EFFECT OF WEARING AN N95 FILTERING FACEPIECE RESPIRATOR ON SUPEROMEDIAL ORBITAL INFRARED INDIRECT BRAIN TEMPERATURE MEASUREMENTS

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Abstract

Purpose—To determine any effect of wearing a filtering facepiece respirator on brain temperature.

Methods—Subjects (n=18) wore a filtering facepiece respirator (FFR) for 1h at rest while undergoing infrared thermography measurements of the superomedial periobital region of the eye, a non-invasive indirect method of brain temperature measurements we termed the superomedial orbital infrared indirect brain temperature (SOIIBT) measurement. Temperature of the facial skin covered by the FFR, infrared temperature measurements of the tympanic membrane and superficial temporal artery region were concurrently measured, and subjective impressions of thermal comfort obtained simultaneously.

Results—The temperature of the skin under the FFR and subjective impressions of thermal discomfort both increased significantly. The mean tympanic membrane temperature did not increase, and the superficial temporal artery region temperature decreased significantly. The SOIIBT values did not change significantly, but subjects who switched from nasal to oronasal breathing during the study (n=5) experienced a slight increase in the SOIIBT measurements.

Conclusions—Wearing a FFR for 1h at rest does not have a significant effect on brain temperatures, as evaluated by the SOIIBT measurements, but a change in the route of breathing may impact these measurements. These findings suggest that subjective impressions of thermal discomfort from wearing a FFR under the study conditions are more likely the result of local dermal sensations rather than brain warming.

Keywords

filtering facepiece respirators; thermal discomfort; orbital infrared indirect brain temperature measurements

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INTRODUCTION

A frequent complaint voiced by a substantial number of users of protective facemasks (e.g., filtering facepiece respirators [FFR], medical/surgical masks, etc.) regards thermal discomfort that is manifested as subjective impressions of increases in facial warmth or total body heat [1–3]. This is an important issue given that thermal intolerance to protective facemasks impacts compliance and, by extension, protection [3]. Prior investigations have demonstrated that increases in core body temperature (T_{core}) associated with wearing these devices are minimal (<0.13°C) over 1-2h at low-moderate work rates, and thus unlikely to be a major stimulus for thermal intolerance [4, 5]. Potential pathways for perceptions of increased heat include warming of the facial skin that is covered by the protective facemask or brain warming [3]. Facial skin is very thermosensitive and a portion of the face covered by protective facemasks (i.e., the lips, vermillion cutaneous border) is especially dense in sensory receptors [6], so that increases in the temperature of protective facemask-covered facial skin may result in increased trigeminal nerve afferent sensory impulses conducted to the brain [7]. Alternatively, research by Cabanac *et al* 8] has suggested that brain temperature (as indicated by tympanic membrane temperature), rather than other deep body T_{core}, is the major determinant of thermal comfort in humans. It has been postulated that some protective facemask-associated thermal discomfort sensations could be related to warming of the anterior portion of the brain by rebreathing of warmed, humidified exhaled air retained within the deadspace of the protective facemask [4]. Studies of post-operative neurosurgical patients with thermal sensors implanted in brain tissue have documented the effect of nasal airflow on temperatures of the brain's frontal lobes and hypothalamic region [9, 10]. Therefore, it seems possible that nasal inhalation of rebreathed warmed, humidified air from a protective facemask might have a warming effect on brain structures and resulting thermal discomfort. However, the invasive nature of implanted temperature sensors in the brain relegates their use to neurosurgical interventions or animal studies. Brain tissue is in thermal equilibrium with its surrounding venous blood [11], and a portion of the brain's venous drainage (superficial middle cerebral vein and inferior cerebral veins [12]) empties into the cavernous sinus that also receives flow from the superior ophthalmic vein (SOV). The lack of valves in the dural sinuses, cerebral veins and SOV (in a majority of instances) allows blood to flow in either direction according to pressure gradients in the vascular system [13, 14]. The SOV thus serves as a thermal conduit for the temperature of the cavernous sinus blood that is in equilibrium with brain tissue [14]. Noninvasive dermal temperature sensors, placed over the passage (termed the brain temperature tunnel [BTT]) encompassing the SOV in the superomedial orbit region of the eye and coursing between the orbit and the cavernous sinus, offer a site for core temperature measurement [15]. Infrared thermography (IRT) studies have demonstrated that the site of origin of the SOV, the thin, fat-free skin of the superomedial orbit area of the face, emits more infrared energy than any other facial area [16, 17] and could thus serve as an indirect, non-invasive measure of brain temperature. The current study was undertaken by the National Personal Protective Technology Laboratory of the National Institute for Occupational Safety and Health (NIOSH) to evaluate the use of superomedial orbital infrared indirect brain temperature (SOIIBT) measurements as an alternative to invasive brain temperature monitoring. The

object of the study was to determine if brain warming occurs with wearing FFR, the most commonly used respirators in U.S. industry and healthcare.

MATERIALS AND METHODS

Eighteen healthy subjects (9 men, 9 women) were enrolled in the study. Subject demographic mean values for men were age 23 ± 1.6 yrs, height 182 ± 7.7 cm, weight 78.3 ± 9.4 kg, and Body Mass Index (BMI) 23.6 kg/m^2; for women, these values were age 21.5 ± 1.5 yrs, height 164.1 ± 5.3 cm, weight 61.9 ± 5.2 kg, and BMI 22.8 ± 2.5 kg/m^2. Subjects were examined by a licensed physician immediately prior to engaging in the study. During trials (carried out during the winter months in the northern hemisphere), subjects wore standard clothing and were seated upright in a physiology laboratory and with mean ambient temperature $24.2\pm2.6°C$ and mean relative humidity (RH) $20.5\pm5.5\%$. Natural and artificial light were minimized to reduce any reflected or direct light impact on IRT measurements [18]. A FLIR Model SC 5600-M High Resolution cooled, infrared camera (FLIR Systems, Inc., North Billerica, MA) was utilized for the study and positioned 1½ meters from the subject's face [19]. The camera focused on the region of interest ipsilateral to the dominant brain hemisphere side that was determined by the subjects' right or left handedness (17 subjects were right-handed) [20]. Camera emissivity was set at 0.98 and, based upon differences in the sizes of the regions of interest, a ~1:5 ratio of minimum pixels was utilized for recordings of the dominant superomedial canthus area (208 pixels) (Figure 1a) and the dominant superficial temporal artery region (1020 pixels) [21] (Figure 1b). Maximum SOIIBT measurements and superficial temporal artery area dermal temperatures were identified in real time (2sec recordings at a recording frame rate of 60 Hz) using a fluctuating histogram plot on FLIR-specific software (Research IR™). A flat-fold surgical N95 FFR (SN95 FFR), model 3M 1870 (3M Company, St Paul, MN), was outfitted with a small wireless sensor (iButton, Dallas, TX) attached with adhesive to its inner surface for measurement of respirator deadspace temperature and RH. The iButton sensors are calibrated against a National Institute of Standards and Technology (NIST) traceable source. An identical sensor was attached to the subject's perioral skin area of the dominant brain side to capture temperatures of the skin covered by the SN95 FFR. Respiratory rate (RR) was measured with the BioHarness 3™ (Zephyr Technology Corporation, Annapolis, MD), a physiological monitoring chest strap [22]. Baseline IRT measurements of the dominant side superomedial orbit area and the superficial temporal artery region (Figure 1), as well as tympanic membrane temperatures, were obtained after the subjects were seated for 10min in the physiology laboratory to allow for adaptation to room temperature [23]. The SN95 FFR was then donned, as per the manufacturer's recommendation, and the same measurements were repeated at 30min and 60min of SN95 FFR wear. Anatomic areas of subjective impressions of facial warmth were documented with the use of a facial mannequin placard with numbered anatomic landmarks (Figure 2). Subjective scoring of thermal comfort of facial skin areas was obtained using the International Standards Organization (ISO) Thermal Scale ($+3$ = hot; $+2$ = warm; $+1$ = slightly warm; 0 = neutral; -1 = slightly cool; -2 = cool; -3 = cold) [24]. Subjects were queried as to their route of breathing (i.e., nasal, oro-nasal or oral) at baseline and during temperature measurements.

Statistical analysis

One way repeated measures ANOVA was carried out at three time points (0 [baseline], 30min, and 60min) on all dependent variables with Greenhouse-Geisser correction for a designation of statistical significance. For a variable with a significant F-ratio, post-hoc pairwise comparison with Bonferroni adjustment was carried out to determine a difference between the time points. Independent samples t-test was carried out to analyze the impact of the route of breathing (nasal vs oronasal) on SOIIBT. Statistical significance was accepted at $p < 0.05$.

RESULTS

The RR did not change significantly over 1h (F=0.89, p=0.41). The SN95 FFR deadspace temperature was significantly higher over 1h than baseline (F=94.37, p<0.001), but there was no significant difference between the 30min and 60min values. The SN95 FFR deadspace RH was significantly greater than baseline over 1hr (F=157.70, p<0.001), and was significantly greater (p<0.001) at 60min than 30min. The temperature of the facial skin covered by the SN95 FFR increased significantly over 1h (F=41.83, p<0.001), but no significant difference was noted between the 30min and 60min measurements. There was no significant difference either in SOIIBT measurements (F=0.69, p=0.46) or tympanic temperature (F=0.21, p=0.74) over 1h. Switching from nasal to oronasal breathing (n=5) resulted in a non-significant increase in their SOIIBT (p=0.09) (Figure 3). The superficial temporal artery area temperature decreased significantly over 1h (F=6.18, p=0.008), but there was no significant difference between the 30min and 60min values. Thermal comfort scores rose significantly over 1h (F=-26.08, p<0.001), but no significant difference was noted between 30min and 60min scores (Table 1). Facial areas 3, 4, and 5 (Figure 2) were most frequently reported as becoming increasingly warm while wearing the SN95 FFR (Figure 4).

DISCUSSION

The resting status of the current study's subjects, coupled with a relatively thermo-neutral environment, allowed us to isolate primarily the effect of wearing a SN95 FFR upon various indicators of body temperature. The lack of significant effect (p=0.41) on the RR (Table 1) attests to the previously-demonstrated minimal impact of FFR on breathing parameters, even at low-moderate work rates [25]. The stability of the tympanic temperature measurements, throughout the study (Table 1), is evidence of the subjects' resting state and supports the recently-reported lack of clinically-significant effect of wearing an FFR upon IR tympanic membrane temperature measurements [26]. At baseline, nasal breathing was reported by 15/18 subjects and oro-nasal breathing by 3/18 subjects. At the end of 1h of SN95 FFR use, 5/15 initial nasal breathers switched to oro-nasal breathing, and this change was associated with an increase in the SOIIBT that may have been due to loss of the recognized conditioning effect on the temperature of air passing through the nasal passages (Figure 3) [27]. Wearing respiratory protective equipment can result in breathing pattern changes due to such factors as pressure on the nasal alae from moldable nasal bars, work rate or psychogenic issues [28]. Suggestions have been put forth that worker education in the use of

such equipment should emphasize nasal breathing as the preferential route of respiration, if tolerable [28]. The mean temperatures of the facial skin covered by the SN95 FFR increased significantly (p<0.001) at 30min and 60min, and are in the temperature range at which dermal warmth receptors are activated [29]. It has previously been reported that respirator acceptability by the wearer decreases as upper lip temperature exceeds 34.5°C [30]. The increase in the facial skin temperature in the current study coincided with increasing subjective impressions of facial warmth (p<0.001) that continued to increase over 1h of SN95 FFR use (Table 1). The facial areas most commonly affected by increased warmth were those that were most centrally located (regions 3, 4, 5) (Figures 2, 4). There was no significant mean difference in SOIIBT from baseline values over 1h of SN95 FFR wear (Table 1).

The superficial temporal artery region has been touted as a reliable site for temperature determination because its perfusion is thought to be relatively constant and it is the only arterial supply of the head and face that is (generally) devoid of arterio-venous anastomoses [31]. It is thus considered by some researchers to be an accurate indicator of T_{core} [32], though this is debated by others [33]. Under temperate ambient conditions, skin temperatures will always be lower than T_{core} due to radiant heat loss through the skin and many IRT temperature studies (temporal, forehead, BTT) do not report actual skin temperatures but, rather, algorithm-derived temperature measurements that correct for ambient conditions to provide estimates of brain temperatures or other T_{core} [[33, 34]. The unadjusted superficial temporal artery area mean IRT temperatures declined significantly (p=0.008) with the use of the SN95 FFR, and this effect stabilized at 30min (Table 1). This is somewhat intriguing given that the SOIIBT and tympanic temperatures remained relatively stable without significant changes noted over baseline (Table 1). However, it is recognized that superficial temporal artery region temperatures are subject to various modifying inputs (blood flow, ambient environmental conditions, sweating, etc.) [33]. It is also possible that the straps of the SN95 FFR, which traverse the superficial temporal artery region, may have compressed the vessel somewhat and altered its flow and perfusion characteristics. In a study utilizing the highest value of frontal area IRT temperatures of 99 clinic patients who had a mean tympanic temperature (36.6°C) similar to that of the current study, wearing a surgical mask was associated with a 0.5°C decrease in IRT [35]. The baseline superficial temporal artery region temperatures in the current study mirror closely the findings from a prior IRT study of 1,517 subjects [36].

The superior ophthalmic vein (SOV), the largest orbital vein and principal route of orbital venous drainage, is formed by the union of the supraorbital and angular veins at ~6 mm posterior to the superior sulcus of the eyelid [37]. The SOV flows from the superior medial orbit region through the superior orbital fissure to empty into the cavernous sinus [38]. The length of the SOV is variable (due to the variability in the depth of the human orbit), but recent cadaveric research has shown an average length of 49.2±16.2 mm (range 33.9 – 65.7 mm) [14]. The SOV is insulated somewhat from heat loss along its course because it is layered between the superior rectus muscle and a fascial hammock-like sling formed by connective tissue septa of the medial, superior and lateral rectus muscles' suspensory systems [39]. The SOV is thus thought to serve as a thermal conduit for the temperature of the cavernous sinus blood that is in equilibrium with brain tissue [15] in accordance with

Fournier's Law of Heat Conduction (i.e., heat flows from regions of higher temperature to lower temperature along the temperature gradient).

Under normal conditions, average brain temperature is ~0.3°C higher than other T_{core} sites [40], due to the relatively high metabolic rate of the central nervous system, and reflects a balance between heat production from cerebral metabolism and heat removal primarily by cerebral blood flow [41]. This high convectivity of heat between brain tissues and capillaries allows removal of the 0.16°C/min heat generated by the brain [11]. Arterial blood supplied to the brain and body is cooled primarily by the venous blood from the skin [10] with a minor component of cooling (0.1°C) via heat exchange from the lungs [41, 42] that is dependent on the level of ventilation. The brain as a whole does not exhibit one global temperature because the regulation of brain temperature depends primarily on the temperature of the incoming cerebral arterial blood flow [40]. Thus, brain areas with high blood flow (i.e., cortex) have lower temperatures than areas with lower blood flow (i.e., white matter) [43]. In general, the center of the brain is from 0.5 – 1.0°C warmer than the epidural space [44]. Data on cavernous sinus temperatures are sparse, but experiments with horses at rest (ambient conditions 19°C, 25%RH) have indicated a 0.9°C lower temperature in the cavernous sinus compared with the cerebrum [45]. The SOV likely is more reflective of brain superficial cortical temperature rather than deeper brain structures inasmuch as the inferior and superficial medial cerebral veins that flow into the cavernous sinus drain the superficial areas of the brain [12].

The inner canthus of the superomedial periorbital region of the eye is consistently the warmest area on the head [34] due to its vascularity (fed by the ophthalmic artery, a branch of the internal carotid artery), thinness of the overlying skin (enhanced radiant heat loss) and concavity (inhibits cooling effects of ambient airflow on the skin) [46]. The SOIIBT in the current study mirrors previously-reported data for similar sedentary states without respirator use [36, 47, 48], thereby further suggesting that the SN95 FFR had no impact on the SOIIBT. It is also interesting to note that the 0.3°C higher temperature of the brain temperature surrogate (i.e., SOIIBT) compared with the unadjusted T_{core} surrogate (i.e., superficial temporal artery area temperature) in the current study is the same as the reported usual difference between average brain temperature and other T_{core} in invasive studies [40]. The present study findings indicate that wearing a SN95 FFR at rest for 1h did not result in an increase in brain temperature, as indicated by the SOIIBT. This suggests that complaints of respirator-associated thermal discomfort are more likely related to thermal sensations of the facial skin covered by the protective facemask. Increases in the temperature of the skin covered by a protective facemask activate facial skin warmth receptors (consisting of free nerve endings of unmyelinated C-fibers). These receptors then direct afferent nerve impulses to the central nervous system via sensory fibers of the three divisions of the trigeminal nerve to its spinal nucleus and then to the post central gyrus of the parietal lobe cortex of the brain [49]. The SOIIBT noted in the current study is not the actual brain temperature (due to dampening effects on the SOV of the facial skin circulation), but may indicate a normal superficial cortical brain temperature in young, healthy adults in a resting state. However, this supposition will require significantly greater numbers of subjects to fully verify. Prior IRT investigation has reported that a superomedial canthus temperature of 36.3°C is the

optimal temperature to maximize sensitivity (85.4%) and specificity (95%) for fever screening [50].

Limitations of the current study include the relatively small number of subjects tested (n=18). Our findings should not be extrapolated to children, inasmuch as an IRT study of 173 afebrile children (ages 1 – 17 yrs) determined an unadjusted mean orbital region temperature of 36.61°C (calculated from a rectangular area encompassing both eyes) [51]. The most accurate non-invasive assessment of brain temperature is by measurement of the latency of auditory-evoked brain potentials (as these are impacted by brainstem temperature); a prior investigation has noted no impact of breathing warm air on brain temperature [52]. We only tested one model of FFR (3M 1870 flat-fold model) and cannot comment on other models that might have larger respirator deadspaces, or on other classes of negative pressure respirators (e.g., elastomeric air-purifying respirators). Higher ambient temperatures and high workloads resulting in increased ventilation of warmer air could theoretically result in brain warming, but this remains speculative and requires further investigation.

CONCLUSIONS

The use of a SN95 FFR at rest over 1h did not result in brain warming, as indicated by the SOIIBT. However, the increase in SOIIBT noted in the minority of subjects who switched from nasal to oro-nasal breathing over 1h suggests that the route of breathing may impact SOIIBT measurements. Reported increases in warmth sensations with wearing FFR are likely due to the barrier effects of the device upon heat release mechanisms of facial skin (convection, radiation, evaporation) that result in increased dermal afferent sensory signals to the brain via branches of the trigeminal nerve. Efforts at relieving the perceptions of increased thermal discomfort with protective facemasks should look into measures that result in cooling of the covered facial skin utilizing technologies such as mini-fans, improved exhalation valves, phase change materials, etc. [3]. Further research into SOIIBT is also warranted to develop guidelines determining febrile states and optimizing its use in such areas as medicine, sports and exercise regimens.

Acknowledgments

REFERENCES

1. Radonovich L, Cheng J, Shenal BV, Hodgson M, Bender BS. Respirator tolerance in health care workers. J Am Med Assoc. 2009; 30:36–38.

2. Baig AS, Knapp C, Eagan AE, et al. Health care workers' views about respirator use and features that should be included in the next generation of respirators. Am J Infect Control. 2010; 38:18–25. [PubMed: 20036443]

3. Roberge RJ, Kim J-H, Coca A. Protective facemask impact on human thermoregulation: an overview. Ann Occup Hyg. 2012; 56:102–112. [PubMed: 21917820]

4. Roberge RJ, Benson SM, Kim J-H. Thermal burden of N95 filtering facepiece respirators. Ann Occup Hyg. 2012; 56:808–814. [PubMed: 22294505]

5. Roberge RJ, Kim J-H, Benson SM. Absence of consequential changes in physiological, thermal and subjective responses from wearing a surgical mask. Resp Physiol Neurobiol. 2012; 181:29–35.

6. Prasad, S., Galetta, S. The trigeminal nerve. In: Goetz, C., editor. Textbook of Clinical Neurology. 3rd. Philadelphia: Elsevier; 2007. p. 166

7. Nielsen R, Gwosdow AR, Berglund LG, et al. The effect of temperature and humidity levels in a protective mask on user acceptability during exercise. An Ind Hyg Assoc J. 1987; 48:639–645.

8. Cabanac M, Caputa M. Natural selective cooling of the human brain: evidence of its occurrence and magnitude. J Physiol. 1979; 286:255–264. [PubMed: 439025]

9. Mariak Z, White MD, Lewko J, et al. Direct cooling of the human brain by heat loss from the upper respiratory tract. J Appl Physiol. 1999; 87:1609–1613. [PubMed: 10562598]

10. Harris BA, Andrews PJD, Murray GD. Enhanced upper respiratory tract airflow and head fanning reduce brain temperature in brain-injured, mechanically ventilated patients: a randomized, crossover, factorial trial. Neurosci Neuroanaest. 2007; 98:93–99.

11. Yablonskiy DA, Ackerman JJ, Raichle ME. Coupling between changes in human brain temperature and oxidative metabolism during prolonged visual stimulation. Proc Nat Acad Sci USA. 2000; 97:7603–7608. [PubMed: 10861022]

12. Kulkarni, NV. Clinical Anatomy for Students: Problem Solving Approach. New Delhi: Jaypee Brothers Medical Publishers Ltd; 2006. p. 366

13. Boatright D, Wiler JL. Diagnosis: septic cavernous sinus thrombosis. Emerg Med News. 2015; 37:15–20.

14. Zhang J, Stringer MD. Ophthalmic and facial veins are not valveless. Clin Experimental Ophthal. 2010; 38:502–510.

15. Clebone AL, Banack TM, et al. Repeated comparisons of brain tunnel and sublingual temperature (Abstract) San Diego, CA. American Society of Anesthesiologists. 2009:A1654.

16. Haddadin A, Abreu M, Silverman T, Amalu W, Silverman D. Infrared thermographic analysis of temperature on the face, forehead, neck, and supero-medial orbit. (Abstract) San Diego, CA. American Society of Anesthesiologists. 2009:A190.

17. Wagner J, Abreu M, Piepmeier J, Silverman DG, Ruskin K. Detection of brain cooling during craniotomy with a surface temperature monitor. (Abstract) San Diego, CA. American Society of Anesthesiologists. 2009:A1352.

18. Or CKL, Duffy VG. Development of a facial skin temperature-based methodology for non-intrusive mental workload measurement. Occup Ergon. 2007; 7:83–94.

19. Roberge RJ, Monaghan WD, Palmiero AJ, Shaffer R, Bergman MS. Infrared imaging for leak detection of N95 filtering facepiece respirators: a pilot study. Am J Indust Med. 2011; 54:628–636.

20. Banack TM, Liang I-H, Gianaroli V, Nie S, Nordquist D, Silverman DG. Temperature of dominant versus nondominant cerebral hemispheres: can a difference be detected via the brain temp tunnel? (Abstract) San Diego, CA. American Society of Anesthesiologists. 2009:A1211.

21. Ring EJF, McEvoy H, Jung A, Zuber J, Machin G. New standards for devices used for the measurement of human body temperature. J Med Engineer Technol. 2010; 34:249–253.

22. Kim J-H, Roberge R, Powell JB, Shafer AB, Williams WJ. Measurement accuracy of heart rate and respiratory rate during graded exercise and sustained exercise in the heat using the Zephyr Bioharness™. Int J Sports Med. 2013; 34:497–501. [PubMed: 23175181]

23. Lou, CZ., Cao, GQ., An, DW., Lou, G. A new control strategy of indoor air temperature in an air-conditioning system. International Refrigeration and Air Conditioning Conference; July 12-15, 2004; Purdue University. 2004. http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1729&context=iracc

24. Parsons, KC. [Accessed 10 April 2015] Introduction to thermal comfort standards. 2002. http://www.utci.org/cost/publications/ISO%20Standards%20Ken%20Parsons.pdf

25. Roberge RJ, Coca A, Williams WJ, Powell JB, Palmiero AJ. Physiological impact of the N95 filtering facepiece respirator on healthcare workers. Resp Care. 2010; 55:569–577.

26. Kim J-H, Roberge RJ, Powell JB. Effect of wearing an N95 respirator on infrared tympanic membrane temperature measurements. J Clin Monit Comput. 2014

27. Holden WE, Sippel JM, Nelson B, Giraud GD. Greater nasal nitric oxide output during inhalation: Effects on air temperature and water content. Respir Physiol Neurobiol. 2009; 165:22–27. [PubMed: 18952009]

28. Kim J-H, Roberge RJ, Powell JB, Shaffer RE, Ylitalo CM, Sebastian JM. Pressure drop of filtering facepiece respirators: how low should we go? Inter J Occup Med Environ Health. 2015; 28:1–10.

29. Morrison, SF., Blessing, WW. Central nervous system regulation of body temperature. In: Llewellyn-Smith, IJ., Verberne, AJM., editors. Central Regulation of Autonomic Functions. 2nd. New York: Oxford Press; 2011. p. 327

30. Gwosdow AR, Nielsen R, Berglund LG, DuBois AB, Tremml PG. Effect of thermal conditions on acceptability of respiratory protective devices on humans at rest. Am Ind Hyg Assoc J. 1989; 50:188–195. [PubMed: 2705368]

31. Bergersen TK. A search for arteriovenous anastomoses in human skin using ultrasound Doppler. Acta Physiol Scand. 1993; 147:195–201. [PubMed: 8475746]

32. Harioka T, Matsukawa T, Ozaki M, et al. "Deep-forehead" temperature correlates well with blood temperature. Can J Anaesth. 2000; 47:980–983. [PubMed: 11032273]

33. Low DA, Vu A, Brown M, et al. Temporal thermometry fails to track body core temperature during heat stress. Med Sci Sports Exer. 2007; 30:1029–1035.

34. Mercer JB, Ring EF. Fever screening and infrared thermal imaging: concerns and guidelines. Thermol International. 2009; 19:67–69.

35. Chan L-S, Cheung GTY, Lauder IJ, Kumana CR. Screening for fever by remote-sensing infrared thermographic camera. J Travel Med. 2004; 11:273–279. [PubMed: 15544710]

36. Cheung BMY, Chan LS, Lauder IJ, Kumana CR. Detection of body temperature with infrared thermography: accuracy in detection of fever. Hong Kong Med J. 2012; 18(Suppl 3):S31–S34.

37. Reis CV, Gonzalez FL, Zabramski JM, et al. Anatomy of the superior ophthalmic vein approach for direct endovascular access to vascular lesions of the orbit and cavernous sinus. Neurosurg. 2009; 64(Suppl5):318–323.

38. Hayreh SS. Orbital vascular anatomy. Eye. 2006; 20:1130–1144. [PubMed: 17019411]

39. Dutton, JJ. Atlas of Clinical and Surgical Orbital Anatomy: Expert Consult. 2nd. London: Elsevier Health Sciences; 2011. p. 104

40. Zhu M, Ackerman JJH, Yablonskiy DA. Body and brain temperature coupling: the critical role of cerebral blood flow. J Comp Physiol B. 2009; 179:701–710. [PubMed: 19277681]

41. Nybo L, Secher NH, Nielsen B. Inadequate heat release from the human brain during prolonged exercise with hyperthermia. J Physiol. 2002; 545(Part 2):697–704. [PubMed: 12456844]

42. Afonso S, Rowe GG, Castillo CA, Crumpton CW. Intravascular and intracardiac blood temperatures in man. J Appl Physiol. 1962; 17:706–708. [PubMed: 13859540]

43. Hyashi, N., Dietrich, DW., editors. Brain Hypothermia Treatment. New York: Springer Science and Business Media; 2004. Brain tissue temperature measurements in clinical setting; p. 918

44. Mellergard P. Intracerebral temperature in neurosurgical patients; intracerebral temperature gradients and relationships to consciousness level. Surg Neurol. 1995; 43:91–95. [PubMed: 7701435]

45. McConaghy FF, Hales JRS, Rose RJ, Hodgson DR. Selective brain cooling in the horse during exercise and environmental heat stress. J Appl Physiol. 1995; 79:1849–1854. [PubMed: 8847243]

46. Mapstone R. Ocular thermography. Brit J Ophthal. 1970; 54:751–754. [PubMed: 5484742]

47. Teunissen LPJ, Daanen HAM. Infrared thermal imaging of the inner canthus of the eye as an estimator of body core temperature. J Med Engineering Technol. 2011; 35:134–138.

48. Hindman HB. Eyelid, periorbital, and ocular surface temperature differences of Sjogren's eyes and asymptomatic controls (Poster). American Society of Cataract and Refractive Surgery Symposium and Congress, San Diego, CA. 2015 Apr 17–21.

49. Patestas, MA., Gartner, LP., editors. A Textbook of Neuroanatomy. Malden, MA: Blackwell Publishing; 2006. p. 138-170.

50. Ng EY, Kaw GJ, Chang WM. Analysis of IR thermal imager for mass blind fever screening. Microvasc Res. 2004; 68:104–109. [PubMed: 15313119]

51. Ring, EFJ., Jung, A., Zuber, J., Rutowski, P., Kalicki, B., Bajwa, U. Detecting fever in Polish children by infrared thermography. 9th International Conference on Quantitative InfraRed Thermography; July 2-5, 2008; Krakow, Poland. 2008. http://qirt.org/archives/qirt2008/papers/03_07_17.pdf

52. Mekjavic IB, Rogelj K, Radobuljac M, Eiken O. Inhalation of warm and cold air does not influence brain stem or core temperature in normothermic humans. J Appl Physiol. 2002; 93:65–69. [PubMed: 12070187]

Compliance with Ethical Standards

- the authors declare that they have no conflicts of interest

- the study was approved by the NIOSH Institutional Review Board and all subjects provided written and

- verbal consent.

- National Personal Protective Technology Laboratory internal operating funds were used for the study
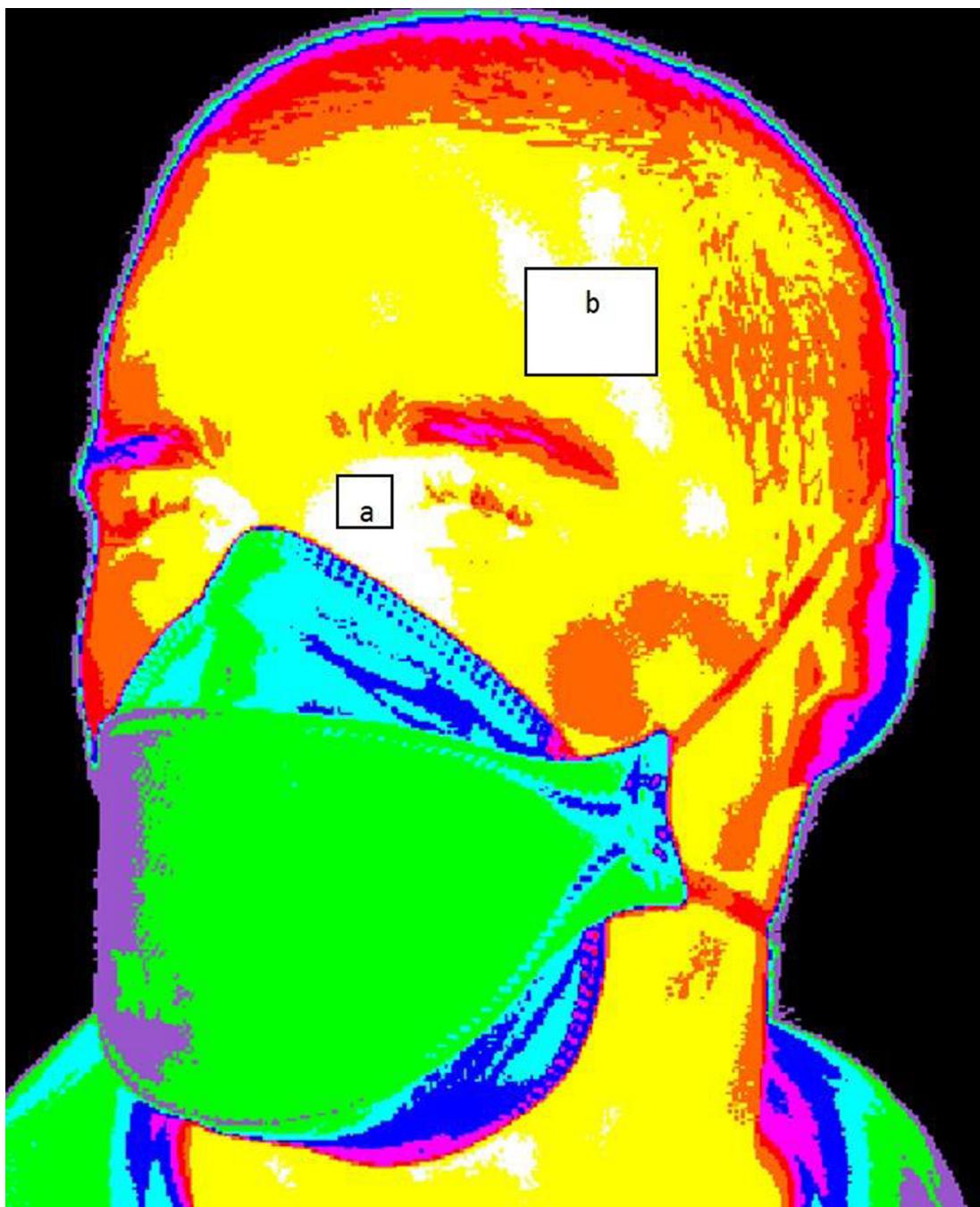
Figure 1.
Infrared thermography image of superomedial periorbital area (a) and superficial temporal artery area (b) temperature measurement sites in a right hand dominant subject
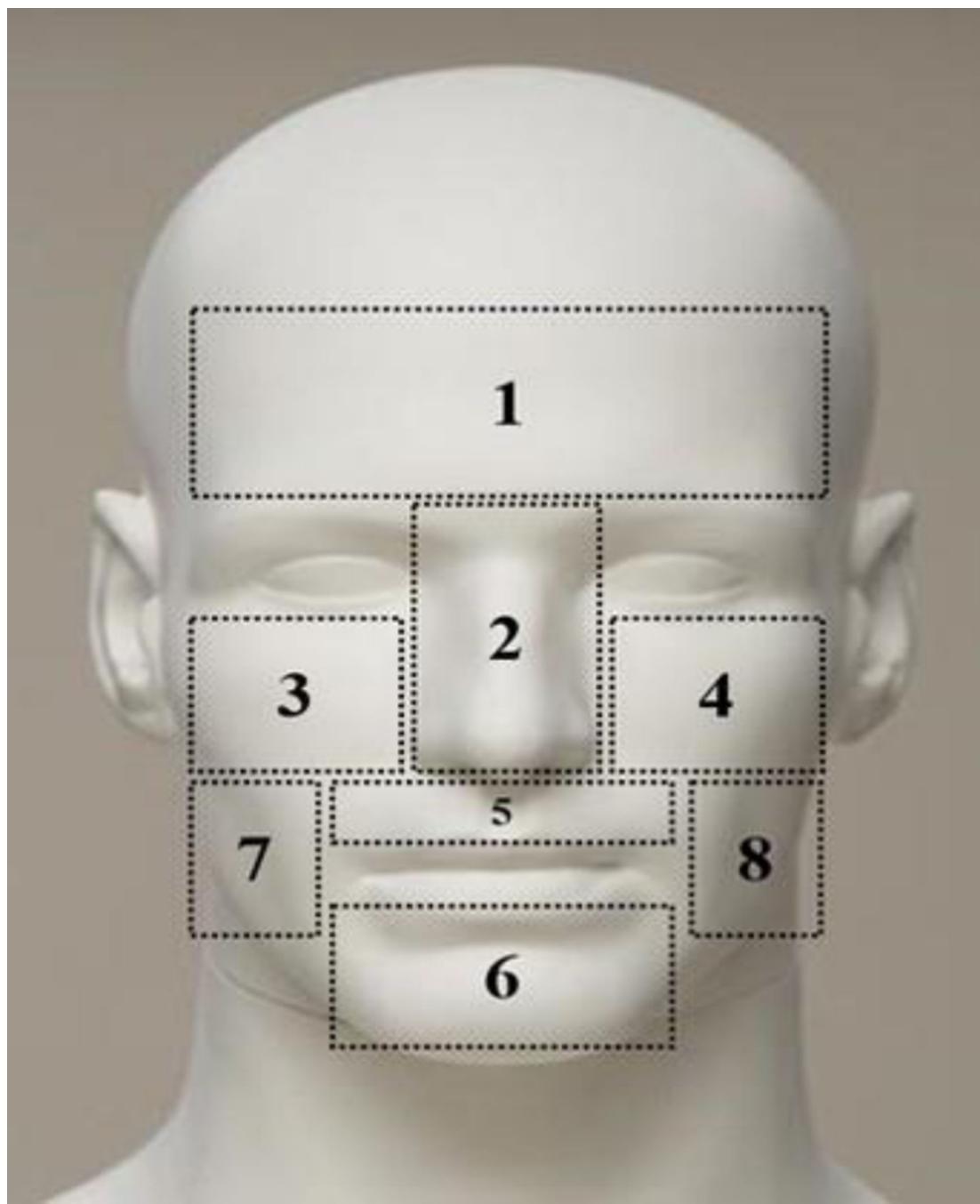
Figure 2.
Facial mannequin placard with numbered anatomic areas used for denoting regional subjective temperature changes while wearing a filtering facepiece respirator (1 = forehead, 2 = nasal region, 3 & 4 = malar regions, 5 = upper lip region, 6 = chin area, 7 & 8 = cheeks)
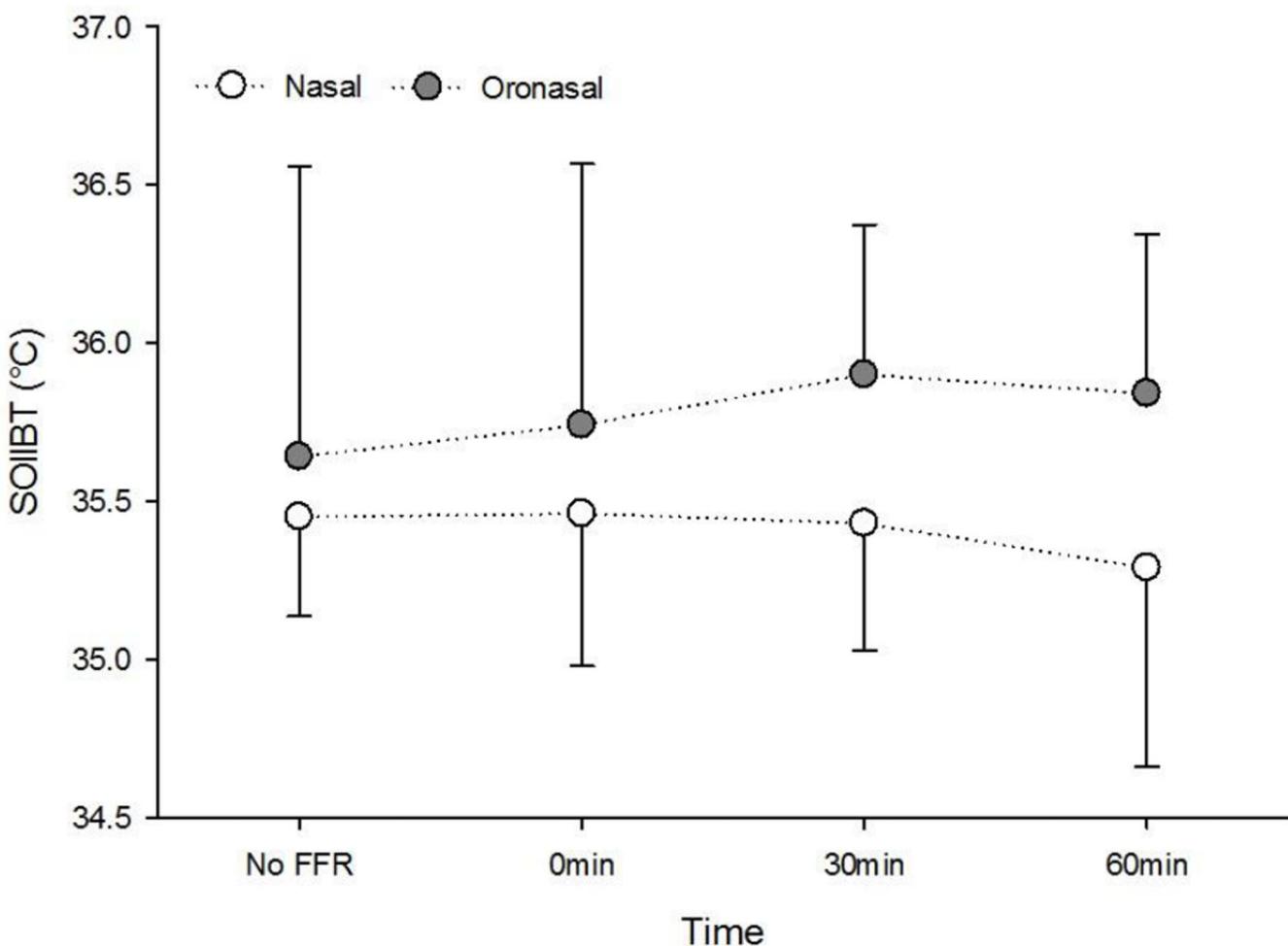
Figure 3.
Comparison of superomedial orbital infrared indirect brain temperature measurements of subjects who remained nasal breathers throughout the study (n=10) with those who converted from being nasal breathers to oronasal breathers (n=5) during one hour of wearing a filtering facepiece respirator
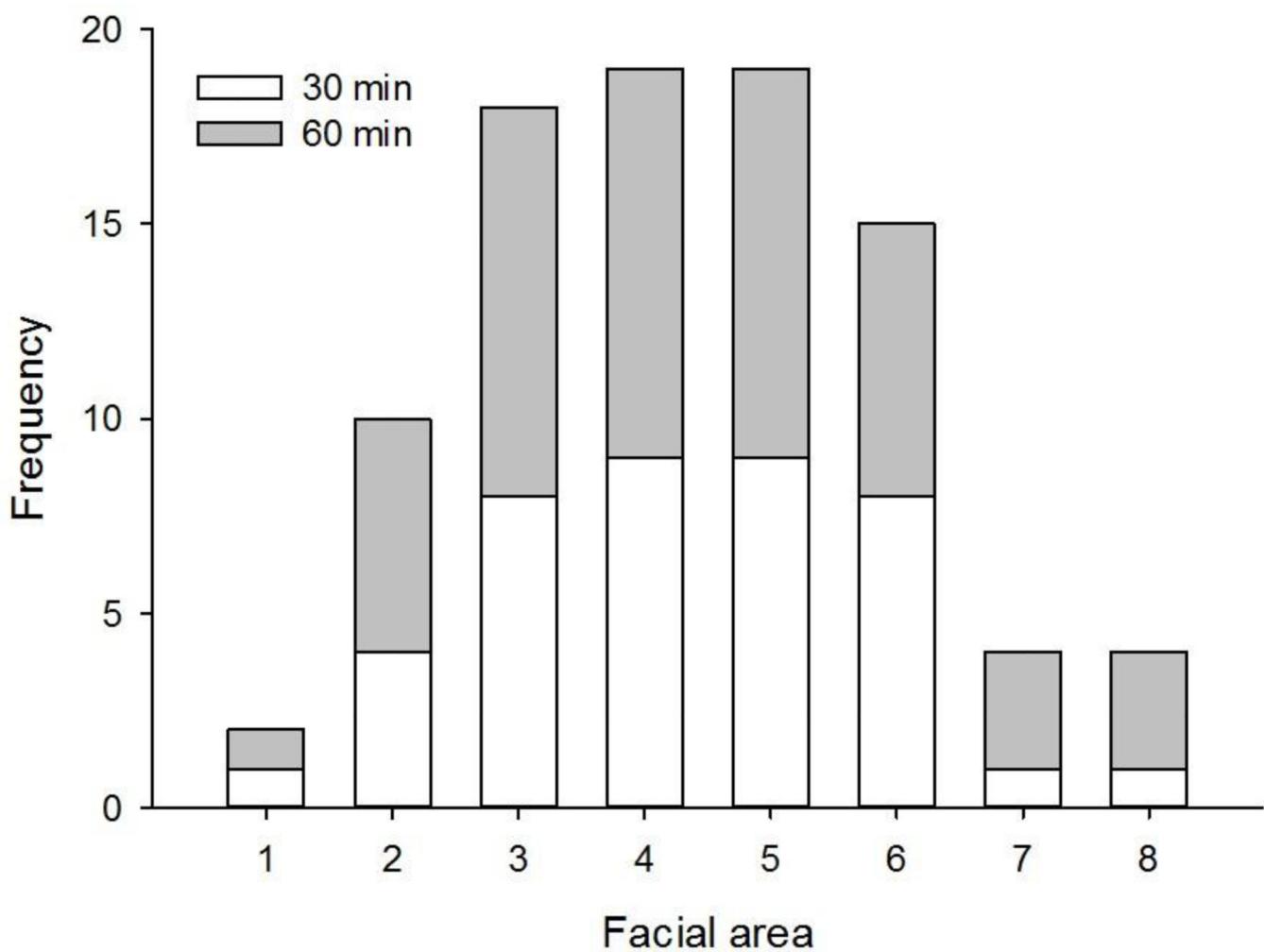
Figure 4.
Frequency distribution of facial areas perceived as experiencing increased warmth while
wearing a SN95 filtering facepiece respirator at a sedentary work rate over one hour (n=18)

Table 1

Mean values of measured study variables

Variable	Time		
	0 min (baseline)	30 min	60 min
Superomedial periorbital temperature	35.61 ± 0.58	35.62 ± 0.46	35.53 ± 0.61
Temporal artery temperature	35.41 ± 0.36	35.28 ± 0.41[*]	35.28 ± 0.46[*]
Tympanic temperature	36.77 ± 0.28	36.75 ± 0.26	36.76 ± 0.27
Facial temperature	32.76 ± 1.39	34.25 ± 0.92[*]	34.38 ± 0.71[*]
Thermal comfort	−0.4 ± 0.5	0.9 ± 0.9[*]	1.1 ± 1.1[*]
Deadspace temperature	26.5 ± 2.4	34.0 ± 2.5[*]	34.4 ± 0.7[*]
Deadspace humidity	20.5 ± 5.3	54.5 ± 11.2[*]	67.4 ± 7.6[*#]
Respiratory rate	15.1 ± 2.0	14.3 ± 2.1	14.8 ± 2.4

[*] Significantly different from baseline.

[#] Significantly different from 30 min. (p<0.001)