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Effects of temperature and wind on facial temperature, heart rate, and sensation

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LEBLANC, J., B. BLAIS, B. BARABÉ, AND J. CÔTÉ. *Effects of temperature and wind on facial temperature, heart rate, and sensation.* J. Appl. Physiol. 40(2):127–131. 1976.—Skin temperature measurements of the face have shown that the cheek cools faster than the nose and the nose faster than the forehead. The cooling effect of wind is maximum at wind speeds between 4.5 and 6.7 m/s. Cold winds produce significant bradycardia, which is, however, much more pronounced during the expiratory phase of respiration. A significant correlation was noted between cooling of face and the reflex bradycardia observed. Similarly, a very significant correlation was noted between drop in skin temperature and subjective evaluation of cold discomfort. Consequently, the drop in skin temperature, reflex bradycardia, and subjective evaluation are parameters which are directly affected by cold wind and can be used as adequate indicators of the degree of discomfort. When comparing the present results with the windchill index, it was found that in the zone described as "dangerously cold" the index fits well with the physiological measurements. In the zone described as "bitterly cold," the index by comparison with actual skin temperature measurements and subjective evaluation underestimates the cooling effects of combined temperature and wind by approximately 10°C.

cold wind; skin temperature; bradycardia; man

SURFACES OF THE BODY which are not covered by clothing serve as sensing elements between the organism and the environment and in cold weather these parts may also become the limiting factor for tolerance. The cooling effect of wind has been measured and is most commonly expressed in terms of windchill index (9). Data used to calculate this index were obtained from a can of water cooled by various combinations of temperatures and winds. The question is raised as to whether the responses would be the same if the measurements were made directly on the face because of the influence of such factors as vascular blood flow, level of heat production, and parts of the face concerned such as the nose, cheek, and forehead. Actual measurements of skin temperatures were made on the different parts of the face exposed to various temperatures and winds.

As was shown recently, cooling of the face produces systemic cardiovascular responses, such as an increase in blood pressure and decrease in heart rate, which are significantly modified by the degree of adaptation (4). To further this study the systemic action of temperature and wind on heart rate was also investigated. Results obtained made it possible to calculate the correlation between skin temperature of the face and heart rate responses under the various conditions described. Finally, a subjective evaluation of the environment was attempted by asking the subjects to give a rating of the environment in all experiments.

PROTOCOL AND METHODS

A group of 25 male subjects, ranging in age between 25 and 30 yr, was used in this study. In a first study, the subject's face was exposed to various temperatures (from −20 to +24°C) and winds (0, 2.24, 4.47, 8.94, and 17.88 m/s). Tests were done in the morning between 10 and 12 o'clock and a given subject was only exposed to one test per day. Subjects were not engaged in physical activity prior to the test and rested in a control test chamber kept at 21°C while measurements of skin temperatures on the nose, forehead, and cheek were made and heart rate recorded. Immediately before entering the cold room the subjects were dressed with a Skidoo suit which adequately protected the whole body except for the face, which was exposed. The adjacent cold room was preset at the desired temperature. Upon entering the room, the subject sat and immediately the wind was blown on his face. The blower was linked to a linear motor and the calibrated rheostat allowed various wind speeds. The wind was blown through a square tunnel with 22.5-cm sides 60 cm in length. Two metal grills were placed inside the tunnel to reduce variations in wind velocity at the opening. The face of the subject was placed 25 cm from the end of the wind tunnel. In this study the exposure lasted 10 min, and the average of temperatures and of heart rates between the 9th and 10th min were used because preliminary studies had shown a maximum drop in skin temperature at that time. On leaving the cold room the subjects were asked to give a subjective evaluation by rating the specific conditions to which they were exposed on a scale ranging from 0 to 1,000.

Copper-constantan thermocouples were fixed to the skin with small pieces of adhesive tape and the temperatures were recorded every four seconds throughout the experiment on a recorder with 0.1°C accuracy. A telemetry system was used for heart rate and the data obtained were digitized, recorded on tape, and subsequently analyzed by appropriate programs on a 360/APL computer. Subjects were asked to rate their experience of comfort and discomfort. They were told to give a number between zero and 1,000 on a scale where 1,000 corresponded to most comfortable conditions and zero to extreme discomfort; no further instructions were given. Subjects show a remarkable consistency in evaluating a given set of conditions. As will be seen (Fig. 8), the result of this rating was sufficiently reliable to allow accurate quantitative evaluation of the environmental conditions. Since all subjects were used for every experiment, the effects of wind and temperature were analyzed by the method of pairing in which each subject served as his own control. The significance of the various correlations tested were based on data from 25 subjects. For example in Fig. 7, each point represents a mean for the 25 subjects and a test of significance was done for the slope of the curves; on Fig. 4, each point also represents 25 subjects, but this time the significance is found for the level of the curves, but not for the slope.

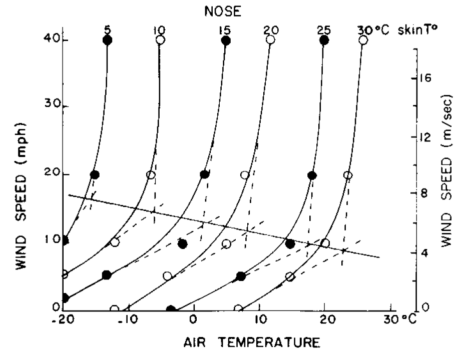

FIG. 1. Effect of air temperature and wind on skin temperature of nose. Intercepts of broken lines, which are drawn along linear parts of solid lines, allow extrapolation of wind speed at which near maximum cooling effect is observed.

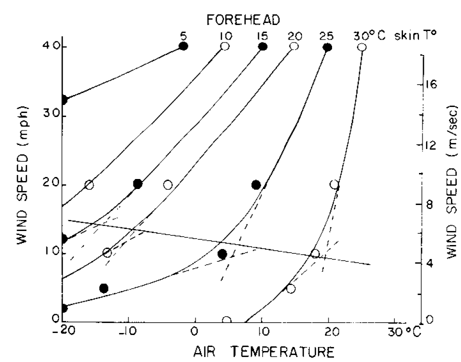

FIG. 2. Effect of air temperature and wind on skin temperature of forehead. Intercepts of broken lines, which are drawn along linear parts of solid lines, allow extrapolation of wind speed at which near maximum cooling effect is observed.

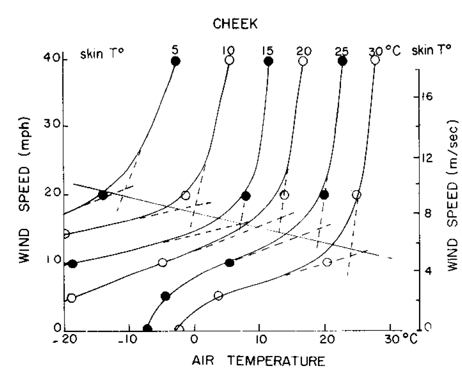

FIG. 3. Effect of air temperature and wind on skin temperature of cheek. Intercepts of broken lines, which are drawn along linear parts of solid lines, allow extrapolation of wind speed at which near maximum cooling effect is observed.

RESULTS

Figures 1, 2, and 3 were made as follows: after recording skin temperatures on the nose, cheek, and forehead of 25 subjects, averages were taken and a series of figures drawn for each wind speed (0, 2.24, 4.47, 6.71, 8.94, and 17.88 m/s) giving the skin temperatures against air temperatures. A regression line was calculated and drawn on these figures. Once these curves were made the actual air temperatures were noted for various skin temperatures (5, 10, 15, 20, 25, and 30°C). We were then able to find, for a given wind speed and at the specific skin temperatures mentioned above, the corresponding air temperatures. These data were subsequently arranged in the manner shown on Figs. 1, 2, and 3. The series of curves presented show that for the three skin locations the cooling effect of wind is not linear; the maximum effect is noted between 0 and 8.9 m/s. At wind speeds above 8.9 m/s, the cooling effect of wind persists but is only slightly increased at speeds up to 17.9 m/s. The different curves presented tend to be parallel, indicating that for all wind speeds there is a linear correlation between air temperature and skin temperature, at least in the range used for this study. The same figure also shows that, of the skin sites studied, the warmer, in order, are: the forehead, the nose, and the cheek. Indeed at 10°C with wind at 8.94 m/s, the temperature of the forehead, nose, and cheek are, respectively, 20, 15 and 10°C. This is further illustrated in Table 1, which shows that at a fixed wind speed of 8.94 m/s a skin temperature of 15°C is noted at air temperatures of −8°C for the forehead, +1°C for the nose, and +8°C for the cheek; these results indicate that the skin of the cheek cools faster than that of the nose or forehead. The same table shows that if the air temperature is kept constant at 0°C, a skin temperature of 15°C is noted at wind speeds of 6.3 m/s for the cheek, 8.5 m/s for the nose, and 12.5 m/s for the forehead.

The bradycardia which results from face stimulation by cold is illustrated in Fig. 4. For wind speeds between 0 and 8.94 m/s the effects of air temperature on bradycardia yields a series of curves which are parallel and relatively equidistant. This indicates that in this range of air temperature (25 to −15°C) and wind speed (0 to 8.9 m/s) the effect of air temperature is fairly constant and relatively small (approximately 5 beats/min) for a drop of 40°C (25 to −15°C). On the other hand the effect of wind on slowing of heart rate is relatively constant for all temperatures used and varies between 10 and 13 beats/min for a 8.9 m/s increase in wind speed. At 17.9 m/s only two temperatures were tested because of the danger of freezing the skin at −15°C.

So far the effect of temperature and wind on heart rate has been calculated by taking an average over a period of one minute. As this appeared to be influenced by respiratory phases, the effect of three temperatures, (20, 8, and −4°C), in a situation of wind (17.9 m/s) and no

TABLE 1. *Effects of air temperature and wind speed on facial temperatures*

	Forehead	Nose	Cheek
Part A			
Wind, m/s	8.94	8.94	8.94
Air Temp, °C	−8	1	8
Part B			
Wind, m/s	12.5	8.5	6.25
Air Temp, °C	0	0	0

A: air temperature required to cool forehead, nose, and cheek to 15°C with a constant wind of 8.94 m/s; *B:* wind speed required to cool the forehead, nose, and cheek to 15°C with a constant air temperature of 0°C.

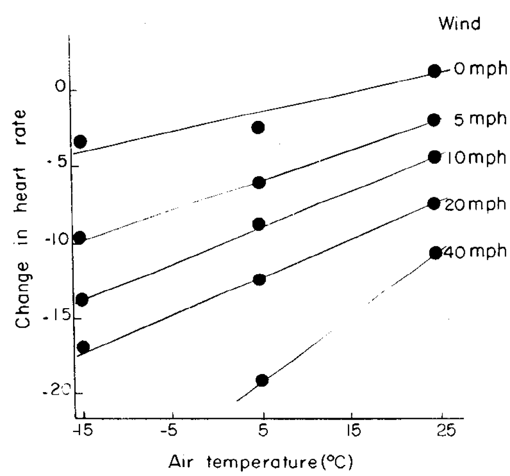

FIG. 4. Effects of various temperatures and wind on heart rate response (beats/min) to face cooling.

wind, were studied both during the inspiratory and the expiratory phase of respiration. Figure 5 shows that bradycardia is not very important during inspiration; even with a fall in air temperature of 24°C (20 to −4°C) and increase in wind to 17.9 m/s, the fall in heart rate is at the most 8 beats/min. On the other hand, the effect of temperature and wind on fall in heart rate during expiration is much more pronounced. Even at 20°C without wind, heart rate is 7 to 8 beats lower during expiration; a fall of 24°C in air temperature and an increase to 17.9 m/s in wind speed causes an additional fall in heart rate of approximately 14 beats/min. The same figure shows that upon removing the wind, heart rate tends to return towards initial levels. This probably reflects parallel action on skin temperature of the face, as the next figure indicates. Indeed, Fig. 6 represents the variations in skin temperatures of the forehead, nose, and cheek in relation to changes in heart rate at various temperatures (25, 5, and −15°C) and wind speeds (0 to 17.9 m/s). A significant negative correlation is noted between the skin temperature of either the forehead, the nose, or the cheek and the slowing of heart rate. Subjective evaluation of cold wind on the face was estimated for temperatures ranging from 0 to 38°C and winds from 0 to 17.9 m/s. Figure 7 shows the correlation between forehead temperature and subjective evaluation under these different experimental conditions. At a skin temperature of 33°C, maximum thermal comfort was reported by the subjects. At forehead temperatures above 33°C, the subjects felt uncomfortable, whereas between 33 and 16°C the subjects reported a significant but relatively small decrease in comfort. Below 16°C, a marked drop in comfort sensation was experienced.

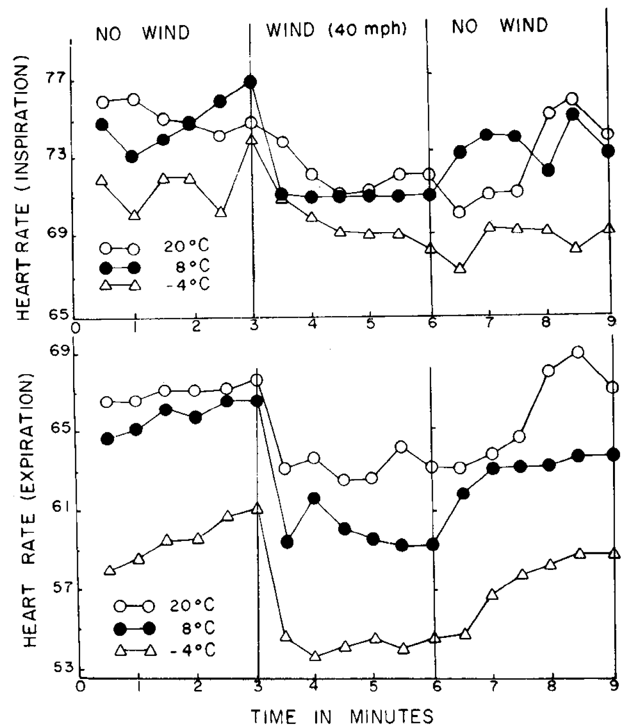

FIG. 5. Effect of temperature and wind on heart rate responses (beats/min) measured during respiratory inspiration and expiration.

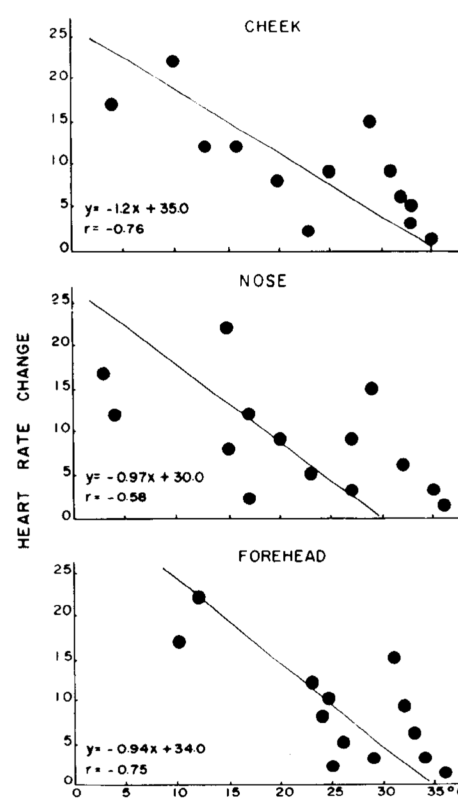

FIG. 6. Relationship between skin temperature changes on nose, forehead, and cheek, and variations in heart rates (beats/min) for various temperatures and wind speeds.

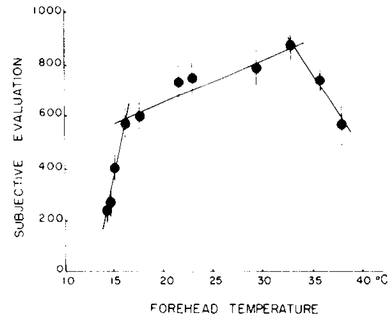

FIG. 7. Relationship between variations of skin temperatures of forehead and subjective evaluation of various temperatures and wind speeds. Standard errors of subjective evaluations are given.

DISCUSSION

For a given wind speed, the different curves shown on Figs. 1, 2, and 3 are relatively parallel, indicating that the effect of air temperature per se on skin temperatures of the face is linear, and this effect is constant whatever the wind speed. The same figures also show that the marked cooling effect of wind, at whatever air temperature, reaches a close to maximum effect at relatively low speeds. This wind speed, estimated by referring to the average intercept of the dashed lines, would be on the average 5.4 m/s for the nose, 4.9 m/s for the forehead, and 6.7 m/s for the cheek. If we consider the temperatures of the cheek, the wind effect would be equivalent to as much as a 40°C fall in air temperature for an increase in wind speed from 0 to 6.7 m/s, but for an increase in wind speed from 6.7 to 17.9 m/s, the comparable effect would be equivalent to 2–3°C at the most.

Table 1 shows the different responses of the forehead, nose, and cheek to variations in wind and air temperature. The cheek cools more than the nose and the nose more than the forehead under the different conditions described. The differences are probably related to the following characteristics. The forehead is well vascularized, and has a uniform surface with a relatively thin layer of subcutaneous fat. The cheek, at the level of the pad where the temperature measurements were made, is where the layer of subcutaneous fat on the face is thickest. Since the temperature of the skin is lower when the subcutaneous fat is more abundant (3), it is possibly for that reason that the cheek cools more rapidly than the other parts of the face studied. Because of its anatomy, the nose is exposed to cold air not only on the outside but also on its inner surface through breathing. For this reason the cooling effect of environmental temperature is relatively pronounced on the nose, but not quite as much as on the cheek.

The windchill index has been used extensively to estimate the cooling effect of temperature and wind. This index describes 5 zones, identified as comfortable, very cold, bitterly cold, dangerously cold, and the zone at which exposed flesh freezes within one minute (8). It might be interesting to try to relate this scale to our own observations. Figure 7 shows that when skin temperature reaches approximately 15°C, the environment becomes very uncomfortable rapidly and conditions can be described as bitterly cold. Our results and the windchill index were compared on that basis. Thus, Fig. 8 represents temperatures and winds which correspond to the bitterly cold zone on the windchill index, and the temperture and wind at which the temperature of the nose is 15°C which also correspond, by subjective evaluation, to a bitterly cold sensation. It would seem that in the zone described as "bitterly cold," the windchill index, compared to actual measurements of skin temperatures and subjective evaluation, underestimates the cooling effect of temperature and wind by approximately 10°C. It might be argued, at this point, that our measurements of skin temperatures are not without error since they were taken with thermocouples. This is not an unlikely possibility, but then our measurements would underestimate actual skin temperature; this would even amplify the underestimation of temperature and wind when using the windchill index.

A better correlation is obtained when we compare the zone described in the windchill index as "dangerously cold" to our results when the average skin temperature was 5°C. On that basis of comparison, one can see that both systems give values which overlap and are somewhat comparable. On the basis of this comparison it would seem that the windchill index, especially when used in extreme conditions, constitutes a simple and useful means of assessing the environment. Our results were also compared to those reported by Burton and Edholm (2). In still air, the air on the surface of the skin or of the clothing provides an insulation which is close to 1 clo. Air movement displaces this air layer and increases heat loss; this effect was called the thermal-wind-decrement; for resting subjects it amounts to 8°C for a wind speed of 40 mph. If we refer to Fig. 1 we see that for the various curves representing the different skin temperatures, an increase in wind speed from 0 to 17.9 m/s in our study would give an equivalent thermal-wind-decrement, using Burton's terminology, of approximately 20°C. In other words, taking the curve for T_s = 20°C for example, we see that heat loss from the nose would be the same at −10°C without wind as at +10°C with 17.9 m/s wind. We then have a much greater affect on heat loss at 17.9 m/s in the present experiment, where actual measurements of skin temperature were

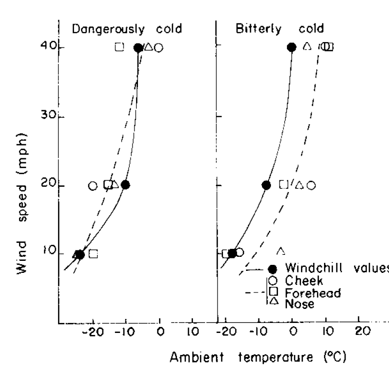

FIG. 8. Comparison, *left*, of various temperatures and wind speeds which correspond to condition described as "bitterly cold" on windchill index (4) and corresponding temperatures and wind speeds causing same sensation as measured in present study. Same comparison, *right*, is made except that basis for comparison is one which corresponds to sensation described as "dangerously cold" in windchill index and present study.

made, than in the study reported by Burton (2). It would seem that both the Burton estimate and the windchill index underestimate the effect of temperature and wind on the face by approximately 10°C.

Figure 4 shows that both air temperature and wind produce a significant slowing of heart rate. This bradycardia caused by cold wind is very significantly related to the temperatures of the skin on different parts of the face. It is observed as soon as a drop in skin temperature takes place, and does not necessarily indicate uncomfortable conditions; indeed, at skin temperatures of 15°C and above, the observed bradycardia is very pronounced. Yet, as shown in Fig. 7, the subjective evaluation indicates relative comfort. This bradycardia is probably of the nature of a vagal reflex, initiated by stimulation of the trigeminal nerve of the face. The general reflex vasodilatation which results from heating the face (1, 6, 8), or the reflex vasoconstriction when the extremities are cooled (5), suggest a possible role for these actions in the bradycardia of face cooling. This is not likely since hand cooling, which produces as much increase in blood pressure due to reflex vasoconstriction as face cooling, results in heart acceleration rather than slowing. In many subjects a slight reduction of heart rate is often observed during expiration even at a comfortable room temperature. In the present study, as shown in Fig. 5, although the bradycardia of face cooling is noted throughout the respiratory cycle, the effect is much more pronounced during expiration. The mechanisms of this action remain unknown.

Conditions which reduce skin temperatures to 15°C or below become very uncomfortable and cause an activation of the sympathetic nervous system (4). The wind is thus an important factor to be considered when estimating the cooling effect of temperatures. Physiological parameters have been used to measure the effect of cold wind on the exposed skin of the face. Skin temperatures, heart rate, and subjective evaluations were shown to be effective means of estimating, quantitatively, the cooling effect of the environment. This study may help clarify some of the discussion evoked some 15 yr ago between the advocates and critics of the windchill index (7). The merits of this index are confirmed, and at the same time its importance is delimited.

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