Scand J Work Environ Health 1990;16(suppl 1):44—50

Thermal stress and human performance

by Ann E Enander, PhD,[1] Staffan Hygge, PhD[2]

ENANDER AE, HYGGE S. Thermal stress and human performance. *Scand J Work Environ Health* 1990;16(suppl 1):44—50. There is evidence that the thermal stress encountered in many work environments may negatively affect various aspects of human performance and behavior. Evaluation of the empirical research is, however, complicated by differences in both the methodology and the definition of the basic stimulus. Effects of heat and cold stress are briefly reviewed, with particular regard to theoretical considerations.

Key terms: cold, heat, performance, social behavior.

People are subjected to thermal stress in many work environments, as, eg, in outdoor work under intemperate climatic conditions or in the processing of products which require heat-producing technology or strict hygienic standards. While physiological limits of endurance are seldom reached in today's work environment, increasing interest is being focused on the possible negative effects on behavior. A relationship between thermal stress and accident occurrence was documented over 50 years ago, and a similar relationship to unsafe work behavior was recently demonstrated (1). These relationships form a background to the following discussion of the central issues in research on the behavioral effects of thermal stress.

Definition of the stimulus

A central problem in this research area is that of establishing a relevant measure of thermal stress to which behavioral effects can be related. Several indices have been developed which combine different parameters into one single value to characterize the external thermal stress on humans. For cold the wind-chill index incorporates the combined effects of air temperature and air velocity. For heat stress a number of indices are in use. The effective temperature (ET) takes into account the air temperature (dry bulb temperature), humidity, and air velocity. Another well-known heat index is the wet bulb globe temperature (WBGT), which also includes radiation heat. For a more-detailed description of thermal stress indices, the reader is referred to McIntyre (2). Empirical assessments and comparisons of several indices have been reported by Mutchler & Vecchio (3) and Beshir (4).

[1] National Defence Research Establishment, Karlstad, Sweden.
[2] The National Swedish Institute for Building Research, Gävle, Sweden.

Reprint requests to: Dr AE Enander, National Defence Research Establishment, Karolinen, S-65180 Karlstad, Sweden.

The stress effects of a defined thermal environment may vary according to several individual characteristics of the subjects, eg, age, sex, fitness, etc. Comparison between different studies is also complicated by the use of different methods to achieve thermal stress, eg, by means of varying air temperature, wind speeds, or physical work or submerging the body in cold or warm water. Measures of individual physiological reactions are therefore often necessary before a relevant indication of the thermal stress imposed can be obtained.

While some simpler performance measures appear to be relatively well related to physiological changes, it has proved considerably more difficult to establish relationships between indices or physiological measures of thermal stress and more complex cognitive and mental tasks. Thus there is a choice of different independent variables in thermal stress research. In a review of environmental factors and performance, Smith & Ottmann (5) pointed to four such basic choices of the independent variable or research paradigms. The first is characterized with effective temperature as the independent variable, while the second paradigm relies on deep body or core temperature. A third type of research paradigm attempts to disentangle core temperature and air temperature, eg, by having the subjects wear vapor suits or having them do physical exercise to increase core temperature. The fourth and last paradigm has its focus on the interaction between different factors, such as heat, noise, sleep deprivation, time of day, in order to determine whether the same or different psychological mechanisms are tapped by different independent variables.

There is a wide array of stimuli definitions in thermal research, each with different theoretical foci. On the distal side, definitions relying on the physical parameters of the environment have an advantage in being able to detect performance effects before ambient conditions have altered skin or deep body temperature. Clearly this trait rests on an assumption that thermal performance effects are not exclusively directed through the same routes as thermoregulation. A deep-body temperature definition of the stimulus implies that the main mediating mechanism for performance effects is dependent upon thermoregulation. The interactionist view of the thermal stimulus definition assumes that thermal effects are interrelated with those of other environmental stressors, and its focus is on common and shared psychological mechanisms.

Theoretical approaches

Bell & Greene (6) have discussed three of the more significant theoretical approaches which have been applied to interpret the effects of thermal stress on performance, namely, body temperature, arousal, and attention.

Body temperature

It has generally proved difficult to establish a direct relationship between body temperature and performance. Interpretation of the available evidence is in part hampered by the general lack of body temperature measurements in research, and also by a lack of consensus as to the relevant measures. Recent evidence indicates that both core and skin temperature, and the relation between them, may have a significant bearing on some measures of performance.

Arousal

The arousal theory is perhaps the most well known of general theories which have been applied to explain the effects of many environmental factors. Stress has been defined in terms of arousal theory by suggesting that both overarousal and underarousal are stressful. Complex, as opposed to simple, task performance decrements would be expected to occur under arousing conditions. During overarousal, a narrowing of attention appears to occur, where the organism focuses on the most important cues available in the situation (7). In complex tasks more such cues per unit of time are necessary for successful task completion. Thus, when a narrowing of attention occurs in the complex task situation, the organism is more likely to ignore cues relevant to successful task completion than in a simple task in which fewer such important cues are necessary for task success.

When applied to heat, the reservation has often been made that mild heat is dearousing and that arousal increases again after some optimum temperature has been reached.

Recent criticism (8) has pointed out several weaknesses in the arousal construct. However, it must be admitted that, to the extent that there are reliable interactions between stressors, the arousal theory has a strong point in its ability to explain antagonistic interactions.

Attention

Humans have a limited information processing capacity. Information overload occurs when the demand for attention exceeds total available capacity. This situation is likely to occur in the presence of an environmental stressor, since it requires the allocation of attention. The most usual strategy employed to deal with such overload is the focusing of available attention on the aspects of the environment most relevant to task performance at the cost of less relevant input. Information overload theories can also be expanded to include how stressors can change cognitive strategies. [See the report of Cohen et al (9).] Task performance will change under stress to the extent that variability in cognitive strategy is possible in the completion of the task. Tasks that only allow one strategy are less likely to be affected by stress.

Recent theoretical developments

In parallel with criticism of traditional theoretical approaches, attempts at integrating and developing them are evolving. In rejecting the unidimensional arousal theory, eg, Hockey & Hamilton (8) suggested that different stressors affect performance differently, and not through any unitary and general arousal mechanism. Different profiles of effects can be discerned for different stressors along the dimensions of alertness, selectivity, speed, accuracy, and short-term memory. Stressors can also be divided into high-arousal (eg, noise, heat) and low-arousal (eg, sleeplessness, alcohol) states, but also within these families different profiles exist. According to Hockey & Hamilton (8), the patterning of states suggests two complementary research strategies, a narrow-band strategy in which a particular test or task is employed across stressors or a broad-band strategy in which different tasks are employed within one single stressor.

Another interesting development can be found in a recent review of vigilance under thermal stress, in which Hancock (10) made a distinction between static and dynamic changes in body temperature. He proposed that the key factor in determining change in vigilance under thermal stress is the thermophysiological state of the person. When conditions are insufficient to change deep body temperature, performance remains essentially unaffected. However, when thermal conditions perturb the deep body temperature away from both normal and steady-state conditions, vigilance is impaired. Static hyperthermic states are assumed to be beneficial with respect to sustained attention.

The theoretical approaches that have been outlined can be regarded within a wider framework encompassing effects of environmental stress in general. The effects of different stressors are being compared, and traditional theories are being reevaluated and redefined. There is, however, a clear need for more direct tests of the hypotheses generated from these new developments.

Thermoregulation and acclimation

In order for a person to maintain body temperature in a cold environment, heat loss must be minimized or heat production increased. Vasoconstriction in the peripheral extremities and the redirection of venous blood flow to deeper lying vessels serve to reduce heat loss, while an increase in heat production is induced by shivering. Human sensitivity to cold acts as a significant stimulus for adaptive behavioral responses such as altering body posture and donning extra clothing.

For warmth the reverse is true. Heat dissipation is accomplished by sweating, increased blood flow, and peripheral vasodilation to increase heat loss through evaporation, radiation, and convection. However, a high level of air humidity will make heat losses through sweating impossible. To counteract ambient heat, activity level can also be reduced to lower the body's internal heat production.

Prolonged exposure to a hot environment leads to a lowering of the body temperature and heart rate and to sweating commencing at a lower body temperature. Exposure durations of 2 to 4 h/d for 5 to 10 d are sufficient (11) for a substantial reduction in heat strain. The point of thermal neutrality does not change with acclimation, but the swings in heat strain are less marked.

Men and women seem to heat acclimate at similar rates, but women regulate body temperature at a slightly higher temperature set-point than men (12). Under higher humidity conditions, women acclimate better than men, apparently because a higher surface area to mass ratio (total area of skin by body weight) for women helps dissipate body heat more readily (13).

While physiological acclimation to heat is a widely accepted phenomenon, the evidence of a corresponding effect as regards cold exposure is less clear-cut and has been widely debated (14). Local acclimation effects, in the form of increased finger temperature and a rapid onset of cold-induced vasodilatation, have been found among habitually cold-exposed subjects, although the relationship between such effects and performance has not always been clear. Conversely, while instances of improved manual performance have been demonstrated among subjects familiar with cold exposure, concomitant physiological changes have not necessarily been established. There is some evidence of psychological adaptation to cold in that subjects accustomed to cold exposure may experience less discomfort than unaccustomed subjects at equivalent skin temperatures (15).

To summarize, compensatory activities of the cardiovascular system are the initial means by which heat and cold are counteracted. When these activities do not suffice, sweating occurs under conditions of heat and shivering under conditions of cold. Physiological acclimation to heat is an established fact, whereas acclimation to cold is more in question.

Manual performance

There has been considerable research interest in the specific effects of cold on the functioning of the hands. This interest reflects the widely documented problems encountered in attempting to protect the hands from cooling while maintaining unimpaired dexterity. There is little evidence that heat has any appreciable effects on manual functioning, other than at very extreme exposures or in connection with prolific sweating.

Research on the effects of cold on tactile sensitivity and finger and hand dexterity has been summarized in several review articles (16—18). Early work indicated that it is the temperature of the hands which is critical for manual performance, although severe body cooling and shivering can also affect the performance of some tasks. Considerable research has been devoted to establishing the range of temperatures within which performance remains unimpaired. Critical skin temperatures of the hands and fingers have been found for unimpaired tactile sensitivity at 8—10°C, and for manual dexterity they occur at 12—15°C.

While the direct relationship between cooling of the hands and a progressive decrement in manual performance is well established, the actual degree of impairment is subject to several task and cooling factors. Tasks involving fine movements of the fingers and hands or manipulation of small objects are particularly sensitive to cold effects. Slow cooling, as found in many occupational settings, is more detrimental to manual performance than rapid cooling to equivalent skin temperatures of the hands (19, 20). The thermal conditions under which manual tasks are practiced or trained appear to affect performance capability under thermal stress, although there is some discrepancy in the results regarding these effects (21, 22).

The progressive development of more sensitive techniques of measurement and analysis has tended to result in effects on manual dexterity being found at increasingly mild levels of cooling. More recent research on manual performance has focused increasingly upon field or field simulation exposure conditions of longer duration (23), and upon the effects of various methods of protection or practice, rather than on laboratory studies of critical hand temperatures.

Simple and choice reaction time

In a review of more than 50 experiments on heat, Grether (24) concluded that simple reaction time became faster with increased heat. Complex reaction time, on the other hand, seemed to become slower with heat. According to Grether (24) the shortened simple reaction times can be explained by a higher neural transmission speed at higher temperatures. For more complex reaction-time tasks, however, he assumed that neural transmission speed had relatively less to do with the ensuing reaction time. The explanation has its merits; it is short and simple and fits a general conception of the facilitating effects of mild heat (25).

The evidence from Teichner's classic studies (26) and other work indicates that reaction speed is little affected by cold other than at more extreme levels. More complex tests of choice reaction time have, however, revealed effects of cold at more moderate levels. Thus Ellis (27) has demonstrated an increase in errors on a serial choice reaction-time test, but no increase in the number of lags registered. Increasing the complexity of the choice in the test led to a relative increase in errors made in the cold (28). Taken together, the results of these two studies were interpreted in terms of arousal theory. The increase in errors was hypothesized to result from a change in strategy caused by a cold-induced increase in cortical arousal.

Recent work at comparatively mild levels of exposure (29) has demonstrated significant increases in the number of errors, speed of incorrect response, and number of false alarms on two computerized tests for a group of women. These effects were only obtained on tests designed to require continuous rapid accurate responding with minimal opportunity to inhibit erroneous reactions. An increased number of responses to blank trials during cold exposure previously noted in the determination of flicker-fusion threshold (30) may be interpreted as demonstrating a similar effect. Thus there is evidence that at least one effect in the possible pattern of cold stress might be a decreased ability to inhibit erroneous responses.

Simple reaction time becomes faster as temperature rises, but is little affected by moderate cold. Complex reaction time is slowed down by heat, while the evidence primarily indicates an increase in errors in the cold.

Tracking, vigilance, and time sharing

In pursuit tracking, the operator's task is to move the controls so that the object follows a predetermined course. A real-life example would be handling the steering wheel of a car to keep it on the road. In the compensatory tracking task the operator has to keep an otherwise moving point in a fixed position. The spot only moves when the task is not performed correctly. The car driver's attempt to keep a constant speed is an example. Variations in road incline, speed losses in bends, head winds, tail winds, etc, must be compensated for by the driver maintaining the speedometer needle in a particular position. Compensatory tracking is clearly more difficult than pursuit tracking. An operator in a compensatory task cannot see what is being done, nor predict what is meant to be done. The operator can compensate only when an error has occurred. While tracking in a pursuit manner, the operator can see the movements produced by the track program, in addition to the effects of the control movements.

Kobrick & Fine (31) summarized studies on manual tracking by first stating that generalization is impossible, but in a number of instances there is some degradation at a wet bulb globe temperature of $>27°C$. (See 31 for references to the original studies.) But different exposure times create a complication. The studies reviewed by Ramsey (11) and Ramsey & Morrissey (32) point to a similar conclusion. In contrast to studies of reaction time, there is, for tracking tasks, a relatively small fraction of studies that show no effects or effects in the opposite direction, and the time dependency is less marked. Therefore, in several ways, the decremental effects of heat on tracking tasks may be more reliable than those inferred for reaction time.

Reviews of studies on tracking proficiency (17, 18) indicate a decrement under cold ambient conditions, although there is some discrepancy as to the optimal temperatures for performance. In a study of long-term exposure to cold, Teichner & Kobrick (33) demonstrated a lowered final limit for visuomotor performance, but no effect on rate of learning. Upon returning to warm conditions after a period of cold exposure, subjects demonstrated a rapid recovery in performance to the expected practice level.

In vigilance tasks the operator is required to act on irregular and infrequent signals, usually against a background of nonsignal stimuli. Early work described this performance as watchkeeping ability or vigilance; later work has labeled it monitoring or sustenance of attention.

The classical empirical works on vigilance were done by Mackworth (34), Pepler (35, 36), and Viteles & Smith (37). Mackworth reported that his artificially acclimatized subjects showed minimal signal omission and optimum efficiency on a combined response measure at 26°C ET compared both to higher temperatures (31 and 36°C ET) and to a lower one (21°C ET). Performance also declined with time over the 2-h experiment, and experienced subjects were less disturbed than inexperienced ones. Pepler (35) used naturally acclimated subjects in Singapore, and in one of his experiments he could confirm Mackworth's findings.

One of the tasks used by Viteles & Smith (37) was to inspect pairs of numeral series and check those pairs which were identical. Errors did not change significantly across temperature conditions, but output was significantly lower at the 31°C ET condition than at 29 and 23°C ET.

Influential reviews (11, 24, 31, 38) have suggested that there is an optimal level for vigilance in the range of around 27 to 32°C ET. The exact borders of this range will, however, vary with the exposure time, difficulty of task, physical exertion, and other helping or counteracting factors in the situation. Hancock (10) has argued that performance impairments in vigilance only occur when the deep body temperature is moving away from a normal steady state. Static elevations of core temperature are beneficial with respect to vigilance.

Comparatively little work has been conducted on vigilance in the cold. A study of shipboard lookouts by Poulton et al (39) is often cited as indicating effects of cold on vigilance, although the interpretation of the results is complicated by confounding wind and rain in the control condition.

Time sharing occurs in situations in which two tasks or more are to be performed simultaneously. In such concurrent tasks, one is usually designated as the primary, another as the secondary, etc. Dual tasks are the most common time sharing tasks, and examples include mental arithmetic and incidental learning, and tracking, together with detection of lights in different spatial locations. A tracking or vigilance task has often been included as the high or low priority subtask. The study by Mackie & O'Hanlon (40) on driver's steering adjustments can be regarded as a time-sharing task as well.

Bursill (41) combined a pursuit rotor-tracking task, designated as the primary task, with a secondary peripheral light task under the conditions of 18 and 35°C ET. His results, although their validity has been questioned (31), indicated a decrement of performance on detecting the peripheral lights under the heat condition, but no heat effect on the primary tracking task. Azer et al (42) reported central tracking and peripheral reaction-time decrements for subjects at a temperature of 35°C and high humidity, although low humidity at 35°C and moderate humidity at 37.8°C did not cause any change in performance. Bell et al (43) reported more missed signals (29.5—58°C dry bulb, different body temperatures) but no vigilance deficits. Bell (44) reported temperature effects of 35 versus 22°C (but not versus 29°C) on a secondary number processing task, but not on the primary pursuit-rotor task.

The present evidence indicates decrements in tracking performance in both heat and cold, while the optimal temperature range for vigilance appears to be relatively higher at 27 to 32°C ET. Clearly there are, however, difficulties in establishing the exact pattern of effects of thermal stress on more complex tasks. The results on time sharing remain similarly equivocal. To the extent that there is a general pattern, the secondary task seems to be at an optimum at a temperature at or above 30°C.

Cognitive and mental tasks

Pepler & Warner (45) had their undergraduates study a self-teaching programed text during exposure to six different temperature levels (16.7—33.3°C) at 45 % relative humidity. The students worked faster at high and low temperatures, where the error rate was also highest.

Wyon (46) summarized a series of the effects of heat on school performance. In a test of learning in a language laboratory the oral performance was worst at 27°C compared with 20°C, and the effects were more marked for the less competent children. In a classroom experiment nine-year-old children took tests at 20, 27 and 30°C. The two higher temperatures produced significantly worse performance than 20°C. Wyon argued that the arousal at 27°C was too low for optimum performance. In another study on a creative task, Wyon (47) found optimum performance on a creative task at 27°C compared to 20 and 23.5°C. Maximum performance at 26°C in a word-memory test was reported by Wyon (48).

Interest in the possible effects of cold on complex mental functions has been stimulated by several studies of divers working in cold water conditions. This work has shown some effects of cold on tasks of, eg, word recognition and problem solving (49, 50). Memory registration has been shown to be progressively impaired with decreased core temperature from a level of about 36.7°C, while recall of previously learned data proved highly resistant to effects of lowered body temperature (51).

Overall there has been relatively little research on the effects of thermal stress on cognitive and mental tasks. The focus on vigilance types of tasks in heat and more manual functions in cold reflects the pragmatic purpose of much of the empirical work, which has primarily been geared towards particular work environments and military settings. While difficult to interpret, the few results available do seem to indicate that cognitive functions may indeed be sensitive to thermal stress and deserve more specific study.

Social behavior

Some studies have reported heat to decrease attraction to a bogus stranger, as described by responses to an attitude survey (52, 53), while others have failed to replicate this finding (54, 55).

Quite a few studies, in the laboratory as well as employing archival records, have been made on heat and aggression. Baron & Bell (54) summarized and explained the results from the Baron research group in terms of negative affect. Heat per se did not produce more aggression. Heat and insult from an accomplice of the experimenter is assumed to increase discomfort, and the hypothesis is that there is an inverted-U relationship between negative affect and aggression. This phenomenon would imply that at intermediate levels of discomfort aggression would be facilitated, but at more severe levels aggression would be inhibited. Anger in a cool condition or the absence of anger in a hot condition would produce the optimum level of aggression.

Baron & Ransberger (56) reported the number of riots in the United States as a function of ambient temperature. Carlsmith & Anderson (57) pointed out that the Baron & Ransberger study had not taken the number of days in different temperature ranges into account. When this variable was controlled for, the conditional probability of a riot increased monotonically with temperature.

While several researchers have noted irritation or apathy in subjects experimentally exposed to cold, social behavior has not been the focus of systematic study. One study concerning the willingness of passersby to help others showed no inhibitory effect of extreme temperatures (58).

Thus no simple main effects of thermal stimulation on social behavior have been indicated. In the subdomain that has attracted most of the empirical studies, heat and aggression, any demonstrable effects of heat seem to be mediated by or interacting with, eg, feelings of negative affect.

Concluding remarks

Recent theoretical development in the area of thermal stress and performance implies a movement away from single unidimensional concepts such as body temperature, arousal, or distraction as the stimulus or mediating mechanism. The movement is towards more differentiated concepts such as dynamic or static body temperature or profiles of thermal effects with respect to alertness, selectivity, speed, accuracy, and short-term memory. A characteristic of this latter development is the attempt to relate the profile of thermal stress to other stressors, such as noise, time of day, sleep loss, boredom. Thereby an integration of behavioral effects across stressors is on its way.

In general, the more complex the task at hand, the more likely it will deteriorate with heat or cold. Most manual performance measures are sensitive to effects of cold. Simple reaction time increases with heat but is little affected by cold. Complex reaction time slows down in heat, and more errors are made in cold. Vigilance tasks and dual tasks seem to have an optimal range from around 27 to 32°C ET. Tracking tasks seem to deteriorate in the same range. Learning tasks seem to reach their optimum in the comfort zone around 21°C, while tasks in which the correct response consists of finding an unusual or unlikely answer, such as creative tasks, benefit from temperatures closer to 27°C, at which arousal is assumed to be low.

Social behaviors, such as aggression or helpfulness, do not seem to have direct main effects from thermal stress. The effects reported are mediated by or in interaction with, eg, anger and feelings of negative affect.

References

1. Ramsey JD, Burford CL, Beshir MY, Jensen RC. Effects of workplace thermal conditions on safe work behavior. J Saf Res 1983;14:105—14.
2. McIntyre DA. Indoor climate. London: Applied Science Publishers, 1980.
3. Mutchler JE, Vecchio JL. Empirical relationships among heat stress indices in 14 hot industries. Am Ind Hyg Assoc J 1977;38:253—9.
4. Beshir MY. A comprehensive comparison between WBGT and Botsball. Am Ind Hyg Assoc J 1981;42: 81—7.
5. Smith AP, Ottmann W. Einfluss von Umgebungsfaktoren auf die psychische Leistung. In: Kleinbeck U, Rutenfranz J, ed. Arbeitspsychologie. Göttingen: Verlag für Psychologie, 1987.
6. Bell PA, Greene TC. Thermal stress: physiological, comfort, performance and social effects of hot and cold environments. In: Evans G, ed. Environmental stress. Cambridge: Cambridge University Press, 1982:75—104.
7. Easterbrook JA. The effect of emotion on cue utilization and the organization of behavior. Psychol Rev 1959;66:183—201.
8. Hockey R, Hamilton P. The cognitive patterning of stress states. In: Hockey R, ed. Stress and fatigue in human performance. New York, NY: John Wiley & Sons, 1983:331—62.
9. Cohen S, Evans GW, Stokols D, Krantz DS. Behavior, health and environmental stress. New York, NY: Plenum Press, 1986.
10. Hancock PA. Sustained attention under thermal stress. Psychol Bull 1986;99:263—81.
11. Ramsey JD. Heat and cold. In: Hockey R, ed. Stress and fatigue in human performance. New York, NY: John Wiley, 1983:33—60.
12. Roberts MF, Wenger CB, Stolwijk JAJ, Nadel ER. Skin blood flow and sweating changes following exercise training and heat acclimation. J Appl Physiol 1977;43: 133—7.
13. Wyndham CH, Morrison JF, Williams CG. Heat reaction of male and female caucasians. J Appl Physiol 1965;20:357—64.
14. Hellström B. Local effects of acclimatization to cold in man. Oslo: Universitetsförlaget, 1965.
15. Enander A, Sköldström B, Holmér I. Reactions to hand cooling in workers occupationally exposed to cold. Scand J Work Environ Health 1980;6:58—65.
16. Enander A. Performance and sensory aspects of work in cold environments: a review. Ergonomics 1984;27: 365—78.
17. Fox WF. Human performance in the cold. Hum Factors 1967;9:203—20.
18. Provins KA, Clarke RSJ. The effect of cold on manual performance. J Occup Med 1960;3:169—76.
19. Clark RE. The limiting hand skin temperature for unaffected manual performance in the cold. J Appl Psychol 1961;45:193—4.
20. Lockhart JM, Kiess HO, Clegg TJ. Effect of rate and level of lowered finger surface temperature on manual performance. J Appl Psychol 1975;60:106—13.
21. Clark RE, Jones CE. Manual performance during cold exposure as a function of practice level and the thermal conditions of training. J Appl Psychol 1962;46:276—80.
22. Enander A. Sensory reactions and performance in moderate cold. Solna (Sweden): National Institute of Occupational Health, 1986:VI:1—VI:17. (Arbete och hälsa 1986:32.)
23. Meese GB, Kok R, Lewis MI, Wyon DP. A laboratory study of the effects of moderate thermal stress on the performance of factory workers. Ergonomics 1984;27: 19—43.
24. Grether WF. Human performance at elevated environmental temperatures. Aerosp Med 1973;44:747—55.
25. Davies DR, Parasuraman R. The psychology of vigilance. London: Academic Press, 1982.
26. Teichner WH. Reaction time in the cold. J Appl Psychol 1958;42:54—9.
27. Ellis HD. The effects of cold on the performance of serial choice reaction time and various discrete tasks. Hum Factors 1982;24:589—98.
28. Ellis HD, Wilcock SE, Zaman SA. Cold and performance: the effects of information load, analgesics, and the rate of cooling. Aviat Space Environ Med 1985; 56:233—7.
29. Enander A. Effects of moderate cold on performance

of psychomotor and cognitive tasks. Ergonomics 1987; 30:1431—45.
30. Lockhart JM. Ambient temperature and the flicker-fusion threshold. J Exp Psychol 1971;87:314—9.
31. Kobrick JL, Fine BJ. Climate and human performance. In: Oborne DJ, Gruneberg MN, ed. The physical environment at work. Chichester (England): John Wiley & Sons, 1983.
32. Ramsey JD, Morrissey SJ. Isodecrement curves for task performance in hot environments. Appl Ergon 1978;9: 66—72.
33. Teichner WH, Kobrick JL. Effects of prolonged exposure to low temperature on visual-motor performance. J Exp Psychol 1955;49:122—6.
34. Mackworth NH. Researches on the measurement of human performance. London: Her Majesty's Stationery Office, 1950. (Medical Research Council special report series 268.)
35. Pepler RD. The effect of climatic factors on the performance of skilled tasks by young European men living in the tropics: 4. a task of prolonged visual vigilance. London: Medical Research Council, Royal Naval Research Committee, Applied Psychology Unit, 1953. (Report no 156/53.)
36. Pepler RD. Warmth and performance: an investigation in the tropics. Ergonomics 1958;2:63—88.
37. Viteles MS, Smith KR. A experimental investigation of the effect of change in atmospheric conditions, and noise upon performance. Heat Piping Air Cond 1946;8:107—12.
38. Hancock PA. Effect of environmental temperature on display monitoring performance: an overview with practical implications. Am Ind Hyg Assoc J 1984;45:122—6.
39. Poulton EC, Hitchings NB, Brooke RB. Effects of cold and rain upon the vigilance of lookouts. Ergonomics 1965;8:163—8.
40. Mackie RR, O'Hanlon JF. A study of the combined effects of extended driving and heat stress on driver arousal and performance. In: Mackie RR, ed. Vigilance: theory, operational performance and physiological correlates. New York, NY: Plenum Press, 1977:537—58.
41. Bursill AE. The restriction of peripheral vision during exposure to hot and humid conditions. Q J Exp Psychol 1958;10:113—29.
42. Azer NZ, McNall PE, Leung HC. Effects of heat stress on performance. Ergonomics 1972;15:681—91.
43. Bell CR, Provins KA, Hiorns RF. Visual and auditory vigilance during exposure to hot and humid conditions. Ergonomics 1964;7:279—88.
44. Bell PA. Effects of noise and heat stress on primary and subsidiary task performance. Hum Factors 1978;20: 749—52.
45. Pepler RD, Warner RE. Temperature and learning: an experimental study. ASHRAE Trans 1968;74:211—9.
46. Wyon DP. Studies of children under imposed noise and heat stress. Ergonomics 1970;13:598—612.
47. Wyon DP. The effects of moderate heat stress on the mental performance of children. Stockholm: National Swedish Institute for Building Research, 1969. (Report no D8/69.)
48. Wyon DP, Andersen I, Lundqvist GR. The effects of moderate heat stress on mental performance. Scand J Work Environ Health 1979;5:352—61.
49. Davis FM, Baddeley AD, Hancock TR. Diver performance: the effect of cold. Undersea Biomed Res 1975;2: 195—213.
50. Vaughan WS Jr. Distraction effect of cold water on performance of higher-order tasks. Undersea Biomed Res 1977;4:103—16.
51. Coleshaw SRK, Van Someren RNM, Wolff AH, Davis HM, Keatinge WR. Impaired memory registration and speed of reasoning caused by low body temperature. J Appl Physiol 1983;55:27—31.
52. Griffitt W, Veitch R. Hot and crowded: influences of population density and temperature on interpersonal affective behavior. J Pers Soc Psychol 1971;17:92—8.
53. Griffitt W. Environmental effects on interpersonal affective behavior: ambient effective temperature and attraction. J Pers Soc Psychol 1970;15:240—4.
54. Baron RA, Bell PA. Aggression and heat: the influence of ambient temperature, negative affect, and a cooling drink on physical aggression. J Pers Soc Psychol 1976; 33:245—55.
55. Bell PA, Baron RA. Environmental influences on attraction: effects of heat, attitude similarity and personal evaluations. Bull Psychon Soc 1974;4:479—81.
56. Baron RA, Ransberger VM. Ambient temperature and the occurrence of collective violence: the "long hot summer" revisited. J Pers Soc Psychol 1978;36:351—60.
57. Carlsmith JM, Anderson CA. Ambient temperature and the occurrence of collective violence: a new analysis. J Pers Soc Psychol 1979;37:337—44.
58. Schneider FW, Lesko WA, Garrett WA. Helping behavior in hot, comfortable and cold temperatures: a field study. Environ Behav 1980;12:231—40.