Ergonomics

ISSN: 0014-0139 (Print) 1366-5847 (Online) Journal homepage: http://www.tandfonline.com/loi/terg20

Effects of heat on visual acuity

J. HOHNSBEIN , C. PIEKARSKI , B. KAMPMANN & Th. NOACK

To cite this article: J. HOHNSBEIN , C. PIEKARSKI , B. KAMPMANN & Th. NOACK (1984) Effects of heat on visual acuity, Ergonomics, 27:12, 1239-1246, DOI: 10.1080/00140138408963605

To link to this article: https://doi.org/10.1080/00140138408963605

Published online: 30 May 2007.

ERGONOMICS, 1984, VOL. 27, NO. 12, 1239–1246

Effects of heat on visual acuity

By J. HOHNSBEIN, C. PIEKARSKI, B. KAMPMANN and Th. NOACK
Institut für Arbeitsphysiologie, Ardeystrasse 67, D-4600 Dortmund, F.R. Germany

Visual acuity of nine subjects was measured with Landolt 'C's during 3 hours of exposure to either (*i*) a neutral control, (*ii*) a warm humid or (*iii*) a hot dry atmosphere. The luminance of the background was either 450 cd/m^2 or 5 cd/m^2. Simultaneously, rectal temperature and heart rate were recorded as indicators of thermal strain. A significant loss of visual acuity, linearly correlated with thermal strain, was found in both lighting conditions.

1. Introduction

Several studies have shown that heat stress can reduce performance in complex sensory–cognitive–motor tasks (Viteles and Smith 1946, Mackworth 1950, Pepler 1958, 1960, Rutenfranz *et al.* 1971, Wenzel and Ilmarinen 1977, Repperger *et al.* 1978). In order to determine in which of the components (sensory, cognitive or motor) a reduction occurs, we investigated, in an earlier study (Hohnsbein *et al.* 1983), the effect of heat stress on visual contrast sensitivity (see, for example, Braddick *et al.* 1978) alone by measuring the visibility of sinusoidally modulated gratings in a neutral control, a hot dry and a warm humid climate. We found for both of our subjects that warmth caused a significant loss of contrast sensitivity at high spatial frequencies but not at low ones which suggests a loss of visual acuity.

Although measurement of the contrast sensitivity function yields more information about the visual system than an ordinary test of visual acuity (Woodhouse and Barlow 1982), the exact relation between these two measures does not seem to be quite clear. We have now tested the visual acuity of nine subjects by a conventional method (Landolt 'C's) in the same climatic conditions as used in our previous investigation.

2. Methods

2.1. *Measurement of visual acuity*

Acuity was measured using Landolt 'C' patterns. The Landolt ring consists of a line whose thickness is one-fifth the outer diameter. The gap width is also one-fifth the outer diameter (Deutsche Normen 1974). Acuity is defined as the reciprocal of the width (in minutes of arc) of the gap; thus, a width of 1·0 min arc corresponds to an acuity of 1·0, or in Snellen notation of 6/6 (or 20/20). The size of our 'C's corresponded to decimal acuity levels between 0·1 and 2·0 in steps of 0·1 at a viewing distance of 5 m. Four 'C's were presented on each acuity level simultaneously, the gap being distributed randomly over eight possible positions (0°, 45°, ..., 315°). The four 'C's were painted in black on a white background (contrast near 0·9). The luminance of the background (size: 10° × 10° visual angle) was either 450 cd/m^2 ('bright') or 5 cd/m^2 ('dim'). The subjects had to identify verbally the position of the gaps. The test at each acuity level was repeated three times in an irregular order with new positions of the gaps. Thus, the subjects could name between 0 and 12 positions correctly on each acuity level. They did not get any feedback about their performance.

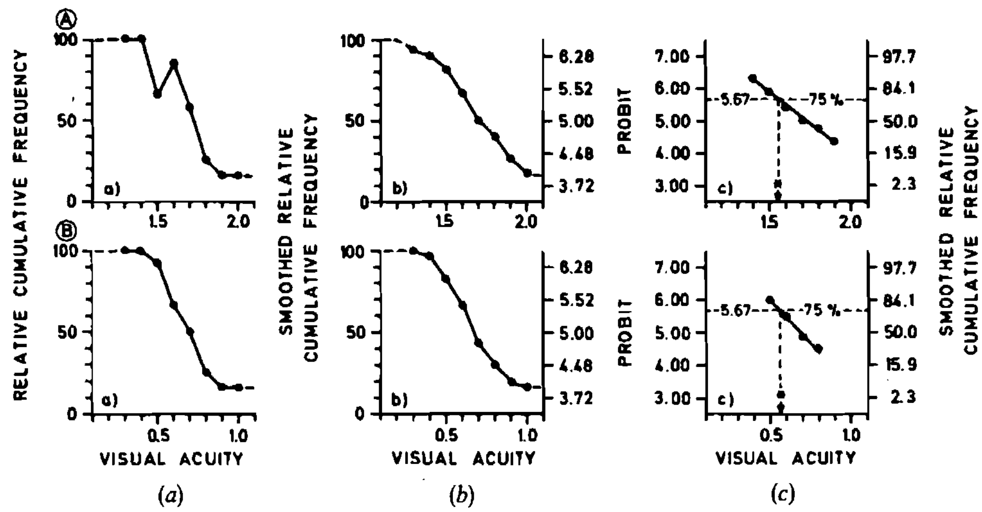

Figure 1. Graphical illustration of the determination of the '75% correct visual acuity level' (subject WJ) in the bright (A) and dim (B) visual situation. (*a*) Percentage 'or more' ogive for correct identifications of Landolt 'C's as a function of decimal acuity (1/min arc). (*b*) Smoothed percentage ogive; non-linear probit scale on the right allows transformation from percentages to probits. (*c*) Least-squares fit between 4·33 probits (25%) and 6·28 probits (90%); * denotes 75% correct visual acuity level.

To determine the visual acuity, the identification of a Landolt 'C' was considered as a partly statistical process. If an identification of a Landolt 'C' on a given acuity level was correct, it could indicate either an accidentally correct guess (probability 0·125) or this or a higher level of visual acuity was reached at that moment. The frequency of correct identifications (in percent of 12) over the acuity level yielded the relative 'or more' cumulative frequency distribution (see figure 1). This distribution was numerically smoothed by a running-average calculation: $n_i = (n_{i-2} + n_{i-1} + n_i + n_{i+1} + n_{i+2})/5$ for the bright condition and $n_i = (n_{i-1} + n_i + n_{i+1})/3$ for the dim condition; a wider window had to be chosen in the bright condition (*i*) since the values in the region of transition (between the '100% correct' level and the 'pure guessing' level (12·5%)) showed more scatter and (*ii*) because the region of transition was usually broader compared with the dim condition.

The smoothed relative cumulative frequencies were transformed to probits (Finney 1980). On a linear probit scale that part of the distribution between 6·28 probits (90%) and 4·33 probits (25%) was linear to a very good approximation. (The lower boundary was chosen since, because of guessing, the frequency distribution approaches 12·5% rather than 0%.) The equation for the least-squares line was calculated and the visual acuity at 5·67 probits (75% correct acuity level) determined. The effects on the data of these steps are illustrated in figure 1.

2.2. *Climatic conditions*

The climatic conditions used were identical to those of our previous experiment: the hot dry condition, ambient temperature 50°C, relative humidity 10%; the warm humid condition, ambient temperature 38·5°C, relative humidity 65%; and the control condition, ambient temperature 29°C, relative humidity 40%. The climates were kept constant within 0·1°C for both ambient and wet-bulb temperatures. There was no difference between the ambient and radiation temperature. Air speed near the subjects was kept at 0·3 m/s. The subjects were clothed only in shorts. The two warm conditions were quite stressful for unacclimatized subjects, and were chosen to mimic rather extreme natural or industrial environments (Wenzel and Pickarski 1982, Piekarski and Wenzel 1983).

The climates were produced in two adjacently located climatic chambers which are described in detail elsewhere (Wenzel *et al.* 1980). In one chamber (I) only the control climate (c) for the first and fifth test was established and in the other chamber (II) the three experimental climates for the second, third and fourth test were (see §2.3).

2.3. *Experimental programme*

All subjects participated in a training session at room temperature. The purpose of this session was to familiarize the subjects with the chambers and the tests. Then the subjects, two at a time, conducted the experiments on 3 days (1 day for each climate). The sequence of the climates was varied for the subjects. In order to avoid acclimation, a pause of at least 2 days was observed between two hot conditions.

The programme of each day took about 5 hours (it is illustrated in figure 2): (*i*) 30 min rest, lying on a couch in a quiet room at uncontrolled room temperature; (*ii*) 30 min in chamber I in the control climate, sitting on a chair—in the first 20 min the acuity measurements were made (and two further perceptual tests, the results of which will be communicated elsewhere); (iii) 2 hours 50 min in chamber II in one of the experimental climates, sitting on a chair—the acuity tests and perceptual measurements were made 30, 90 and 150 min after the beginning of this phase; (*iv*) 40 min rest in a quiet room (see (*i*)); (*v*) 20 min in chamber I (see (*ii*)), repeat of the tests.

Throughout the whole programme rectal temperature and heart rate were recorded continuously as physiological strain parameters. In order to equalize circadian influences all sessions started at the same time of day, namely 8·00 a.m. for one subject and 30 min later for the other subject.

2.4. *Subjects*

Subjects were nine healthy men between 19 and 34 years of age. Their visual acuity was, where necessary, fully corrected and the mean lay close to 1·7 (75% correct with both eyes open) as measured with our experimental procedure (see above). All men were physically fit. All nine men were tested in the bright luminance condition, six of the nine were also tested in the dim one.

2.5 *Statistics*

Statistical analysis of the data was performed on a DEC/VAX computer. For the calculation of the ANOVAs the BMDP-77 program P2V (Brown 1977) was applied. Conventional methods (see, for example, Sachs 1978) were used in the estimation of coefficients of linear correlation, including corrections for small sample sizes (r^*), the tests of significance of these coefficients and the calculations of least-squares regression lines.

3. Results

3.1. *Rectal temperature and heart rate*

Figure 2 shows the rectal temperature and the heart rate schematically. For each subject the mean over a sampling period of 5 min (designated by a black bar) was calculated as the individual's rectal temperature or heart rate during that time interval.

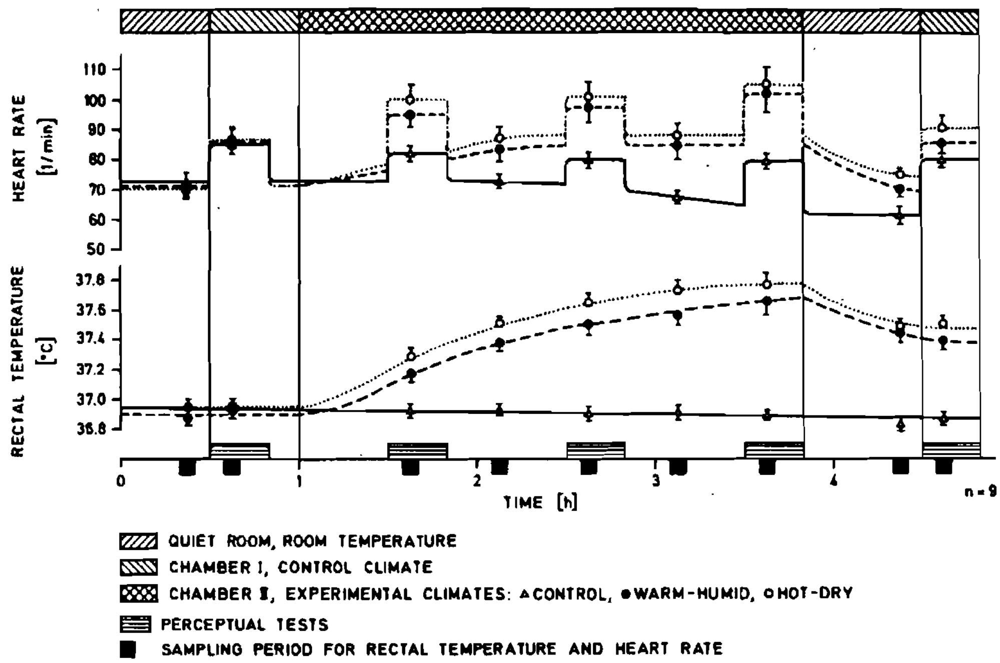

Figure 2. Rectal temperature and heart rate over time elapsed in experimental session. Curves fitted half-schematically by eye. Time of perceptual tests denoted by hatched bar (bottom). Periods of individual sampling of rectal temperature and heart rate denoted by black bar (bottom). Points and error bars indicate mean value (±S.E.) for nine subjects.

In the figure the mean of these individual values (±S.E., $n=9$) was drawn and the curves were fitted by eye.

The rectal temperature increased continuously during both of the almost 3 hours long hot sessions; no clear steady state was reached. In agreement with subjective assessments asked for in a questionnaire, the hot dry climate was the most straining condition for most subjects. This result can also be found in the curves of the heart rate. It is interesting to note that an increase in heart rate, above that induced by heat, occurred during the perceptual tests. This will be discussed in detail elsewhere.

3.2. *Effects of learning*

In order to test whether acuity changed as a result of practice during the course of the study, the first acuity measurement on each day (made under control conditions in chamber I) was tested with a one-way ANOVA. No significant order effect was found in either the bright (nine subjects; $p=0{\cdot}16$) or dim (six subjects; $p=0{\cdot}34$) condition. In any case, the sequence of the experimental climates was different for the subjects, so that possible learning effects would not have influenced the results systematically.

3.3. *Visual acuity*

Figure 3 shows the visual acuity over time of exposure to the different climates, for the bright and dim conditions, averaged across the subjects. Both heat conditions cause a systematic reduction of acuity, with a general greater reduction under the hot dry

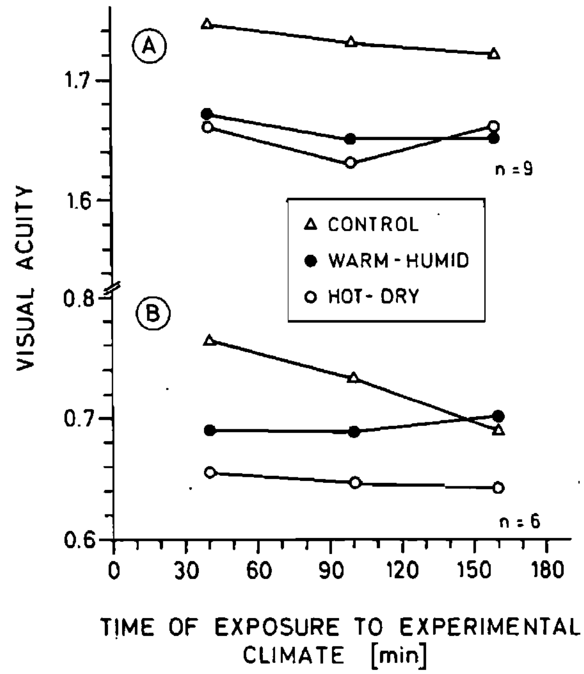

Figure 3. Visual acuity over time of exposure to experimental climate (chamber II)—(A) bright and (B) dim visual condition.

condition. A two-way ANOVA performed on the individual data showed a significant effect of climate for both luminance conditions (bright: $p=0{\cdot}029$; dim: $p=0{\cdot}010$). Neither time of exposure (bright: $p=0{\cdot}501$; dim: $p=0{\cdot}177$) nor climate × exposure (bright: $p=0{\cdot}933$; dim: $p=0{\cdot}240$) were significant. Thus, the apparent drop in acuity with time for the dim-luminance control condition is not statistically significant. Averaged over time of exposure, acuity in the bright condition dropped from 1·73 in the neutral climate to 1·66 in the warm humid climate and to 1·65 in the hot dry climate. The corresponding mean values for the dim condition were 0·73 (neutral), 0·69 (warm humid) and 0·65 (hot dry).

3.4. *Visual performance and strain parameters*

We also investigated whether a correlation exists between visual acuity and thermal strain, as measured by elevated rectal temperature or increased heart rate. Rectal temperature is shown in the left-hand panels of figure 4, where each data point is the mean across observers of rectal temperature and visual acuity during one measurement period under a single climate condition. The right-hand side of figure 4 shows the corresponding mean data for heart rate. It is evident that both measures of thermal stress correlate negatively with acuity, and that the effect is similar for both the bright and dim condition. Similar correlations are found if the individual data for all observers are analysed as a group. Because of the scatter in these data, statistical significance is, in general, only found in the group data: similar plots for individual subjects show the same trend as the group data, but seldom reach significance.

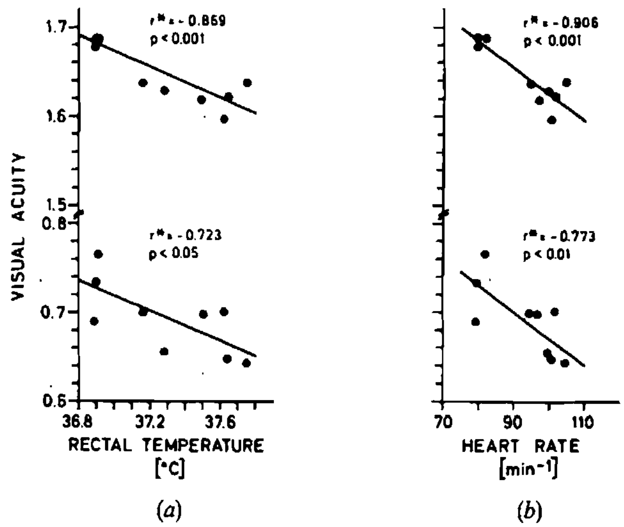

Figure 4. Correlation between visual acuity and heat-induced physiological strain, as measured by (*a*) rectal temperature and (*b*) heart rate for the bright (top) and dim (bottom) visual condition. Points give means for nine subjects in the bright and six in the dim condition. r^* indicates the coefficient of linear correlation corrected for small sample size ($n=9$); p gives the significance of r^*. Lines are the least-squares regressions.

4. Discussion

In a previous investigation with two subjects we observed an increasing loss of contrast sensitivity in elevated temperatures. The loss increased with increasing spatial frequency (Hohnsbein *et al.* 1983). We believe, for two reasons, that this is a specific effect of heat on the visual system and not a general distressing effect of heat: first, no comparable effect was detectable at low spatial frequencies; and second, the effect occurred within roughly 30 min of exposure to heat.

The high frequency boundary of the contrast sensitivity function corresponds to visual acuity (see, for example, Woodhouse and Barlow 1982). We therefore expected that heat would also reduce acuity. The exact relations, though, between contrast sensitivity (a threshold phenomenon) and traditionally measured visual acuity are not quite clear. In this series of experiments we used a conventional method for the measurement of visual acuity, namely Landolt 'C's. In order to increase the sensitivity of the method the procedures to determine the '75% correct level of visual acuity' had to be somewhat elaborate (see §2). The luminance of the background ($10° \times 10°$ visual angle) was 450 cd/m^2, which represents a 'daylight' situation, and 5 cd/m^2, which corresponds to the mean screen luminance of our previous contrast sensitivity experiments.

Our present results are compatible with the results of our previous investigation. In both hot conditions visual acuity was reduced compared with a control climate. The main reduction occurred within 30 min of exposure to heat; and more severe heat stress was more effective in the reduction of acuity. It is worth noting that although the absolute levels of visual acuity were quite different in the dim and bright visual situations the heat-induced changes were very similar.

It has been shown that human performance in non-physical tasks can stay constant over a wide range of heat strains and that only extremely high strains eventually lead to an abrupt deterioration (Rutenfranz *et al.* 1971). Our results do not support this conclusion. Figure 4 illustrates that visual acuity was linearly correlated with rectal temperature as a measure of heat strain. As rectal temperature and heart rate under heat stress are strongly correlated (Wenzel and Piekarski 1982), it is no surprise that a significant correlation between heart rate and acuity was also observed. Again, these findings are very similiar in the dim and bright visual condition. Our results are compatible with results of investigations showing continuous reduction of performance (sensory perception tasks) in heat conditions (see, for example, Mackworth 1950, Viteles and Smith 1946). Campbell and Green (1965) reported a frequency-specific loss of contrast sensitivity due to a (artifical) reduction of the refractive power of the eye. We considered this a possible explanation for our previous results on a heat-induced, frequency-specific loss of contrast sensitivity (Hohnsbein *et al.* 1983). To assume a heat-induced myopia could also explain the presently reported effects of heat on visual acuity.

The practical significance of these results should be evaluated within the context that an increasing number of jobs which are performed under conditions of heat stress are changing their nature from pure physical labour to psychophysical or sensory–motor tasks (e.g. control activities). Under these new, and purely understood, conditions the worker may find his sensory–motor capacity pushed to its limit. We suggest that when this occurs, relatively small changes in visual acuity may seriously degrade performance.

Acknowledgment

The authors thank Professor C. R. Cavonius, Institut für Arbeitsphysiologie, Dortmund, for critical comments on the manuscript.

L'acuité visuelle de 9 sujets a été mesurée à l'aide des anneaux (C) de Landolt pendant une exposition de trois heures, soit à une condition de référence neutre, soit à une ambiance chaude-humide, soit à une ambiance très chaude-sèche. L'éclairage du fond était soit 450 cd/m, soit 5 cd/m. On a enregistré simultanément la température rectale et la fréquence cardiaque en tant qu'indicateurs de la charge thermique. Pour les deux conditions d'éclairage on a observé une détérioration significative de l'acuité visuelle, correlée linéairement avec la charge thermique.

Bei 9 Versuchspersonen wurde die Sehschärfe mit Landolt-Ringen während dreistündiger Exposition in einem (*i*) neutralen Kontrollklima, (*ii*) einem feucht-warmen oder (*iii*) einem trockenheißen Klima gemessen. Die Leuchtdichte des Hintergrundes betrug entweder 450 cd/m^2 oder 5 cd/m^2. Gleichzeitig wurden Rektaltemperatur und Herzfrequenz als Parameter thermischer Beanspruchung registriert. Unter beiden Beleuchtungsbedingungen wurde ein signifikanter Rückgang der Sehschärfe festgestellt, der mit der thermischen Beanspruchung linear korreliert war.

9名の被験者の視力を3つの条件下でランドルト環を用いて測定した。3つの条件とは，(i)平常状態のコントロール，(ii)温暖湿潤，(iii)高温乾燥の環境で，各条件とも被験者を3時間放置した。背景照度は450と5 cd/㎡とした。熱による負担の指標として，直腸温と心拍数を同時に測定した。両方の照明条件下において，熱による負担と一次相関を示す視覚機能の有意な低下が見られた。

References

BRADDICK, O., CAMPBELL, F. W., and ATKINSON, J., 1978, Channels in vision: basic aspects. In *Handbook of Sensory Physiology*, Vol. VIII (Edited by R. HELD, H. W. LEIBOWITZ and H. L. TEUBER) (Berlin: SPRINGER-VERLAG), pp. 3–38.

BROWN, M. B., (editor), 1977, *BMDP-77 Biomedical Computer Programs P-Series*. (Berkeley, California: UNIVERSITY OF CALIFORNIA PRESS).

CAMPBELL, F. W., and GREEN, D. G., 1965, Optical and retinal factors affecting visual resolution. *Journal of Physiology*, **181**, 576–593.

DEUTSCHE NORMEN. 1974, DIN 58220, Sehschärfebestimmung (Berlin and Köln: BEUTH-VERTRIEB).

FINNEY, D. J., 1980, *Probit Analysis* (Cambridge: CAMBRIDGE UNIVERSITY PRESS).

HOHNSBEIN, J., PIEKARSKI, C., KAMPMANN, B., 1983, Influence of high ambient temperature and humidity on visual sensitivity. *Ergonomics*, **26**, 905–911.

MACKWORTH, N. H., 1950, *Researches on the Measurement of Human Performance*. Medical Research Council, Special Report Series, Vol. 268 (London: H.M.S.O.).

PEPLER, R. D., 1958, Warmth and performance: an investigation in the tropics. *Ergonomics*, **2**, 63–88.

PEPLER, R. D., 1960, Warmth, glare and a background of quiet speech: a comparison of their effects on performance. *Ergonomics*, **3**, 68–73.

PIEKARSKI, C., and WENZEL, H. G., 1983, Das Arbeitsklima. In *Praktische Arbeitsphysiologie*, Aufl. 3 (Edited by W. ROHMERT and J. RUTENFRANZ) (Stuttgart: THIEME VERLAG), pp. 227–266.

REPPERGER, D. W., SMILES, K. A., NEFF, J. A., and SUMMERS, W. C., 1978, A feature selection approach in evaluation of parameter changes on the human operator under thermal stress. *Ergonomics*, **21**, 35–48.

RUTENFRANZ, J., WENZEL, H. G., SINGER, R., MOCELLIN, R., and HAWEL, W., 1971, *Einfluß hoher Umgebungstemperaturen auf die Leistung und einige physiologische Größen bei einer Tracking- und einer optischen Vigilanz-Aufgabe*. Forschungsberichte des Landes Nordrhein-Westfalen, No. 2200 (Opladen: WESTDEUTSCHER VERLAG).

SACHS, L., 1978, *Angewandte Statistik* (Berlin: SPRINGER VERLAG).

VITELES, M. S., and SMITH, K. R., 1946, An experimental investigation of the effect of change in atmospheric conditions and noise upon performance. *Heating, Piping, and Air Conditioning*, **18**, 107–112.

WENZEL, H. G., and ILMARINEN, R., 1977, Effects of environmental heat on performance and some physiological responses of a man during a psychomotor task. *Journal of Human Ergology*, **6**, 139–152.

WENZEL, H. G., and PIEKARSKI, C., 1982. *Klima und Arbeit*, 2. Aufl., Bayerisches Staatsministerium für Arbeit und Sozialordnung, München.

WENZEL, H. G., PIEKARSKI, C., KAMPMANN, B., ANDORF, P., and SCHULZ, P., 1980, Klimasimulation industrieller Arbeitsplätze im Laboratorium. In *Arbeitsbedingte Gesundheitsschäden—Fiktion oder Wirklichkeit*? Bericht über die 20. Jahrestagung der Deutschen Gesellschaft für Arbeitsmedizin e.V. in Innsbruck vom 27.–30.4. 1980 (Edited by W. BRENNER, J. RUTENFRANZ, E. BAUMGARTNER and M. HAIDER) (Stuttgart: GENTNER-VERLAG), pp. 577–579.

WOODHOUSE, J. M., and BARLOW, H. B., 1982, Spatial and temporal resolution and analysis. In *The Senses* (Edited by H. B. BARLOW and J. D. MOLLON) (Cambridge: CAMBRIDGE UNIVERSITY PRESS), pp. 133–164.

Manuscript received 12 January 1984.
Revised manuscript received 1 March 1984.