Work 34 (2009) 359–364
DOI 10.3233/WOR-2009-0934
IOS Press

Description and clinical studies of a device for the instantaneous detection of office-place stress

James A. Levine[a,*], Ioannis T. Pavlidis[b], Leslie MacBride[a], Zhen Zhu[b] and Panagiotis Tsiamyrtzis[c]
[a]*Experimental Office Facility, Centre on NEAT, Mayo Clinic, Rochester, MN, USA*
[b]*Computational Physiology Lab, University of Houston, Houston, TX, USA*
[c]*Department of Statistics, Athens University of Economics and Business, Athens, Greece*

Received 25 December 2007
Accepted 27 July 2008

Abstract. Occupational stress is universally experienced and is emerging as a major risk factor for physical and mental illness and a key factor in poor work performance and low job satisfaction. However, the technology does not currently exist to unobtrusively measure occupational stress in real-time. Here, we describe the design and clinical validation of an automated high-definition thermal imaging system that can be used to quantify human stress, remotely and instantaneously. Healthy human subjects underwent a computer-based version of the Stroop-color conflict test, which is a validated stress provocation test, in an experimental office facility. In separate experiments, the same subjects completed a mental arithmetic challenge. The thermal signal associated with stress provocation is near-instantaneous corrugator warming. The stress response was detected in all subjects for all stress-events compared to the respective baselines. Furthermore, there was remarkable inter-individual preservation of the corrugator signal with stress ($R^2 = 0.96$, $P < 0.001$). High-definition thermal imaging can be used for real-time detection of stress provocation. This technology may prove to be of help in ameliorating office-place stress.

1. Introduction

Occupational stress is the harmful physical and emotional response that occurs when there is a poor match between job demands and the capabilities, resources, or needs of the worker [21]. Occupational stress is universally experienced and is emerging as a major risk factor for physical and mental illness [1,18] and a key factor in poor work performance and low job satisfaction [17]. However, the technology does not currently exist to unobtrusively measure occupational stress in real-time. Here, we identify that automated high-definition thermal imaging of the face can be used to quantify human stress, remotely and instantaneously.

*Address for correspondence: James Levine, M.D., Ph.D., Endocrine Research Unit, Mayo Clinic, Rochester, MN, 55905, USA. Tel.: +1 507 284 2191; Fax: +1 507 255 4828; E-mail: levine.james@mayo.edu.

Other technologies have been used to measure human stress such as brain imaging through functional MRI [23] and vital sign monitoring through probe sensing [22]. Although, these technologies are useful, they have some problems. Stress studies through functional MRI are restrictive by nature and do not allow monitoring in the work place. Stress studies through probe-based monitoring of vital signs are relatively obtrusive and may be affected by irrelevant patho-physiology (e.g., arrhythmias).

Measuring stress through thermal imaging of the face could be viewed as complimentary technology that addresses some inherent problems other methods have. First, it is totally unobtrusive and allows natural observation in the work place. Second, it measures local (not vital) physiological signs on the face, one of the most heavily innervated areas of the human body. Therefore, these signs are not only sympathetically relevant, but also least affected by patho-physiology. Third, the specific facial sign presented in this paper (i.e., supraorbital) is tightly related to mental stress. Thus, it is more specific to the type of stress that usually develops in an office working environment. The association of supraorbital physiology with mental effort is further supported from evidence in other investigations. In particular, Larson et al. in [7] measured increased activation of the corrugator muscle (using EMG sensing) when typographic quality deteriorated, rendering creative reading harder. Topolinski et al. [20] measured increased activation of the corrugator muscle in semantically incoherent word triads. By contrast, in semantically coherent word triads the corrugator muscle relaxed and the (smiling) zygomaticus major muscle was engaged, indicating positive affect and decreased mental effort.

More than half the work force in the developed world uses computers as a major part of daily office work [12]. In this effort we studied stress that develops as part of computing work using a thermal imaging system ('Stress-Cam'). We simulated office stress conditions through mental and divided attention stimuli. Arithmetic is a mental test that is frequently used in stress experiments [9]. It emulates effectively tasks that naturally arise in certain office environments (e.g., stock trading). The Stroop color-word task is a standard test that is used to gauge resistance to distraction, a quality exemplified in difficult multi-tasking occupations (e.g., air-traffic controllers) or challenging work conditions (e.g., high noise levels) [16].

The human face is quintessential to sensing and communication needs. Accommodation of these needs is manifested through peripheral cues that are driven by central loci of the brain [4]. Regarding the sensing aspect, heightened vision needs during moments of perceived danger are facilitated through sympathetic activation of the ocular muscles. For example, with fear caused by startle, the amygdala precipitates an outflow of central signals via the sympathetic nervous system. We previously demonstrated using high-definition – thermal imaging that both the acute effect of a startle and lying are accompanied by predictable, instantaneous changes in facial blood flow and periorbital warming [8,13]. Such acute stress phenomena may naturally arise in the context of job or evaluation interviews.

Regarding the communication aspect, autonomic activation of facial muscles acts as a conveyor of nonverbal emotional cues through facial expressions and micro-movements [10]. For example, activation of the corrugator muscle in the supraorbital area, results in frowning, which heralds an ongoing thought process [7, 20]. Thinking is a ubiquitous office place activity and henceforth, activation of the corrugator muscle may serve as an indicator of mental stress at work. An indirect quantification of corrugator activation can be provided though the thermal effect of increased muscular metabolism – a measurement that can be performed via thermal imaging.

This paper focuses on the study and unobtrusive measurement of sustained mental stress, as it is manifested in the corrugator area. This is in contrast to the previous work, which focused on the fleeting 'fight or flight' stress manifested in the periorbital area [8].

2. Subjects and methods

2.1. Stress Cam for detecting office stress

To examine whether high definition thermal imaging, focused on the corrugator muscle, could detect office stress in real-time we devised a thermal imaging system that was mounted over a computer screen that we call Stress-Cam. The centerpiece of the system is a FLIR Mid-Wave Infra-Red camera with an Indium Antimonite detector operating between 3–5 μm (Model SC6000). The camera has a maximum focal plane array resolution of 640 $\times$ 512 pixels and a maximum capture rate of 120 frames per second (fps); however, all of the thermal clips were taken at a resolution of 320 $\times$ 256 pixels and processed in a Dell Precision 650 with a Xeon CPU (2.66 GHz). This resolution was chosen to keep the frame capture rate at 31 fps as well as to keep the storage size at a minimum. The system employs facial tracking algorithms [3] that enabled the corrugator region to be automatically identified and then the thermal signal derived despite the presence of head motion.

We asked $n = 11$ subjects (4 males and 7 females) to undergo a computer-based version of the Stroop-color conflict test, which is a validated stress provocation test that targets multitask-conflict as the means of stress induction [5,19]. The Stroop-color conflict test uses the words, 'green', 'red', 'yellow' or, 'blue' that are displayed in a contrasting color (e.g., the word 'red' is displayed in blue font). Subjects are asked to name the color of the font and not to read the word. By asking subjects to resolve the read-display conflict progressively faster, whilst not allowing errors, stress is heightened [14]. Figure 1(a) depicts a relevant snapshot.

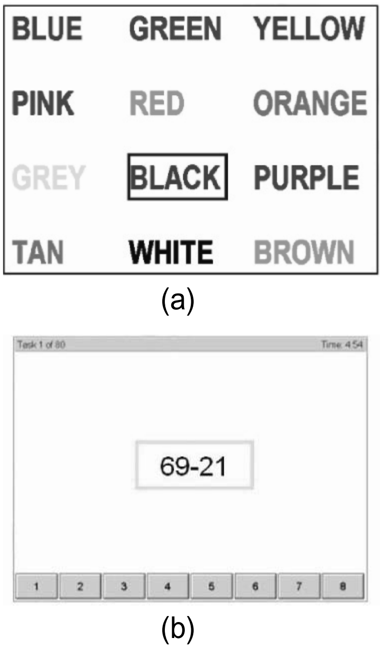

Fig. 1. (a) Snapshot screen from the Stroop-color conflict test. (b) Snapshot screen from the mental arithmetic test.

The Stroop test is a convenient standardized instrument that simulates divided attention situations, which often arise in a modern computing environment. For example, while the office worker is concentrated on reading a document, noise from neighboring booths or intervening computer applications (e.g., the arrival of new email) frequently distract his/her attention.

We wanted to verify whether stress-provoked corrugator muscle warming could be independently verified with another stress-evoking maneuver. Hence, in a separate experiment, our volunteers underwent stress provocation using a mental arithmetic challenge [2]. Figure 1(b) depicts a screenshot of an arithmetic prompt, one of many the subject had to go through the 5 min testing period. Arithmetic testing is widely used as a mental stress inducer and simulates high concentration situations that are typical in an office computing environment. A case in point is when the office worker studies or composes financial data and analysis in a spreadsheet.

Both the Stroop and mental arithmetic tests lasted 5 min. Both were preceded by a 2 min baseline period, where the user was relaxing by looking at a pleasant desktop screen. Also, both tests were followed by a 5 min recovery period. Thermal recording and measurements were performed during the baseline, test (Stroop or arithmetic), and recovery periods. Both tests were also supervised to ensure that subjects were engaged and performed reasonably well.

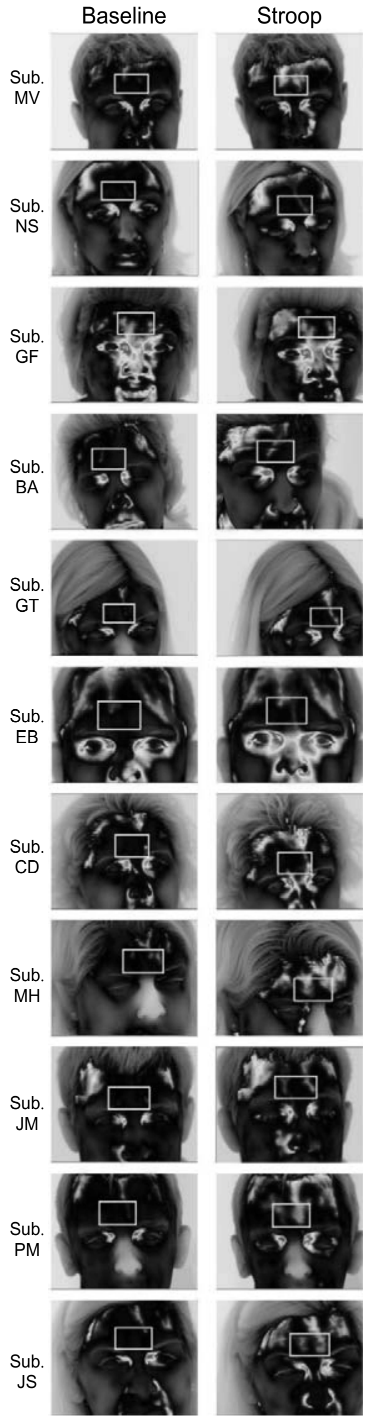

Fig. 2. Thermal snapshots of subjects before and during the Stroop test. Supraorbital warming (in white), indicating muscle activation, is evident in all subjects, but at various degrees.

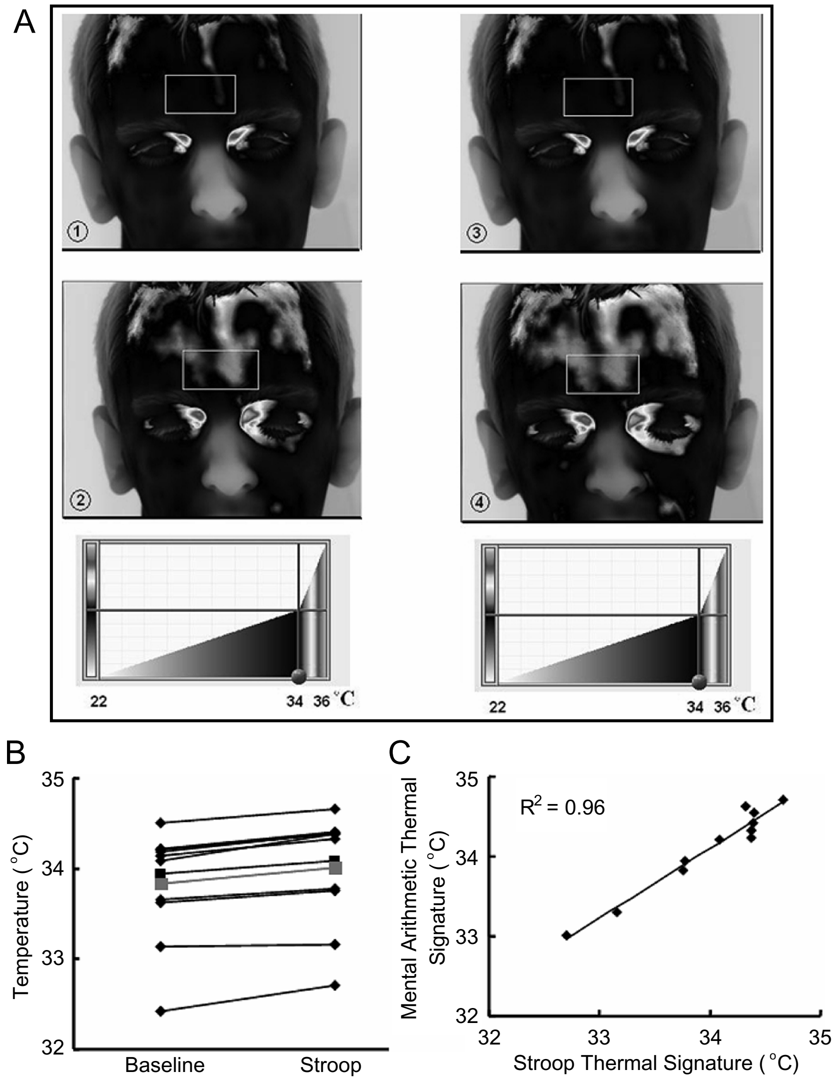

Fig. 3. A. Facial thermal images from a male subject before (1) and during (2) the Stroop stress provocation test and before (3) and after (4) the mental arithmetic stress provocation. The white-lined box is the 'rea of interest' for the corrugator region. B. Raw thermal data for the corrugator area of interest before and after the Stroop provocation in 11 healthy subjects not on medications. The gray line represents the mean; a 2-tailed paired t-test was statistically significant ($P < 0.000001$). C. The stress provocation response temperatures for the corrugator muscle region for the Stroop versus the Mental Arithmetic tests.

3. Results

3.1. *Stress Cam for detecting office stress*

Using high definition thermal imaging, we found that with stress-provocation, there was progressive and sustained corrugator muscle warming in all the subjects (Fig. 2). Control areas of the face distant from the corrugator muscle (e.g., zygomatic), did not show warming; suggesting that the effect was specific for this muscle group.

When our volunteers underwent stress provocation using a mental arithmetic challenge, corrugator muscle warming again occurred in all 11 subjects we studied. The thermal response showed remarkable inter-individual consistency ($R^2 = 0.96$) between the two mental tests (Fig. 3).

4. Discussion

Office-place stress is ubiquitous. Since computers are used by more than half of the workers in the developed world, we have devised technology that shows promise in detecting workplace stress remotely and instantly using high definition thermal imaging.

High definition thermal imaging of the face has the potential to unobtrusively detect computer associated stress at work. Prior data [7] and our proof-of-concept experiment suggest that the stress-provoked supraorbital warming is likely to be a consequence of corrugator muscle activity that in turn reflects increased regional blood flow. The reason that high definition thermal imaging is effective for detecting corrugator muscle activity is that the skull lies close-behind the corrugator muscle and is an excellent thermally-stable background. Also, there is no adipose tissue pad above the corrugator muscle and so there is minimal thermal inertia that is needed to initiate changes in surface thermal emission. It is therefore tenable that high definition thermal imaging can detect subtle and rapid changes in corrugator heat loss.

In the pilot experiment, after the stress-provocation was complete, subjects returned to baseline values. It was interesting, however, that there was marked inter-individual variability in the latency of the return to baseline suggesting that some people 'calm-down' more rapidly after stressful stimuli than others.

Stress, either mental or 'fight or flight,' is effected through blood flow redistribution and loads the cardiovascular system. In the former case blood is redistributed towards the head, while in the latter towards sensory organs and muscle-skeletal tissue. Frequent bouts of intense stress can exacerbate cardiovascular problems [15]. Stress may also lead to negative behavioral changes [6]. Having an unobtrusive way to quantify stress in natural conditions may enable longitudinal studies to better understand the problem and develop precise preventive guidelines.

Even in the absence of pathological implications, work overload (like the one emulated by the Stroop test) may lead to errors [11]. Depending on the office worker's occupation, this may have from mild to disastrous effects. A case in point for the latter is air-traffic controller. The relation of stress to work performance has been inadequately studied and this methodology may offer a valuable tool in future research efforts.

Were it possible to broadly apply this approach using a computer-mounted Stress-Cam, we envisage a host of applications in the workplace and at home to detect stress automatically, passively and remotely. High-definition thermal imaging of the face may allow occupational stress to be more clearly defined and its effects ameliorated.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant # ISS-0414754, entitled "Interacting with Human Physiology." Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References

[1] C.L. Cooper and J. Crump, Prevention and coping with occupational stess, *Journal of Occupational Medicine* **20** (1978), 420–426.

[2] K. Dedovic et al., The Montreal Imaging Stress Task: Using functional imaging to investigate the effects of perceiving and processing psychological stress in the human brain, *Journal of Psychiatry and Neuroscience* **30** (2005), 319–325.

[3] J. Dowdall, I.T. Pavlidis and P. Tsiamyrtzis, Coalitional Tracking, *Computer Vision and Image Understanding* **106** (2–3 May–June 2007), 205–219.

[4] D.A. Fitzerald et al., Beyond threat: Amygdala reactivity across multiple expressions of facial affect, *Neuroimage*, 2005.

[5] B.J. Harrison, M. Shaw and M. Yucel, Functional connectivity during Sroop task performance, *Neuroimage* **24**, 181–191.

[6] N. Kawakami et al., Relations of work stress to alcohol use and drinking problems in male and female employees of a computer factory in Japan, 314, New York: Academic Press, *Japanese Environmental Research* **62**, 1993.

[7] K. Larson et al., Measuring the aesthetics of reading, *People and Computers XX – Engage*. s.l.: Springer, 2007, pp. 41–56.

[8] J.A. Levine, I. Pavlidis and M. Cooper, The face of fear, *Lancet* **357** (2001), 1757.

[9] U. Lundberg et al., Psychophysiological Stress and EMG Activity on the Trapezius Muscle, 4, *International Journal of Behavioral Medicine* **1** (1994), 354–370.

[10] H.K. Meeren, C.C. van Heijnsbergen and B. de Gelber, Rapid perceptual integration of facial expression and emotional body language, *Proceedings of the National Academy of Sciences* **102** (2005), 16518–16523.

[11] J.C. Neuman and J.R. Hubbard, Stress in the workplace: An overview. [book auth.] in: *Stress Medicine: An Organ System Approach*, J.R. Hubbard and E.A. Workman, eds, Boca Raton: CRC Press, 1997, pp. 323–335.

[12] Office of Technology Assessment, Congress of the United States, *Automation of America's Offices*, 1985. OTA 1985.

[13] I. Pavlidis, N.L. Eberhardt and J.A. Levine, Seeing through the face of deception, *Nature* **415** (2002), 35.

[14] P. Renaud and J.P. Blondin, The stress of Stroop performance: Physiological and emotional responses to color-word interference, task pacing, and pacing speed, *International Journal of Psychophysiology* **27** (1997), 87–97.

[15] H. Ruddel et al., Hemodynamic response patterns to mental stress: Diagnostic and therapeutic implications, *American Heart Journal* **116** (1988), 617–627.

[16] A, Smith et al., Combined effects of occupational factors on objective measures of performance and health. [book auth.] in: *Contemporary Ergonomics*, M. Hanson, ed., s.l.: CRC Press, 2001.

[17] M.J. Smith et al., Employee stress and health complaints in jobs with and without electronic performance monitoring, *Applied Ergonomics* **23** (1992), 17–27.
[18] M.J. Smith, F.T. Conway and B.T. Karsh, Occupational stress in human computer interaction, *Industrial Health* **37** (1999), 157–173.
[19] J.R. Stroop, Studies on interferences in serial verbal reactions,*Journal of Experiemntal Psychology* **18** (1935), 643–662.
[20] S. Topolinski et al., The face of fluency: Semantic coherence automatically elicits a specific pattern of facial muscle reactions, *Cognition and Emotion*, 2008.
[21] United States National Institute for Ocuupational Safety and Health, *Stress at Work* (1999), 99–101.
[22] T.G.M. Vrijkotte, L.J.P. van Doornen and E.C.J. de Geus, Effects of Work Stress on Ambulatory Blood Pressure, Heart Rate, and Heart Rate Variability, *Hypertension* **35** (2000), 880–886.
[23] J. Wang, H. Rao and G.S. Wetmore, Perfusion functional MRI reveals cerebral blood flow pattern under psychological stress, *Proceedings of the National Academy of Sciences* **102** (2005), 17804–17809.