in one's socioemotional functioning, has been frequently found among sleep-deprived individuals or those with insomnia symptoms. For example, individuals with physiological insomnia were found to perceive fearful and sad faces as less emotional compared with good sleepers (Kyle et al., 2014). Another study found that 31.5-hour sleep deprivation led to less accurate recognition of sad faces (Cote et al., 2014). In addition, an fMRI study found that sleep deprivation made participants more likely to classify facial expressions as angry, and this effect was coupled with their diminished neural discrimination between threatening and non-threatening stimuli (in the anterior cingulate and anterior insula; Goldstein-Piekarski et al., 2015). Nevertheless, the underlying mechanism for the disturbed perception of emotional facial expressions among insomniacs remains unclear (Kyle et al., 2014).

In addition to emotional functioning, insomniacs and sleep-deprived individuals are commonly found to have impaired performance in visuospatial attention tasks (Marchetti et al., 2006), and this behavioral impairment is associated with attenuated activation in the attention neural network comprising the prefrontal, parietal, and cingulate cortex (Tomasi et al., 2009; Mander et al., 2008). The impairment in the attention network may have a profound impact on cognitive performance in general, as it can significantly influence how task relevant information is selected. Indeed, attenuated activations in the attention network were reported to be associated with less explorative eye movement patterns and worse performance in face recognition (Chan et al., 2016). It is thus possible that insomniac individuals adopt different eye movement patterns from good sleepers in emotional facial expression judgments as a result of their impaired visual attention control, leading to compromised recognition performance.

Here we aim to investigate the role of visual attention functions in accounting for insomniacs' compromised identification of emotional facial expressions through eye tracking. Individuals with insomnia symptoms and non-insomniac controls completed an emotional facial expression judgement task in which they were required to recognize emotional facial expressions and rate the emotional intensity with eye tracking. Recent studies have suggested four basic facial expressions that are recognized across cultures: 'happy', 'sad', 'fear' and 'anger' (Jack et al., 2016). Accordingly, here we examine participants' perception of these four facial expressions. Previous research did not consistently find disturbed perception of a particular facial expression in sleep-deprived or insomniac individuals. However, most of the expressions reported to be affected were negative expressions (e.g., sadness in Cote et al., 2014; anger in Goldstein-Piekarski et al., 2015; sadness and fear in Kyle et al., 2014). Thus, here we hypothesize that insomniac individuals may be less accurate in recognizing the negative facial expressions than non-insomniac controls, and that this behavioral difference may be associated with differences in eye movement patterns adopted by the two groups.

While eye movements are important measures for visual attention functions, recent studies have reported substantial individual differences in eye movements in visual tasks (e.g. Kanan et al., 2015), which were not adequately reflected in most of the current analysis methods. In view of this, Chuk, Chan, and Hsiao (2014) have recently proposed a Hidden

Markov Model (HMM, a type of time-series probabilistic model in machine learning) based approach for analyzing eye movement data. This approach assumes that the current eye fixation during a task is conditioned on previous fixations. Thus, eye movements in the task can be considered a Markov process, which can be better understood using HMM. In this approach, each individual's eye movements are modeled with an HMM, including both person-specific regions of interests (ROIs) and transitions among the ROIs. Thus, it reflects individual differences in both spatial and temporal dimensions of eye movements. Individual HMMs can be clustered to discover common patterns among individuals (Coviello, Chan, & Lanckriet, 2014), and similarities between individual eye movement patterns can be quantitatively assessed by calculating the likelihoods of the patterns being generated by a given HMM. Thus, this approach is especially suitable for examining the relationship between eye movement patterns and other outcome measures such as task performance (e.g., Chuk, Chan, & Hsiao, in press). Here we aim to apply this method to examine the relationship among insomnia, eye movements, and performance in facial expression categorization. We hypothesize that there may be more insomniac individuals adopting an eye movement pattern that overlooks diagnostic features for the negative facial expressions than non-insomniac controls, and participants' likelihoods of adopting this pattern may be associated with their performance in recognizing the negative expressions.

Methods

Participants

23 individuals with insomnia symptoms and 23 non-insomniac controls classified by the Sleep Condition Indicator (SCI, Espie et al., 2014) were recruited (Table 1). The SCI consists of 8 items concerning an individual's sleep condition during the recent month in a 0-4 Likert-style scale. The Chinese SCI has been validated and recommended as a screening tool for clinical insomnia with an original cut-off at 21/22 (Wong et al., 2017). To increase the contrast between the two groups, individuals with SCI scores $\leq$ 19 were classified as individuals with insomnia symptoms, and those with SCI scores $\geq$ 24 were classified as non-insomnia controls. Participants in the two groups were individually matched in gender and age. They were ethnically Chinese from Hong Kong and right-handed (Edinburgh Handedness Inventory, EHI; Oldfield, 1971). They had normal or corrected-to-normal vision and no history of head trauma or psychiatric conditions.

Table 1. Participants' demographics and sleep conditions

	Controls (*n*=23)	INS (*n*=23)	Comparison test
Age ($M \pm SD$)	18.91±0.90	18.74±0.81	$t(44) = .689$
Gender (%male)	30.43%	30.43%	$\chi^2(1) = 0$
SCI ($M \pm SD$)	27.61±1.80	15.70±2.94	$t(44) = 16.54$**

SCI: Sleep Condition Indicator; INS: insomnia group.
* $p < .05$; ** $p < .01$

Design & Procedures

Participants completed an emotional facial expression judgment task adapted from Kyle et al. (2014), which required participants to categorize and rate emotional intensity of 4 facial expressions (i.e. happiness, sadness, fear, and anger; Figure 1A). The task consisted of 2 blocks with 40 trials in each block (10 trials for each expression). In each trial, a solid dot first appeared at the screen center for drift correction, and it was replaced by a fixation cross for 500 ms. Once a fixation was detected at the cross at the end of the 500 ms, a color picture of an Asian individual's face with an emotional facial expression (Figure 1B; 450 x 600 pixels) was presented either above or below the center of the screen until the participants categorized it as a happy, sad, fearful, or angry face by pressing corresponding buttons. Participants were asked to respond as quickly as possible. After a 250-ms pause, they were asked to rate the emotional intensity of the facial expression on a 6-point scale, ranging from "1-not very intense" to "6-extremely intense". Half of the face images were male faces; the faces spanned around 8° of visual angle at the viewing distance of 60 cm (Hsiao & Cottrell, 2008). The participants had a practice of 24 trials at the beginning of the task.

Participants' eye movements were recorded by an EyeLink 1000 eye tracker. The standard 9-point calibration procedure was used at the beginning of each block and was repeated whenever the drift-correction error was larger than 1° of visual angle. The tracking mode was pupil and corneal reflection and the sampling rate was 2000 Hz. A chinrest was used during the task to reduce head movements.

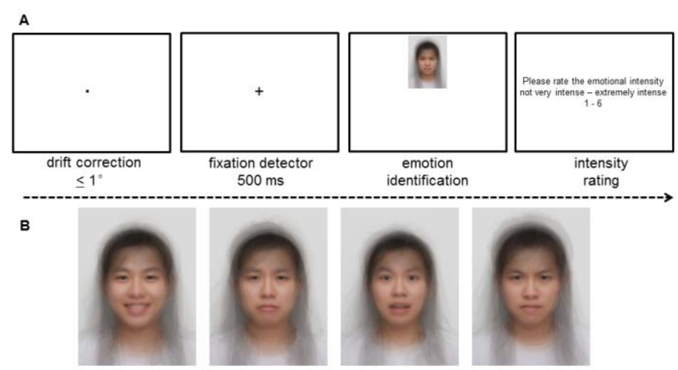


Figure 1. (A) A demonstration of a trial with an angry face. (B) The average pictures of the 20 stimuli used in each emotional expression. From left to right: happiness, sadness, fear, anger.

The eye movement data were analyzed using the EMHMM (Eye Movement analysis with Hidden Markov Models, http://visal.cs.cityu.edu.hk/research/emhmm/; Chuk et al., 2014) approach. Each participant's eye movements while viewing one type of facial expressions was summarized with an HMM. The optimal number of ROIs for each model was determined automatically through a variational Bayesian approach, by selecting the model with the highest marginal likelihood. For each facial expression, we clustered all individual HMMs into 2 groups to reveal common patterns. We then examined the distributions of the insomniacs and the controls in the 2 common patterns, and the correlations between their likelihoods of adopting each pattern and behavioural performances.

Results

Behavioral results

A 2 (group: insomnia vs. control) by 4 (emotion: happy, sad, fearful and angry) repeated measures ANOVA revealed a significant interaction between group and emotion on the accuracy of the facial expression judgment task, $F(3, 132) = 2.68$, $p = .049$, $\eta^2 = .057$. Independent t-tests between the insomnia and the control group in each emotion condition indicated that there was 8.4% higher accuracy on average to recognize angry faces in the control group than the insomnia group, $t(44) = 2.12$, $p = .039$, $d = .63$ (Figure 2A). This group difference was not found in other emotion conditions, *ps* > .05. When we examined the responses participants made towards angry faces (Figure 2B), the 2 by 4 repeated measures ANOVA indicated a significant interaction between group and emotion, $F(3, 132) = 3.57$, $p = .016$, $\eta^2 = .075$. Post-hoc between-group t-tests showed a significantly higher percentage of "fearful" responses in the insomnia group than the control group, $t(44) = 2.07$, $p = .045$, $d = .62$.

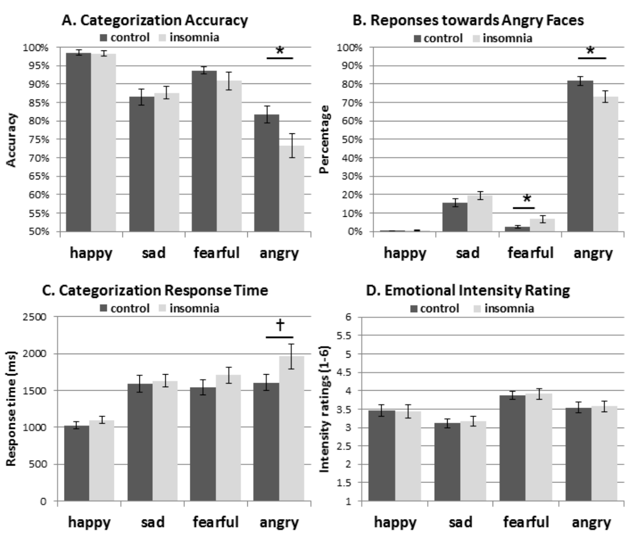


Figure 2. (A) The accuracy to categorize happy, sad, fearful, and angry facial emotions in the control and the insomnia group. (B) Reponses made while angry faces were presented. (C) Response time to accurately categorize emotional facial expressions. (D) Emotional intensity rating of the 4 facial emotions in the two groups. (* $p < .05$; † $.05 < p < .10$; error bars: 1 s.e.m.)

In the correct response time (RT) data (Figure 2C), a 2 (group) by 4 (emotion) repeated measures ANOVA indicated a main effect of emotion (adjusted post-hoc comparisons: happy < sad, fear, and anger), $F(3, 132) = 40.72$, $p < .001$, $\eta^2 = .48$. This effect did not interact with group. When we examined the difference between the two groups in categorizing different expressions separately, the insomnia group responded marginally slower in identifying angry faces than the control group, $t(44) = 1.768$, $p = .084$, $d = .53$. The group by emotion repeated measures ANOVA on emotional intensity rating showed a main effect of emotion (adjusted post-hoc comparisons: fearful > happy, angry > sad; Figure 2D), $F(3, 132) = 23.24$, $p < .001$, $\eta^2 = .35$. However, this effect did not interact with group.

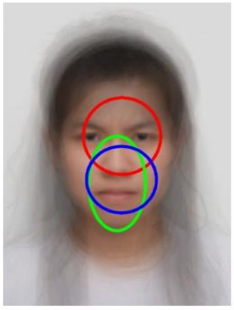
Eye movement data

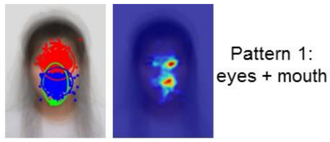
We modeled each participant's eye movements for viewing each type of facial expressions with an HMM. For each expression type, we clustered all participants' HMMs into 2 representative patterns and examined the distributions of the insomniacs and controls adopting the 2 patterns. We observed that the insomnia and control groups differed significantly in their frequencies of adopting the 2 representative patterns when viewing angry faces. Consistent with our behavioral data, this difference was not observed in viewing other expressions[1]. Figure 3A and 3B show the 2 representative patterns. The 3 ROIs were in red, green, and blue respectively and the table showed the priors (the probability of the first fixation being located at an ROI) of the ROIs and the transition probabilities among them. In the eye-mouth pattern (Pattern 1; $n = 21$), the first fixation was most likely to be in eye region (red ROI, 47%) or the mouth region (blue ROI, 42%). The next fixation from the eye ROI had a high probability to stay in the same (eye) ROI, whereas the next fixation from the mouth ROI had a 26% probability to move to the eye region. Thus, participants adopting this pattern focused the most on the eye region, followed by the mouth region, while viewing angry faces. In the nose-mouth pattern (Pattern 2; $n = 25$), the first fixation was most likely to be at the nose/face center (red ROI, 46%) or the mouth and chin region (green ROI, 42%). The next fixation following the first was most likely to stay in the same ROI as the first fixation (> 99%), suggesting few transitions among the ROIs. Thus, participants adopting this pattern tended to focus on the lower part of the face (nose, mouth and chin) but neglect the eye region. Figure 3C shows the difference heat map between the two patterns: the eye-mouth pattern had more fixations on the right eye region (warm colors) while the nose-mouth pattern had more fixations on the mouth and chin regions (cold colors). This clear separation of the eye movement patterns demonstrated well the power of machine learning methods.

Importantly, significantly more insomniacs adopted the nose-mouth eye movement pattern, and more controls adopted the eye-mouth pattern (Figure 3D), $\chi^2(1) = 4.29$, $p = .038$. In addition, insomniacs' eye movement patterns had higher similarities to the nose-mouth pattern than those from controls, $t(44) = -2.37$, $p = .022$, $d = .713$, as measured in the log-likelihoods of their eye movement patterns being generated by the HMM of the nose-moth pattern. In contrast, there was no significant difference in the similarity of eye movement patterns to the eye-mouth pattern between insomniacs and controls, $p > .05$.

[1] Due to space limit, these results were not reported here.

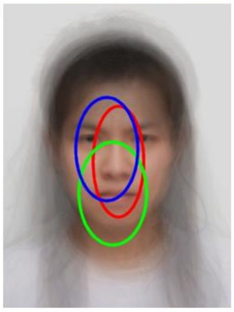
A

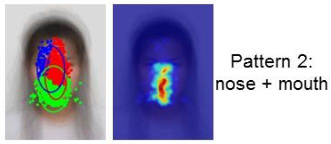




	To Red	To Green	To Blue
Priors	.47	.12	.41
From Red	.94	.06	.00
From Green	.26	.01	.73
From Blue	.04	.01	.95

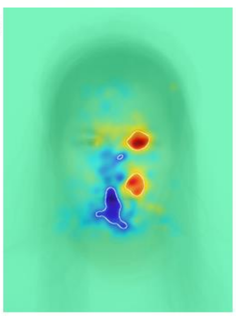
B





	To Red	To Green	To Blue
Priors	.46	.42	.12
From Red	1.00	.00	.00
From Green	.01	.99	.00
From Blue	.01	.00	.99

C



D

No. of individuals	Controls	Insomniacs	Total
Pattern 1	14 (60.9% controls)	7 (30.4% IIS)	21
Pattern 2	9 (39.1% controls)	16 (69.6% IIS)	25
Total	23	23	46

Figure 3. (A and B) The eye-mouth and nose-mouth representative eye movement patterns for viewing angry faces as the result of clustering. Images from left to right: 3 ROIs, actual assignments of the fixations to the ROIs, and heat map of eye fixations. The tables contain the priors and transition probabilities of the ROIs. (C) Difference map of actual fixations between the two patterns. (D) Distribution of the eye-mouth (Pattern 1) and nose-mouth (Pattern 2) patterns in the insomnia group and the control group.

To demonstrate the advantage of using the EMHMM approach to reveal these differences, we plotted the heat maps of the fixations of the insomnia and control groups and the difference map between them (Caldara & Miellet, 2011). As can be seen in Figure 4 difference map, the significantly different areas (circled in white) were scattered and not easily interpretable. This phenomenon was due to significant individual differences in eye movement patterns within each group. The EMHMM approach allows us to identify the eye-mouth and nose-mouth patterns in a data driven fashion and clearly reveal the difference between the two participant groups while accounting for individual differences in eye movement patterns.

When we examined the relationship between eye movement patterns and performances in the facial expression judgment task, we found that the log-likelihood of participants' patterns being classified as the nose-mouth pattern was positively correlated the percentage of "fearful" responses (Figure 5A), r = .423, p = .003[2]: the more similar the pattern to the nose-mouth pattern when viewing angry faces, the more "fearful" mistakes made. In addition, in the control group, the log-likelihood of being classified as the eye-mouth pattern was negatively correlated with the correct RT of identifying angry faces (Figure 5B), r = -.451, p = .031: the more similar the pattern to the eye-mouth pattern, the faster the correct RT. This correlation was not significant in the insomnia group, p > .05.

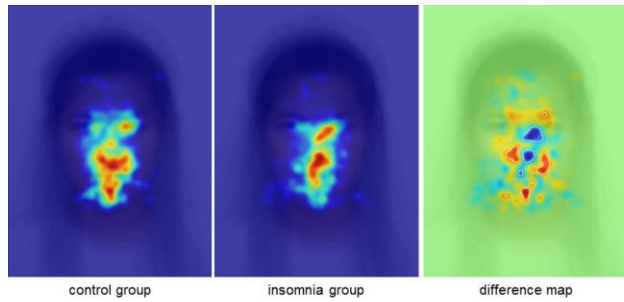


Figure 4. Fixation heat maps of the control and insomnia group and the difference map between the two groups. The areas surrounded by white contours showed significant differences. Warm colors: control > insomnia; cold colors: insomnia > control.

Discussion

In the current study, we aim to test the hypothesis that the compromised perception of emotional facial expressions in insomniacs is related to impaired visual attention functions for selecting diagnostic features as revealed in their eye movements. Our results showed that individuals with insomnia symptoms were less accurate and marginally slower to identify angry faces than non-insomniac controls. Furthermore, insomniacs tended to misidentify angry faces as fearful faces more often than controls. Through the EMHMM approach (Chuk et al., 2014), we discovered two common eye movement patterns among the participants when viewing angry faces: an eye-mouth pattern that looked at the eyes and mouth primarily, and a nose-mouth pattern that fixated at either the nose or the mouth/chin region. Significantly more controls adopted the eye-mouth pattern and more insomniacs adopted the nose-mouth pattern. Indeed, the eye-mouth pattern was associated with faster identification of angry faces in the control group, whereas the nose-mouth pattern was associated with more misidentification of angry faces as fearful faces. These results suggest that insomniacs misidentified angry faces as fearful faces because of missing the eyes. The EMHMM approach is a data-driven method that reflects individual differences in both spatial and temporal dimensions of eye movements and provides quantitative assessments of

[2] The log-likelihood of participants' eye movement patterns being classified as the eye-mouth pattern was also correlated with the percentages of "fearful" responses, but with a smaller Pearson's r, r = .394, p = .007. This effect may be due to the similarities between the two representative patterns. Note that the two patterns were significantly different: eye movements classified as the eye-mouth pattern had higher likelihoods of being generated by the eye-mouth model, and vice versa (Chuk et al., 2014).

similarities among individual eye movement patterns, making it possible to reveal these effects. These findings were not possible with traditional approaches to eye movement data analysis such as using predefined regions of interest (ROIs; Henderson et al., 2005) or fixation heat maps (iMap, Caldara & Miellet, 2011) between the insomniacs and the controls (Figure 3 vs. Figure 4).

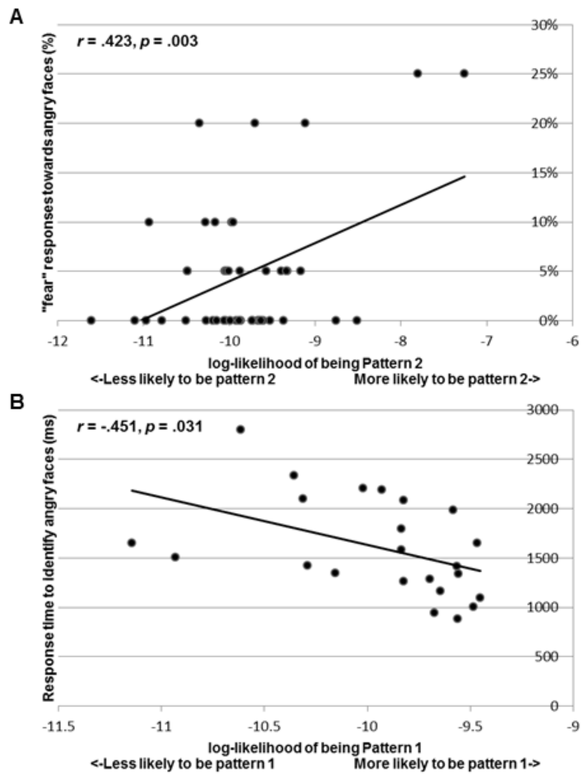


Figure 5. (A) A positive correlation between the log-likelihood of being the nose-mouth pattern and the "fearful" response rate among all participants. (B) A negative correlation between the log-likelihood of being the eye-mouth pattern and the RT to identify angry faces in the control group.

Our finding is consistent with previous studies suggesting that insomnia and sleep loss are associated with compromised recognition of emotional facial expressions (e.g. Kyle et al., 2014; Cote et al., 2014). In particular, in an fMRI study, Goldstein-Piekarski and colleagues (2015) found that experimental sleep deprivation impaired behavioral and neural discrimination of angry faces from neutral faces. Angry facial emotions signal social threats, and thus misidentification or slower identification of angry faces may elevate interpersonal conflicts of insomniac individuals. Interestingly, insomniacs were more likely to misidentify angry faces as fearful faces than controls, suggesting that they may misidentify social threats senders as social threats receivers.

The misidentification of facial anger as facial fear in insomniacs corresponds to their eye movement patterns. Most of the insomniacs adopted a pattern that focused on either the nose or the mouth while missing the eye region. In contrast, most controls adopted a pattern that looked at mainly the eye region or both the eye and the mouth region. The finding that insomniacs missed the eye region may be related to their impaired perception of angry faces. Indeed, through the 'Bubbles' reverse-correlation technique, Smith, Cottrell, Gosselin, and Schyns (2005) showed that eyes are the most diagnostic feature for recognizing angry expressions, whereas the most diagnostic features for recognizing the other three expressions (i.e. 'happy', 'sad', and 'fearful') were either mainly on the mouth region or comprised both the mouth and the eyes (see also Schyns, Petro, & Smith, 2009). Consistent with this finding, Eisenbarth and Alpers (2011) showed that participants looked at the eyes longer than the mouth in recognizing anger and sad expressions, the mouth longer than the eyes for happy expressions, and the mouth and the eyes equally for fear and neural expressions. The exclusive importance of the eye region for recognizing angry faces may explain why we only observed behavioral differences between insomniacs and controls in identifying angry faces, since identifying other expressions do not require specific attention to the eye region as much as identifying angry expressions.

In the literature, biased interpretation of emotional information after sleep loss has typically been attributed to impaired functioning of limbic structures such as amygdala and anterior cingulate cortex and the functional connectivity between the prefrontal cortex and these limbic structures towards emotional stimuli (e.g., Yoo et al., 2007; Goldstein-Piekarski et al., 2015). In addition to this emotional brain network, the current study suggests that impaired attentional functioning may also play an important role in accounting for the misinterpretation of emotional information after sleep loss. Indeed, sleep loss is shown to affect visual attention control and activation in the attention brain network (Tomasi et al., 2009; Mander et al., 2008). Decreased activations in the attention brain network (e.g., the frontal eye field and intraparietal sulcus) are associated with maladaptive eye movement patterns and impaired recognition performance during face viewing (Chan et al., 2016). Impaired visual attention functions may cause failure of selecting diagnostic information for emotional face perception, leading to biased interpretation of emotional information. Our finding is consistent with Cote et al.'s (2014) study, which showed that impaired facial expression identification in sleep-deprived individuals was reflected in early visual ERP components including P1 and N170.

While the current study showed impaired recognition of angry expressions but not other expressions in insomniacs, some previous studies have reported disturbed perception of sad and fearful faces in addition to angry faces (e.g., Kyle et al., 2014). Cote et al. (2014) showed that altered early visual ERP responses due to sleep deprivation were observed for all expressions, whereas difference in identification accuracy between sleep deprived individuals and controls was only observed in sad faces. This effect suggests that while the modulation of sleep loss in attentional functioning may apply to all expressions in general, whether it results in decreased identification accuracy may depend on how it affects selection of diagnostic features, since different facial expressions differ in their diagnostic features (Schyns et al., 2009). There may be individual differences in how features are selected and used for identification; individual differences in emotional functioning may also play a role. Future work will examine these possibilities.

In conclusion, here we showed that insomniacs misrecognized angry expressions because of missing diagnostic features in the eye region. This effect suggests that the impaired perception of facial expressions after sleep loss may be due to diminished visual attention control in addition to impaired emotional functioning. To our knowledge, this is the first to report the role of eye movement in the biased perception of emotional information due to sleep loss. Future studies will examine eye movements in clinical insomnia samples and sleep-deprived individuals to further examine the role of visual attention control in emotional perception after sleep loss.

Acknowledgments

We are grateful to the Research Grant Council of Hong Kong (#17402814 to Hsiao and CityU110513 to Chan). We thank Dr. Tim Chuk for his support in data analysis and Ms. Li-Cih Hsu for her assistance in data collection.

References

Baglioni, C., Spiegelhalder, K., Lombardo, C., & Riemann, D. (2010). Sleep and emotions: a focus on insomnia. *Sleep medicine reviews*, *14*(4), 227-238.

Caldara, R. & Miellet, S. (2011). iMap: a novel method for statistical fixation mapping of eye movement data. *Behavior Research Methods, 43*(3), 864-878.

Chan, C. Y. H., Wong, J. J., Chan, A. B., Lee, T. M. C., & Hsiao, J. H. W. (2016). Analytic eye movement patterns in face recognition are associated with better performance and more top-down control of visual attention: an fMRI study. In *Proceedings of the 38th Annual Conference of the Cognitive Science Society,* 854-859*.*

Chuk, T., Chan, A. B., & Hsiao, J. H. (2014). Understanding eye movements in face recognition using hidden Markov models. *Journal of vision*, *14*(11), 8-8.

Chuk, T., Chan, A. B., & Hsiao, J. H. (in press). Is having similar eye movement patterns during face learning and recognition beneficial for recognition performance? Evidence from hidden Markov modeling. *Vision Research*.

Cote, K. A., Mondloch, C. J., Sergeeva, V., Taylor, M., & Semplonius, T. (2014). Impact of total sleep deprivation on behavioural neural processing of emotionally expressive faces. *Experimental brain research*, 232(5), 1429-1442.

Coviello, E., Chan, A. B., & Lanckriet, G. R. G. (2014). Clustering hidden Markov models with variational HEM. *Journal of Machine Learning Research, 15*(1), 697-747.

Eisenbarth, H., & Alpers, G. W. (2011). Happy mouth and sad eyes: scanning emotional facial expressions. *Emotion*, *11*(4), 860.

Goldstein-Piekarski, A. N., Greer, S. M., Saletin, J. M., & Walker, M. P. (2015). Sleep deprivation impairs the human central and peripheral nervous system discrimination of social threat. *The Journal of Neuroscience, 35*(28), 10135-10145.

Hsiao, J. H., & Cottrell, G. W. (2008). Two fixations suffice in face recognition. *Psychol. Sci., 9(10)*, 998-1006.

Henderson, J. M., Williams, C. C., & Falk, R. J. (2005). Eye movements are functional during face learning. *Memory & Cognition, 33*(1), 98-106.

Kanan, C., Bseiso, D. N., Ray, N. A., Hsiao, J. H., & Cottrell, G. W. (2015). Humans have idiosyncratic and task-specific scanpaths for judging faces. *Vision Research*, *108*, 67-76.

Kyle, S. D., Beattie, L., Spiegelhalder, K., Rogers, Z., & Espie, C. A. (2014). Altered emotion perception in insomnia disorder. *Sleep*, *37*(4), 775-783.

Mander, B. A., Reid, K. J., Davuluri, V. K., Small, D. M., Parrish, T. B., Mesulam, M. M., Zee, P.C., & Gitelman, D. R. (2008). Sleep deprivation alters functioning within the neural network underlying the covert orienting of attention. *Brain research*, 1217, 148-156.

Marchetti, L. M., Biello, S. M., Broomfield, N. M., Macmahon, K., & Espie, C. A. (2006). Who is pre-occupied with sleep? A comparison of attention bias in people with psychophysiological insomnia, delayed sleep phase syndrome and good sleepers using the induced change blindness paradigm. *Journal of Sleep Research*, *15*(2), 212-221.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia*, *9*(1), 97–113.

Schyns, P. G., Petro, L. S., & Smith, M. L. (2009). Transmission of facial expressions of emotion co-evolved with their efficient decoding in the brain: behavioral and brain evidence. PLoS ONE, *4*(5), e5625.

Smith, M. L., Cottrell, G. W., Gosselin, F., & Schyns, P. G. (2005). Transmitting and decoding facial expressions. Psychological Science, 16(3), pp. 184-189.

Tomasi, D., Wang, R. L., Telang, F., Boronikolas, V., Jayne, M. C., Wang, G. J., Fowler, J.S., & Volkow, N. D. (2009). Impairment of attentional networks after 1 night of sleep deprivation. *Cerebral cortex*, 19(1), 233-240.

Wong, M. L., Lau, K. N. T., Espie, C. A., Luik, A. I., Kyle, S. D., & Lau, E. Y. Y. (2017). Psychometric properties of the Sleep Condition Indicator and Insomnia Severity Index in the evaluation of insomnia disorder. *Sleep Medicine*, *33*, 76-81.

Yoo, S. S., Gujar, N., Hu, P., Jolesz, F. A., & Walker, M. P. (2007). The human emotional brain without sleep—a prefrontal amygdala disconnect. *Current Biology*, *17*(20), 877-878.