THE EFFECTS OF MODERATE HEAT STRESS AND OPEN-PLAN OFFICE NOISE DISTRACTION ON OFFICE WORK

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ABSTRACT
Thirty subjects clothed for comfort at 22°C performed simulated office work for 3 hours at 22/26/30°C (7.4 g/kg dry air, i.e. 45/35/28 %RH) in quiet and recorded open-plan office noise (55 dBA) conditions. Warmth decreased perceived air quality (P<0.01) and increased odour intensity (P<0.05) and stuffiness (P<0.01). After 2 hours, forehead sweating was observed on 4/36/76% of subjects (P<0.001), while 0/21/65% felt "warm" or "hot" (P<0.001). Raised temperature increased eye, nose and throat irritation and headache intensity (P<0.05) and decreased concentration (P<0.05) and self-estimated performance (P<0.001). Noise increased fatigue (P<0.05) and decreased concentration (P<0.05) but did not interact with any thermal effects on subjective perception. In an Addition task, noise decreased the workrate by 3% (P<0.05), subjects who felt warm made 56% more errors (P<0.05) and there was a noise-temperature interaction (P<0.01): noise removed the effect of warmth on errors. Noise increased typing speed (P<0.05) and reading speed (P<0.05).

INDEX TERMS
Office noise, Distraction, Heat stress, SBS, Performance

INTRODUCTION
In warm thermal environments and in the absence of conscious effort to the contrary, the human body will tend to respond adaptively by lowering internal heat production, so as to reduce or avoid sweating. This unconscious behavioural adjustment may lead to lower arousal and a slower work rate. Several studies have shown that very moderate heat stress can negatively affect mental performance (Wyon, 1996), but optimal performance may not occur under conditions providing optimal thermal comfort, as was found when subjects performed mental work at air temperatures in the range 20-30°C (Pepler and Warner, 1968). They performed best at 20°C, although most of them felt uncomfortably cold at this temperature. They reported exerting the least effort and performed the least work at 27°C, at which temperature they were the most thermally comfortable. In another experiment, subjects clothed for comfort at two different air temperatures performed sedentary work (Wyon et al. 1975). Self-estimated effort, arousal and fatigue did not differ between the two air temperatures, and although the subjects perceived the air to be fresher in the cool air/warm clothing condition, performance did not differ significantly between the two conditions. This study was carried out in clean air with 40 air changes per hour. Later field studies at more realistic levels of air pollution have shown a powerful effect of air temperature on SBS symptoms (Jaakkola et al., 1989, Krogstad et al., 1991), which may in turn reduce performance.

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Loud noise is assumed to raise arousal and has been found to counteract the effect of moderate heat stress on industrial performance (Wyon et al., 1978). Subjects were industrial workers and were exposed to noise levels of 50 or 85 dBA, so these findings are not necessarily applicable to the office environment. However, tasks involving short-term memory may be negatively affected when noise masks "inner speech" (Salamé and Baddeley, 1982, 1987). Sudden changes in the acoustic environment, including onset and cessation of noise, may cause distraction and thus have negative effects on performance. Many workplace complaints about noise concern irrelevant but clearly audible speech and it seems likely that the information content of the speech is the main determinant of its intrusiveness (Kjellberg, 1990). Noise may lead to a more superficial processing of text when reading and to impaired comprehension. In a study of proof-reading under two different noise conditions (Jones and Broadbent, 1979), subjects read significantly fewer words in "loud" noise (80 dBC) than in "soft" noise (55 dBC) and errors were significantly more frequent in the loud noise. Intermittent noise during proof-reading lowered the detection rate for complicated errors which required comprehension of the text for their identification (Weinstein, 1974, 1977). Speech effects on the performance of a proof-reading task were found to be dependent on whether the speech was meaningful, independent of the noise level, in the range 50 to 70dBA (Jones et al., 1990). The present study examines moderate heat stress effects on the performance of office work in the presence or absence of recorded open-office noise replayed at the realistic level of 55 dBA.

METHODS

Design: The experiment was carried out as a 3x2 repeated-measures design (3 thermal and 2 acoustic conditions) in a low-emission office space (LxWxH = 6x6x3 m^3) used for air quality experiments (Wargocki et al. 2000). The air conditioning equipment and the loudspeakers used to create the experimental conditions were concealed behind a 2m high partition. Circulation fans ensured that air on both sides of it was well mixed. There were six workstations, each consisting of a table, a table lamp, a chair and a computer monitor connected to a personal computer (PC).

IAQ conditions: The experiment included three air temperature levels: 22°C, 26°C, and 30°C. The air temperature of 22°C meets the design criteria for a Category A landscaped office during the heating season (CEN, 1998), while 26°C is just outside the range for Category A during the cooling season. The temperature of 30°C is not unrealistically high for naturally ventilated office environments under summer conditions, even in temperate regions. The absolute humidity content of the office air was maintained at 7.4 g/kg, corresponding to 45%, 35% and 28% RH, to simulate a building without humidification or dehumidification. The PMV equation predicts that 26% and 72% of subjects clothed for comfort at 22°C would be dissatisfied with the 26°C and 30°C conditions, respectively (Fanger, 1972). The outdoor air supply was 90 L/s, corresponding to 3.0 air changes per hour, or 15 L/s/person with 6 subjects present.

Noise conditions: The background noise level in the unoccupied office originated mainly from the fans and was very low ($L_{eq,A}$=35 dB), meeting the requirements for a Category A landscaped office. This was the reference condition. Subjects were not allowed to speak to each other during the sessions but during the text-typing task, keyboard noise increased the overall level to about 50 dBA. The noise distraction condition used in the experiment was a high-fidelity simulation of the noise in a typical open-plan office in which about 50 people are working, played back through a set of loudspeakers concealed by the partition. Recordings of conversations and telephone signals made in a real open-plan office were added. They were of varying length (6-546 seconds, averaging 126 seconds) and were inserted at random intervals, resulting in clearly-audible conversations during 53% of the total exposure time. None occurred more than once. The recording masked the ventilation noise and the amplification was adjusted to provide an equivalent sound pressure level of 55 dBA, which is typical for open-plan offices.

Measurements: Air temperature and relative humidity, operative temperature, CO_2 concentration indoors and outdoors, ventilation rate were continuously recorded. Noise and lighting level were sampled intermittently. Finger skin temperature was measured on several occasions during the experimental sessions as an objective indicator of the subject's thermal state. At the same time, the subject's forehead was covertly noted as being matt, shiny or having visible drops of sweat (Andersson et al. 1975). Based on the CO_2 concentration measured outdoors and in the middle of the occupied space, the average metabolic rate of the subjects was calculated. The calculations were made for each group separately following the procedure given in ISO8996 (1990), assuming a respiratory quotient of 0.85. Subjects rated their thermal sensation, their perceptions of the indoor environment and the intensity of a number of SBS symptoms on standard questionnaires and during each exposure they performed standard tasks simulating different aspects of office work: text-typing, proof-reading, addition, creative thinking (Wargocki et al., 2000) and a diagnostic test of cue-utilisation capacity which is performed better at low arousal (Wyon, 1969).

Subjects: Fourteen female and 16 male subjects aged 18-29 were recruited for the experiment. The inclusion criteria were: familiar with the use of a computer, non-smoker, currently healthy and not suffering from any chronic diseases, asthma, allergy or hay-fever. Subjects were screened for normal olfactory sense and hearing and none were excluded on these grounds. Subjects were randomly assigned to experimental groups of six.

Procedure: Subjects were trained in the performance tasks and in the subjective reporting procedure. Each experimental group of 6 was then exposed on the same day of the week for six successive weeks, meeting a different experimental condition each week in randomized order. Reporting each day at 13:30, they spent 20 minutes at 22°C in a room close to the experimental office, where they adjusted their clothing for comfort while performing a multiplication task. They entered the experimental office at 14:00 for an exposure period of 3 hours, and were allowed to adjust their clothing only during those sessions when the air temperature was 22°C. On three occasions during the session, subjects performed a step-exercise to simulate normal activity, walking up to and over a two-step up, two-step down staircase, then back to their desks. After the exposure, subjects breathed fresh air for 2 minutes and then returned to the office to record perceived air quality as visitors to an office in which bio-effluents are present.

RESULTS

Table 1 shows the results of the physical measurements, and estimated metabolic rates. The environment in the office varied systematically as intended, except that the measured relative humidity was slightly above the intended level on average. The difference was small (max. 9% RH), the actual level being higher than intended under all conditions. Note that keyboard noise during the typing task reduced the difference in measured noise level between the quiet and office-noise conditions. Based on measurements of CO_2 concentrations and recorded occupancy, calculations indicate that subjects' metabolic rate increased significantly at higher temperatures (ANOVA: $P<0.001$). A Newman-Keuls test indicates that metabolic rates at the three temperatures differed significantly from each other ($P<0.05$). The metabolic rate was highest in the 30°C office noise condition, although the main effect of noise on estimated metabolic rate was not significant. Finger temperatures increased significantly with air temperature (Friedman ANOVA: $P<0.001$) and the percentage of subjects with observable forehead sweating in the last two hours of exposure increased likewise (Table 2: Chi-square on 2 df = 60.251, $P<0.001$).

Environmental perception: On entering and after 120 minutes, the reported acceptability of the noise level was affected significantly by whether the noise recording was being played ($P<0.01$). The reported levels indicate that 4% and 68% of a random sample of the population would be dissatisfied with the two noise conditions. There was no adaptation to noise. Both thermal sensation and thermal acceptability were significantly affected by increased temperature (ANOVA: $P<0.001$), on which noise had no significant effect. Upon entering the office, 0%, 2% and 22% of the subjects experienced a thermal sensation of PMV>=2 ("warm" or warmer) at 22°C, 26°C and 30°C, respectively. After 120 minutes of occupation the proportions increased to 0%, 21% and 65%, pooling data from both noise conditions. The overall acceptability of the indoor environment was found to be significantly affected both by noise (ANOVA: $P<0.05$) and by increased temperature (ANOVA: $P<0.001$). Increasing air temperature significantly decreased perceived air quality (ANOVA: $P<0.001$): Upon entering the office, 5%, 34% and 88% were dissatisfied with air quality at 22°C, 26°C and 30°C, respectively. There were no significant effects of temperature on perceived humidity, but the air was perceived as more stuffy at higher temperatures (ANOVA: $P<0.001$) both upon entering and after 120 minutes of exposure. Odour intensity was generally perceived as weak (between "no odour" and "moderate odour") and these ratings increased significantly with increasing temperature ($P<0.05$) both with and without bioeffluents, i.e. on re-entering and on first entering.

SBS: Perceived irritation of the mucous membranes of the eyes, nose and throat was low, below "slight irritation", but Friedman non-parametric ANOVA shows it was affected by temperature ($P<0.05$), except for irritation of the eyes upon entering the office. In testing the directional hypothesis that temperature increases the irritation of mucous membranes, the Page L-test shows a significant effect of temperature for all irritation scales, both on entering and on re-entering the office ($P<0.05$). Neither odour intensity nor irritation of mucous membranes was affected by noise. The intensity of several common SBS symptoms increased with noise and/or temperature (Table 3). No effects approached significance in the unexpected direction.

Performance: Self-estimated performance decreased at raised temperatures ($P<0.001$) but not in noise. In an addition task, office noise decreased the rate of performance by 3% ($P<0.05$), subjects who felt too warm made 56% more errors ($P<0.05$) than subjects who reported feeling thermally neutral and there was a noise-temperature interaction ($P<0.01$): noise removed the effect of warmth on errors. There were no significant main effects of noise or temperature, and no significant interaction between them, on the Tsai-Partington test of cue-utilization or on the creative thinking task. Applying the Page L-test in each noise condition separately to test the hypothesis that raised temperatures decrease arousal and increase cue-utilization yielded a significant result in the office noise condition only ($P<0.05$). In the open-ended creative thinking task, performance as measured by the normalized C-score was higher at the intermediate temperature of 26°C in the quiet, as expected, and was reduced at 30°C in the office noise condition, but only the latter tendency yielded an apparently significant effect of temperature in noise ($P<0.05$). Typing speed ($P<0.05$) and reading speed in a proof-reading task (P<0.05) were higher in the office noise condition than in the quiet, with no significant thermal effects.

Table 1. Measurements recorded in each of the six experimental conditions

	22℃, 35dBA	*26℃, 35dBA*	*30℃, 35dBA*	*22℃, 55dBA*	*26℃, 55dBA*	*30℃, 55dBA*
Air temperature (°C)	22.2	25.9	29.9	22.3	25.8	29.7
Operative temperature (°C)	22.4	26.0	29.7	22.5	26.0	29.7
Relative humidity (%)	50	43	34	50	41	37
Absolute humidity (g/kg)	8.2	9.0	9.0	8.2	8.6	9.8
L_{eq}dBA while typing (2x40m)	53	53	53	56	56	56
Outdoor air supply (L/s)	88	92	88	88	91	90
CO_2 (ppm)	666	704	763	685	729	694
Metabolic rate (met)	0.99	1.06	1.27	0.99	1.10	1.32
Lighting level, (lux)	895	660	635	770	770	925
Finger temperature (°C)	30.1	33.5	34.9	30.6	33.6	34.9

Table 2. Observed forehead sweating, pooling noise conditions (P<0.001)

Condition of forehead	*22℃*	*26℃*	*30℃*
Matt	51 (96%)	38 (64%)	13 (24%)
Shiny	2 (4%)	21 (36%)	39 (71%)
Visible sweat drops	0	0	3 (5%)
No. of observations	53	59	55

Table 3. Significant P-values for effects on reported SBS-symptom intensity

Increased:	*Office noise*	*Air Temperature*
Headache		0.01
Difficulty in thinking		0.01
Difficulty in concentrating	0.05	0.01
Fatigue	0.05	0.05

DISCUSSION AND CONCLUSIONS

Thermal and noise conditions very common in offices today have negative effects on health and performance. They additively decrease subjective acceptability but may interact with each other in their effects on performance. Raised temperatures have negative effects on a range of common SBS symptoms, while open-office noise distraction does not, although it does increase difficulty in concentration and fatigue. In these short exposures noise had a stimulating effect on some routine tasks, which may well have caused the perceived effect of noise on fatigue.

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