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The Mental Performance of Subjects Clothed for Comfort at Two Different Air Temperatures

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Thirty-two subjects (16 male and 16 female students aged 18–25 yr) performed sedentary work in a climate chamber under two different conditions. The subject wore a light standard clothing (0·6 clo) on one occasion and a heavy clothing ensemble (1·15 clo) on the other. Each subject was exposed singly, for 2·5 hr on each occasion. During the exposures the air temperature was continuously adjusted up or down at the subject's request, as indicated on a dial voting apparatus, so that he remained in thermal comfort. Skin temperatures were measured throughout. Performance measures were obtained on a numerical addition task, a recognition memory task, and on a test of cue-utilization. Subjects rated their effort, arousal and fatigue, and the freshness of the air on semantic differential scales. No significant differences in performance could be shown between the two conditions. Subjective effort, arousal and fatigue did not differ, but subjects considered that the air was fresher in the cool air/heavy clothing condition. Skin temperatures were significantly less uniform over the body surface in this condition, although the average skin temperature was the same under both conditions. Male subjects maintained a significantly higher mean skin temperature and a significantly higher evaporative weight loss under both clothing conditions than did female subjects. However, there were no significant differences between the air temperatures preferred by male and female subjects. The average preferred air temperature was 23·2° and 18·7°C for 0·6 and 1·15 clo, respectively.

1. Introduction

Thermal comfort is a function of clothing, activity level, air temperature, thermal radiation, air velocity and humidity. The combinations of these six factors resulting in thermal comfort are predicted by the comfort equation of Fanger (1970).

Although a state of thermal comfort can be achieved under many different combinations of the above parameters, it does not necessarily follow that all combinations are exactly equivalent in terms of their suitability for the performance of mental work. When comfort is achieved at a low air temperature by wearing heavy clothing, there is a local cooling of the head, hands and respiratory system that is not present when comfort is achieved at a high air temperature with light clothing. There is a lower limit to air temperature below which these local cooling effects become uncomfortable in themselves, but above this limit the added stimulus provided by the local cooling might conceivably improve alertness and the performance of mental work. The purpose of the present study is to investigate whether such a direct effect of air temperature on alertness and mental performance does exist for subjects in thermal comfort.

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2. Method

2.1. *Climate Chamber*

The experiments were carried out in the climate chamber of the Laboratory of Heating and Air Conditioning, Technical University of Denmark, which has been described in detail by Fanger (1970 *op. cit.*). The radiant temperature was maintained equal to air temperature, relative humidity at 50%, and air velocity below 0·1 m/sec. Dust concentration and odour level were kept low by the use of high efficiency dust filters and activated charcoal filters, and by keeping the air change in the chamber at 40/hr (1700 m^3/hr).

2.2. *Subjects*

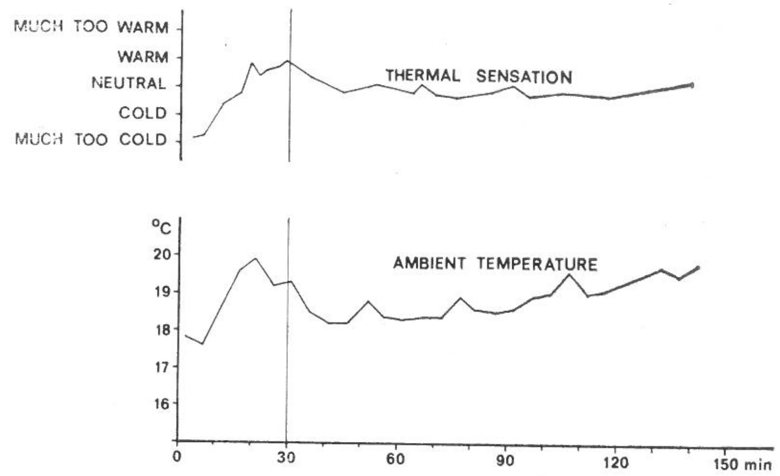
Thirty-two subjects took part in the experiment, 16 male and 16 female students aged 18–25 yr. The average height and weight of the male subjects was 1·79 ± 0·07 m, 69·3 ± 9·2 kg; of the female subjects, 1·67 ± 0·07 m., 55·7 ± 7·2 kg. All subjects were volunteers who were paid for participating in the experiments. Only persons in good health were allowed to participate. Subjects took part in the experiment only if they had had a full night's sleep prior to each exposure, were free from fever, had consumed no alcohol in the previous 24 hours and had eaten a normal meal about one hour before the start of the exposure. All experiments took place during July, August and September 1971.

2.3. *Clothing*

Each subject was exposed singly for 2·5 hr on each of two separate days. The exposures took place during the afternoon in each case, and were either on successive days or with as few days as possible between exposures. On one occasion the subject wore a light clothing assembly with a thermal resistance of 0·6 clo. This was the Kansas State University standard uniform, described by Rohles and Nevins (1971), comprising cotton twill shirt and trousers, cotton underpants and cotton sweat socks (no shoes). On the other occasion the subject wore a heavy clothing assembly with a thermal resistance of 1·15 clo, consisting of three pairs of cotton tracksuit trousers over cotton underpants, two cotton tracksuit tops, a thick woollen sweater, three pairs of woollen socks and a pair of light moccasins. This assembly fitted quite tightly. The clo-values were measured on a thermal manikin (Seppanen *et al.* 1972) at Kansas State University. The order in which the subjects wore the two clothing assemblies was balanced in the design.

2.4. *Thermal Comfort*

Throughout each exposure the subject indicated his thermal comfort sensation on a dial voting apparatus, making new settings whenever and as often as appropriate. The apparatus was connected to an indicator outside the chamber, and the ambient temperature (mean radiant temperature = air temperature) was altered up or down as necessary to ensure that the subject's response remained within the comfort zone marked on the dial, as close to exact thermal neutrality as possible. The figure shows an example of the variation of the ambient temperature and the thermal sensation during an experiment. A stable condition of thermal comfort could almost always be achieved within the first half-hour. The comfort temperature is then taken as the mean of the measurements obtained in the last two hours of the experiment.



An example of the variation of the ambient temperature and the thermal sensation during an experiment with a subject clothed at 1·15 clo. Calculation of the mean value of the ambient temperature is based on measurements taken during the last two hours of the experiment.

2.5. *Physiological Measurements*

The subject wore a harness with 14 thermistors taped to the skin. The thermistors were distributed evenly over the body surface as reported by Olesen *et al.* (1972). Central body temperature was measured with a rectal thermistor probe. All temperatures were registered every five minutes by means of a data recording system outside the chamber, *i.e.* without disturbing the subject in any way. Evaporative weight loss was measured by weighing the subject initially, after 0·5 hr in the chamber, and at the end of the exposure.

2.6. *Performance*

2.6.1. *Addition test*

Subjects worked at a test consisting of the addition of sets of five 2-digit numbers throughout each exposure, with the exception of the short periods during which the other tests were performed. Subjects were paid a small amount for each unit correctly completed when working, and at a flat rate that was slightly less than their average earning rate, when resting. They were free to take rest periods at any time. The duration and number of rest periods were registered by requiring subjects to replace their pen in a holder when not working. A micro-switch on the holder made it possible to register when this occurred. It was pointed out to subjects that if they took a rest period without replacing their pen in the holder, it would continue to be regarded as a work period, and they would thus be earning nothing during that time.

2.6.2. *Word memory test*

Half an hour after the start of each exposure, a list of 25 common words, chosen at random from a much longer list, was read to the subject, each word being simultaneously presented visually. The subject then worked through a list of 50 common words, including the 25 that had been presented. The subject was not told that all the 25 'target' words were included in the list.

His task was to classify each word as seen/unseen, and each answer as certain/uncertain. Two hours later the same list of 50 words was presented, arranged in a different random order, and was to be similarly classified. Parallel versions were used for the two conditions in a balanced design.

2.6.3. *Cue-utilisation test*

At the end of each exposure, before the second presentation of the word list, subjects performed one of two parallel versions of the *Tsai-Partington test*, described by Ammons (1955). Twenty-five circles containing letters or numbers, placed at random on a page, must be linked by drawing a line through 1–A–2–B– and so on. The score was taken as the number of correct links made in 35 seconds. Performance of this test is known to be adversely affected by a high level of arousal (Eysenck and Willett 1962), and moderate heat stress has been shown by Wyon (1969) to improve performance of the test, probably by lowering arousal.

2.6.4. *Subjective judgements*

At the end of each 2·5 hr exposure, subjects were asked to assess their arousal and fatigue, the freshness of the air, and the effort they had exerted by marking four semantic differential scales. Each scale consisted of a line 20 cm long with the mid-point clearly marked, and opposite ends labelled with words of opposing meaning. The four word pairs, which were of course in Danish, may be roughly translated as alert/sleepy (arousal scale), fresh/fatigued (fatigue scale), fresh/stuffy (freshness scale) and slight/strong (effort scale). The distance of each mark from the end of the scale was measured in millimetres and converted to percentage of full scale for analysis.

2.7. *Information to the Subjects*

No mention of performance testing under two different thermal conditions was made to the subjects. Instead, they were told that thermal comfort during light office work was under investigation, and that as the temperature might be changed during the exposures, they should frequently indicate their state of thermal comfort on the dial voting apparatus. They would be reminded to do so by means of a lamp signal if more than 10 min elapsed. They were instructed in the use of the dial voting apparatus. They would be reminded to do so by means of a lamp signal if more than 10 min elapsed. They were instructed in the use of the dial voting apparatus and the pen-holder, and introduced to the word memory and cue-utilization tasks by completing reduced versions of the tasks prior to their first exposure.

3. Results

3.1. *Preferred Air Temperatures*

Tables 1 and 2 show the average air temperatures preferred by each subject under the two clothing conditions, for male and female subjects respectively. Each value in the tables is the average temperature preferred during the last two hours of each exposure. The first eight subjects in each table experienced the lighter clothing condition first.

No significant difference can be shown between male and female subjects under either condition. Taken together, both sexes preferred an average of

Table 1. Preferred ambient temperatures and physiological data for male subjects

Subject no.	Preferred ambient temperature °C		Mean skin temperature °C		Forehead skin temperature °C		Hand skin temperature °C		Evaporative weight loss g/h/m²	
	0·6 clo	1·15 clo	0·6 clo	1·15 clo	0·6 clo	1·15 clo	0·6 clo	1·15 clo	0·6 clo	1·15 clo
1	21·4	16·9	32·7	32·8	33·2	31·5	32·0	32·4	24·8	18·7
2	23·1	18·6	32·4	32·8	33·2	32·7	33·1	31·8	16·4	11·5
3	25·3	20·6	33·5	33·2	34·6	34·2	34·9	34·2	23·1	20·8
4	23·1	19·0	33·1	33·2	33·8	33·0	31·8	30·7	17·3	16·0
5	21·6	17·6	32·6	33·2	34·6	33·5	32·8	31·5	18·9	13·0
6	24·0	17·6	34·0	33·9	34·4	34·0	34·7	32·4	27·4	30·1
7	25·2	19·0	33·4	32·8	35·0	33·3	34·7	32·7	16·5	22·7
8	22·3	18·2	33·0	33·0	33·2	32·9	31·6	30·4	27·1	15·9
9	24·7	21·4	33·4	33·7	34·9	34·1	33·7	31·8	16·8	22·0
10	23·9	17·2	33·7	33·6	33·3	31·8	33·4	31·0	19·4	24·6
11	24·5	23·6	33·7	34·2	34·5	34·1	32·9	33·5	21·3	20·6
12	22·0	16·7	32·5	32·7	34·7	32·7	31·7	31·4	22·7	27·8
13	23·2	18·7	33·4	33·2	34·4	33·0	33·5	32·1	27·4	22·4
14	23·3	17·2	33·7	33·9	33·8	30·6	34·6	33·9	23·3	24·0
15	22·7	17·3	32·3	32·3	34·1	31·5	32·0	31·6	21·3	21·1
16	24·2	17·9	33·9	33·3	34·9	33·7	33·5	31·4	19·6	12·9
Mean	23·4	18·6	33·2	33·2	34·2	32·9	33·2	32·1	21·5	20·3
SD	1·2	1·9	0·6	0·5	0·7	1·1	1·2	1·1	3·9	5·3

Table 2. Preferred ambient temperatures and physiological data for female subjects

Subject no.	Preferred ambient temperature °C 0·6 clo	1·15 clo	Mean skin temperature °C 0·6 clo	1·15 clo	Forehead skin temperature °C 0·6 clo	1·15 clo	Hand skin temperature °C 0·6 clo	1·15 clo	Evaporative weight loss g/h/m² 0·6 clo	1·15 clo
17	24·1	18·1	33·1	32·1	33·6	29·9	32·1	26·9	18·1	12·7
18	24·3	18·3	33·7	33·6	34·1	33·4	31·6	31·0	15·2	16·1
19	21·3	19·8	32·2	32·4	33·9	32·6	31·8	30·6	9·7	8·7
20	23·4	20·2	32·1	32·1	34·0	32·4	30·7	29·3	4·3	8·5
21	20·9	15·6	32·2	32·3	34·6	32·5	30·5	29·6	15·5	11·6
22	24·0	20·2	32·6	32·4	33·4	33·2	31·5	29·7	16·9	12·0
23	24·8	21·9	32·5	32·9	34·0	31·6	33·6	34·1	10·3	13·6
24	21·9	19·8	32·1	32·5	32·6	30·4	30·8	30·9	9·0	16·8
25	23·5	19·5	32·8	32·4	34·2	32·4	30·8	28·9	12·5	16·0
26	23·5	19·3	33·4	33·2	34·5	32·3	33·7	31·7	20·9	10·3
27	19·1	14·9	30·9	31·1	33·2	31·0	26·9	26·9	14·3	22·3
28	21·6	18·6	32·8	33·4	34·4	33·5	31·3	31·5	22·3	25·4
29	26·0	21·6	33·6	33·4	34·6	33·7	31·1	28·1	—	7·9
30	22·8	19·3	33·4	33·0	34·4	33·7	31·7	31·4	8·8	11·3
31	22·7	15·7	33·0	32·3	34·7	32·4	31·5	28·6	16·9	19·4
32	23·0	19·4	33·9	34·6	34·4	32·8	33·2	32·3	17·9	23·9
Mean	22·9	18·9	32·8	32·7	34·0	32·4	31·4	30·1	14·2	14·8
SD	1·7	2·0	0·8	0·8	0·6	1·1	1·6	2·0	5·0	5·4

23·2°C in the light clothing, 18·7°C in the heavy clothing. These values are lower than would be expected for sedentary resting subjects; comfort temperatures of 25·6 and 22·5°C, respectively, are obtained from Fanger's equation, assuming a metabolic rate of 58 watt/m² (50 kcal/h/m²) under both clothing conditions. However, it is probable that subjects performing mental work consciously or unconsciously maintain a higher muscular tonus than when merely resting, and that their metabolic rate is therefore somewhat higher than the value conventionally assumed for resting subjects. If the above procedure is reversed, and the observed comfort temperatures are used in the equation to calculate the probable metabolic rate of the subjects, a value of 78 watt/m² is obtained under both clothing conditions.

There was a tendency ($0·05 < p < 0·10$) for the between-subjects variance of preferred air temperature to be greater in the heavy clothing condition. The tabulated values of the standard deviation are 1·5°C at 0·6 clo, and 2·0°C at 1·15 clo.

3.2. *Physiological Measurements*

Tables 1 and 2 show also the mean skin temperature, forehead skin temperature, hand skin temperature and evaporative weight loss for each subject. The evaporative weight loss was calculated from the weighings after 0·5 hr and 2·5 hr, corrected for the difference between CO_2 loss and O_2 gain. The mean rectal temperature was found to be $37·0 \pm 0·3$°C, with no difference either between sexes or between conditions, and is therefore not shown. As expected, mean hand skin temperatures were significantly less in the heavy clothing condition ($p < 0·05$), as were also mean forehead skin temperatures ($p < 0·001$). These values are for a two-tail sign test on the tabulated data, for each sex separately. Subjects therefore did not choose their comfort temperatures under the two conditions so as to maintain a constant skin temperature on the hand or forehead, though they were free to do so. Rather, they chose to maintain their mean skin temperature and evaporative loss constant under the two conditions; there were no significant differences between conditions for these parameters, either for male or female subjects. This finding is in accordance with the assumptions underlying Fanger's comfort equation.

There were no significant differences between male and female subjects in terms of the air temperature chosen for comfort. A *Kruskal-Wallis analysis* of the tabulated data (Siegel 1956) yields *chi-square* values of 0·540 and 1·410 on one degree of freedom, for light and heavy clothing conditions respectively. These values do not approach significance. However, male subjects maintained higher hand skin temperatures (*c.* 2°C, $p < 0·01$) and higher evaporative weight losses (*c.* 5 g/hr m², $p < 0·01$) than did female subjects, although their mean skin temperature was only slightly higher (*c.* 0·5°C; $0·05 < p < 0·10$ at 0·6 clo; $p < 0·05$ at 1·15 clo). These differences, even where formally significant, are not large. 5 g/hr m² corresponds to only about 3 W/m², or 4% of the total metabolic heat production.

3.3. *Performance*

The results of the performance measurements during the last two hours of the exposures are set out for each subject in Tables 3 and 4, for male and female subjects respectively. The subject identifications are unchanged, and thus

Table 3. Performance data for male subjects: addition, Tsai–Partington

Subject no.	Addition: units/hour 0·6 clo	Addition: units/hour 1·15 clo	Addition: % mistakes 0·6 clo	Addition: % mistakes 1·15 clo	Addition: no. pauses/hour 0·6 clo	Addition: no. pauses/hour 1·15 clo	Addition: total pause time % 0·6 clo	Addition: total pause time % 1·15 clo	Tsai–Partington: units completed 0·6 clo	Tsai–Partington: units completed 1·15 clo
1	282	364	14·2	9·0	2·5	1·0	9·3	3·6	11	18
2	236	241	3·3	3·7	1·0	0·5	1·8	2·8	9	15
3	167	112	8·1	3·7	1·5	1·0	13·6	16·0	12	11
4	197	173	9·1	8·6	4·0	4·5	20·6	18·9	12	13
5	314	346	6·9	5·9	3·0	3·0	9·1	6·3	16	17
6	304	383	2·2	3·4	3·0	1·5	17·4	1·7	14	19
7	296	317	4·1	4·6	1·5	2·5	5·3	6·9	6	14
8	179	244	10·0	10·5	0·5	2·0	1·7	7·1	11	13
9	418	310	2·9	4·5	8·0	4·0	12·8	3·8	16	20
10	304	285	3·9	7·6	0·0	0·0	0·0	0·0	16	12
11	413	307	8·8	10·9	2·5	2·0	12·8	8·7	21	12
12	569	548	2·2	4·4	2·0	2·5	2·6	1·7	17	19
13	267	168	5·6	8·3	1·0	3·5	13·8	20·3	11	11
14	186	219	4·5	5·1	4·5	6·0	15·8	6·8	12	13
15	250	249	2·9	1·6	3·5	3·5	9·8	9·8	14	16
16	275	232	17·3	22·7	0·5	0·5	2·0	1·4	8	5
Mean	291	281	6·6	7·2	2·4	2·4	9·3	7·2	12·9	14·3

Table 4. Performance data for female subjects: addition, Tsai–Partington

Subject no.	Addition: units/hour 0·6 clo	Addition: units/hour 1·15 clo	Addition: % mistakes 0·6 clo	Addition: % mistakes 1·15 clo	Addition: no. pauses/hour 0·6 clo	Addition: no. pauses/hour 1·15 clo	Addition: total pause time % 0·6 clo	Addition: total pause time % 1·15 clo	Tsai–Partington: units completed 0·6 clo	Tsai–Partington: units completed 1·15 clo
17	181	240	3·2	1·8	0·5	0·5	5·6	3·8	21	19
18	214	259	13·0	12·1	2·5	1·0	17·0	11·7	14	16
19	168	176	5·7	5·0	1·5	0·5	18·8	7·7	12	8
20	207	241	5·6	6·0	0·5	1·0	2·2	2·8	14	14
21	167	179	4·8	4·2	2·0	2·0	12·6	13·4	16	17
22	245	287	3·3	1·6	0·0	0·0	0·0	0·0	8	6
23	230	188	4·9	5·3	1·5	1·0	11·3	12·5	10	15
24	401	405	5·7	4·9	0·0	0·5	0·0	0·8	11	13
25	303	259	6·0	8·8	4·5	5·0	24·5	19·2	20	14
26	271	248	2·6	7·2	2·0	2·5	10·0	6·2	17	12
27	266	231	9·3	10·3	1·5	2·0	5·1	10·5	18	18
28	417	252	14·5	9·2	1·5	2·5	3·7	5·8	16	15
29	189	177	0·7	1·3	0·5	1·5	10·0	9·3	11	10
30	424	367	10·4	12·3	0·5	0·5	0·6	0·7	11	16
31	236	215	4·0	6·5	1·5	1·5	2·7	5·0	9	11
32	268	261	7·1	7·2	1·0	0·5	7·4	8·8	13	7
Mean	262	249	6·3	6·5	1·3	1·4	8·2	7·4	13·8	13·2

the first eight subjects in each table again are those that experienced the lighter clothing condition first. *Wilcoxon's matched-pairs signed-ranks analysis* (Siegel 1956 *op. cit.*) was used to test for differences in performance between conditions and between first and second day of testing. *Kruskal-Wallis analysis* was again used to examine the significance of differences between the sexes. These analyses are non-parametric, i.e. no assumptions about the distributions are necessary. They assume only ordinal measurement.

3.4. *Addition*

Comparison between the two clothing conditions was made for rate of working, percentage error, number of voluntary pauses taken, and the total duration of such rest periods. No significant differences could be shown. In order to examine the sensitivity of the method, the difference in performance between first and second day of testing was examined. On the second day subjects worked 12% faster and made 20% fewer mistakes. Both of these differences could be shown to be significant at the 0·05 level.

3.5. *Recognition Memory*

The frequency of correct and incorrect recognitions in each of the four possible response categories was derived. The ratio between the cumulative proportions of correct recognitions and 'false positive' recognitions for each response category (from 'certain no' through 'uncertain no', 'uncertain yes', to 'certain yes') was taken as defining the ROC curve (Receiver Operating Characteristic) of signal detection theory. As suggested by Green and Swets (1966), the dimensionless area under the curve was derived and taken as a convenient non-parametric measure of recognition memory performance. It is independent of the certainty criterion used by each subject. The values are tabulated in Tables 5 and 6; they lie between chance performance 0·5 and perfect performance 1·0. Decimal points have been omitted in the Tables. No significant differences could be shown between clothing conditions in this test, either for short or longer term recognition memory, or for the difference between these two, which is a measure of forgetting. Short term memory was found to be significantly better ($p < 0{\cdot}01$) on the second day, improving from 0·884 to 0·931, a 12% improvement when related to chance performance (0·5). For longer-term memory the corresponding change was from 0·828 to 0·840, a 3·6% improvement which could not be shown to be significant.

3.6. *Tsai-Partington*

No significant differences could be shown between clothing conditions, or between male and female subjects. There was an average increase of 6% in the performance of this test on the second day, a difference that was significant at the 0·05 level. This data is shown in Tables 3 and 4.

3.7. *Subjective Judgements*

In Tables 5 and 6 the subjective judgements made by each subject on the four semantic differential scales are tabulated, expressed as percentage of full scale. Male subjects tended to exert more effort in the cool air condition, female subjects less, while for both sexes the tendency was for subjects to feel more alert and less tired and to judge the air less stuffy, when the air was cool

Table 5. Male subjects: recognition memory performance, subjective judgements

Subject no.	Short term memory: area under ROC 0·6 clo	Short term 1·15 clo	Longer term memory: area under ROC 0·6 clo	Longer term 1·15 clo	Arousal % full scale (1) 0·6 clo	Arousal 1·15 clo	Lack of fatigue % full scale (2) 0·6 clo	Lack of fatigue 1·15 clo	Effort % full scale (3) 0·6 clo	Effort 1·15 clo	Freshness of the air % full scale (4) 0·6 clo	Freshness 1·15 clo
1	762	832	700	698	25·0	71·5	26·0	80·0	50·0	50·0	62·0	78·5
2	920	794	818	674	41·5	35·0	50·0	50·0	50·0	50·0	50·5	50·5
3	846	920	718	802	58·5	30·0	47·5	46·0	29·5	22·5	53·0	73·5
4	891	909	694	812	57·5	45·0	32·5	49·0	68·5	52·5	50·0	75·5
5	888	901	906	642	42·5	62·0	27·5	69·5	61·0	50·0	41·0	76·0
6	858	1000	874	978	35·5	55·5	36·5	75·0	62·0	75·0	50·0	58·0
7	920	837	819	597	38·5	11·5	33·5	19·0	84·0	91·0	71·0	55·0
8	719	800	628	790	27·0	71·5	26·0	28·0	26·5	69·5	72·0	71·0
9	1000	902	916	802	52·0	52·5	53·5	52·5	90·5	96·5	54·0	53·0
10	1000	883	867	762	40·0	70·0	41·5	81·0	64·0	88·5	47·0	91·0
11	955	938	929	926	49·5	47·0	45·0	39·0	69·5	71·5	76·5	72·0
12	880	978	805	881	66·0	61·0	78·0	91·0	92·5	93·0	77·5	71·0
13	880	840	920	760	61·0	65·0	41·0	40·0	57·0	30·5	56·0	60·5
14	992	997	907	908	32·5	42·5	31·5	56·5	39·5	50·0	50·0	71·0
15	995	843	947	855	50·0	41·0	50·0	46·5	56·0	46·0	44·0	72·5
16	904	744	869	791	27·5	28·0	56·5	40·0	17·5	62·0	39·5	51·0
Mean	902	882	832	792	44·0	49·3	42·3	53·9	57·4	62·4	55·9	67·5

(1) 0% ~ sleepy, 100% ~ alert
(2) 0% ~ fatigued, 100% ~ fresh
(3) 0% ~ slight, 100% ~ strong
(4) 0% ~ stuffy, 100% ~ fresh

Table 6. Female subjects: recognition memory performance, subjective judgements

Subject no.	Short term memory: area under ROC		Longer term memory: area under ROC		Arousal % full scale (1)		Lack of fatigue % full scale (2)		Effort % full scale (3)		Freshness of the air % full scale (4)	
	0·6 clo	1·15 clo	0·6 clo	1·15 clo	0·6 clo	1·15 clo	0·6 clo	1·15 clo	0·6 clo	1·15 clo	0·6 clo	1·15 clo
17	884	938	774	819	27·5	56·0	36·0	54·0	42·5	46·0	37·0	58·0
18	908	980	849	936	15·0	39·0	27·0	39·0	18·5	13·5	76·5	90·5
19	807	960	825	940	27·5	29·0	28·5	48·0	61·5	59·0	50·0	86·5
20	921	996	874	874	27·5	61·0	35·0	61·0	27·5	27·5	15·0	86·0
21	979	999	957	978	76·0	50·0	74·5	50·0	50·0	28·5	74·5	72·5
22	957	938	969	938	52·0	50·0	12·0	12·0	50·0	58·5	50·0	55·0
23	886	949	834	706	38·0	47·0	43·0	47·5	57·0	49·5	31·0	67·0
24	830	920	660	880	52·5	42·0	52·5	59·5	48·0	51·0	54·5	41·5
25	853	923	757	822	51·0	46·5	54·5	40·5	50·5	44·0	59·5	51·5
26	937	846	827	794	50·0	46·0	50·0	47·0	49·0	53·0	59·5	69·0
27	940	958	834	890	57·5	65·0	55·0	62·5	46·5	17·5	69·5	75·5
28	1000	993	923	936	53·0	44·0	47·5	46·5	74·0	67·5	53·0	53·5
29	920	896	914	889	49·0	47·0	49·0	48·5	58·5	60·5	48·0	49·0
30	932	833	758	846	54·5	72·5	25·5	19·0	70·5	58·0	93·0	92·5
31	955	911	850	912	50·5	51·0	39·0	35·0	49·5	51·5	70·0	70·0
32	960	832	798	810	49·0	61·5	30·0	51·0	50·0	51·0	54·0	80·5
Mean	917	930	838	873	45·7	50·5	41·2	45·1	50·2	46·0	55·9	68·7

(1) 0% ~ sleepy, 100% ~ alert
(2) 0% ~ fatigued, 100% ~ fresh
(3) 0% ~ slight, 100% ~ strong
(4) 0% ~ stuffy, 100% ~ fresh

and they were wearing heavier clothing. The differences between conditions cannot be shown to be significant for judgements of alertness, fatigue or effort, but the *Wilcoxon matched-pairs signed-ranks test* shows that there was a significant tendency ($p < 0{\cdot}05$) to judge the air more fresh in the heavy clothing/cool air condition. This result is for a two-tail test, and is obtained for each sex separately. No differences can be shown between subjective judgements made on these four scales by male and female subjects, or on first and second days of exposure.

4. Discussion

The most important practical finding in this study is that the subjects worked equally well under both conditions. They found the air to be ‘ fresher ’ when it was cooler, but this did not cause them to work differently. No differences could be shown either in their rest-taking behaviour or in the various parameters of three quite different kinds of mental work. That this negative result is reliable, and not due to the insensitivity of the tasks used, is shown by the ease with which even small changes due to learning could be consistently demonstrated to be significant. If there was a difference in performance between conditions, it must have been considerably less than the demonstrated increases due to learning, *i.e.* the improvement of 12% in the speed of addition, the 12% improvement in memory performance, and the 6% improvement in cue-utilization capacity, for these changes were formally significant, while the differences between conditions did not approach significance. Speculation that thermal comfort achieved by a combination of cool air and heavy clothing would be either better for performing mental work, because it would be more stimulating, or worse, because of peripheral sensations of discomfort, than thermal comfort achieved by a combination of warm air and light clothing, are thus disproved by the present results for the case when exact thermal comfort can be individually achieved.

In the cool air/heavy clothing condition subjects judged the air to be more fresh, but they did not consider that this had affected their effort, arousal or fatigue. A similar effect of cool air was found by Langkilde *et al.* (1973) when the same semantic differential scales were used to evaluate a comfortable and a slightly too cool environment separated by 4°C.

Subjective responses to different combinations of air temperature and radiant temperatures were studied by McIntyre and Griffiths (1972), who found little evidence for an effect of air temperature on freshness at a constant level of subjective warmth. Their 16 subjects experienced a large number of conditions ranging from ‘ much too cold ’ to ‘ much too hot ’. The effect of air-radiant temperature differential on freshness was then examined by multiple regression analysis, and found to be in the expected direction of increased freshness in radiant, low air temperature environments, but small. It is possible that the effect is more marked for subjects in optimal comfort, as in the present experiment, and was therefore obscured by the statistical approach of examining the average effect over a much wider range of conditions.

In another experiment, McIntyre and Griffiths (1974) found that the addition of a sweater, estimated to contribute 0·3 clo to the total insulation value of their subjects' own light clothing, increased sensations of warmth but did not alleviate discomfort at the two air temperatures 15 and 19°C. Subjects were not asked to judge the freshness of the air in this experiment. Their hands felt warmer with the sweater but their feet were still as cold. The authors' conclusion, that a combination of low ambient temperature and high clothing insulation is less satisfactory than less clothing and a higher temperature, is at variance with the findings of the present experiment. Their conclusion is probably restricted to temperatures lower than 19°C where some parts of the body remained inadequately clothed.

In the present experiment the comfort temperatures chosen by the subjects under the two clothing conditions were such that their mean skin temperatures and evaporative losses were the same under both conditions. This is a very satisfactory confirmation of the basic postulate of Fanger's comfort equation, and is in agreement with earlier studies which showed that the mean skin temperature preferred by man is independent of clothing (Gagge *et al.* 1938, Olesen *et al.* 1972). In the cool air condition, the skin temperatures of the unclothed parts of the body were lower than in the warm air condition, but this was compensated by a corresponding increase in the skin temperature of the clothed parts of the body when the clothing insulation was nearly doubled.

The variation between subjects in the air temperatures chosen for comfort was greater in the cool air/heavy clothing condition. When performing mental work, differences in approach will have resulted in differing degrees of concentration and hence of metabolic rate, leading to larger differences between individuals in this respect than would be expected if they were resting. The inter-individual differences in preferred temperature were in fact greater in the present experiment than has been found for subjects not performing mental work (*cf.* Fanger 1973). Furthermore, the effect of differences in metabolic rate on the heat balance of the body is greater for heavy clothing (see for example, Figure 15, Fanger 1970 *op. cit.*), so that individual differences in preferred temperature that are a result of differences in metabolic rate between individuals will be greater than for light clothing, as was indeed found in the present experiment.

The average air temperatures chosen for comfort were much lower than would have been expected for sedentary subjects performing no mental work, the differences being consistent with an increase in metabolic rate from 58 to 78 watt/m^2 under both conditions. An increase of 20% in metabolic rate between resting and the performance of an addition task has been reported by von Eiff and Göpfert (1952), who attributed this to an unconscious increase in muscle tonus during the performance of concentrated mental work. Their addition task was similar to that used in the present experiment, and it is therefore possible that the apparent increase of 30% in the metabolic rate did occur on average over a 2·5 hr exposure. Alternatively, subjects may prefer to feel cooler when performing mental work than when resting. Griffiths and McIntyre (1975) dismiss both possibilities on the basis of an experiment in which subjects performed a paper and pencil task for 40 min, and then rested for 30 min, at an air temperature of 23°C that was judged on average to be rather warmer than neutral. They found no significant difference in thermal sensation or comfort between the working and resting conditions. It seems possible that the metabolic rate of their subjects was that appropriate to the exposure as a whole, and was not affected by the short working period in the clear-cut, rapid way that would have been necessary if thermal sensation was to change measurably in the 40 min between successive questionnaires. Experiments in which oxygen uptake is accurately and continuously measured during resting and during the performance of mental work, for subjects in exact thermal comfort, are clearly necessary, but will be difficult to perform without reducing the realism of the working situation and hence the relevance of the metabolic rate so measured. Meanwhile, an appropriate air temperature for comfort while performing concentrated sedentary mental work can evidently be calculated by assuming a metabolic rate of 75 watt/m^2, as recommended in any case by McIntyre (1973) for 'office work' as opposed to 'sitting at rest', for which he assumes the 60 watt/m^2 found appropriate in Fanger's experiments with sedentary subjects not performing mental work.

5. Conclusions

The performance of widely different kinds of mental work was shown to be reliably the same (*i.e.* the differences, if any, were considerably less than 10% on all parameters) under two conditions of thermal comfort, achieved in the one case with light clothing (0·6 clo) at an average air temperature of 23·2°C, and in the other case with heavy clothing (1·15 clo) at an average air temperature of 18·7°C. Subjects considered the air to be subjectively 'fresher' in the latter condition, in which there was also a greater diversity of preferred air temperature between subjects. Male and female subjects, wearing identical clothing, chose the same air temperatures for comfort, but male subjects maintained significantly higher skin temperatures and higher evaporative losses than female subjects under both conditions.

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Trente-deux sujets (16 étudiants et 16 étudiantes âgés de 18 à 25 ans) ont effectué un travail sédentaire dans une chambre climatique, sous deux conditions différentes. Les sujets étaient revêtus d'une vêture légère (0,6 clo) dans un cas et d'une vêture lourde (1,15 clo) dans l'autre. Chaque sujet a été exposé individuellement pendant 2½ heures. Durant l'exposition, la température de l'air a constamment été ajustée vers le haut ou vers le bas à la demande du sujet et selon les indications fournies par le cadran de l'appareil de mesure, de manière a maintenir constante le confort thermique. Les températures cutanées ont été relevées pendant toute l'exposition. Les performances ont été déterminées dans une tâche d'addition, dans une tâche de reconnaissance et dans une épreuve d'utilisation d'indices. Les sujets évaluaient leur effort, leur niveau d'éveil, leur fatigue ainsi que leur sensation thermique de l'air ambiant au moyen d'échelles de différenciateurs sémantiques. Aucune différence statistiquement significative n'est apparue entre les deux conditions en ce qui concerne les performances. On n'a pas noté non plus de différences dans l'effort subjectif, dans le niveau d'éveil et le degré de fatigue, mais les sujets ont estimé que l'air était plus frais dans la condition air frais—vêture lourde. Les sujets soumis à cette condition présentaient également des températures cutanées significativement plus dispersées selon les différentes régions du corps, bien que la température cutanée moyenne ait été la même dans les deux conditions. Les sujets de sexe masculin ont maintenu leur température cutanée moyenne à un niveau significativement supérieur à celui des sujets de sexe féminin. Il en était de même de la perte de poids par évaporation quelle que fût la condition de vêture. Cependant il n'y avait pas de différences significatives entre les températures ambiantes préférées des sujets masculins et celles des sujets féminins. La température de l'air préférée moyenne se situe à 23°2 C pour, 0,6 clo et à 18°7 C pour 1,15 clo.

16 Studenten und 16 Studentinnen im Alter von 18 bis 25 Jahren leisteten Arbeit im Sitzen in einer Klimakammer unter zwei verschiedenen Bedingungen. Unter der einen Bedingung trug die Person eine leichte Standard-Kleidung (0·6 clo), unter der anderem Bedingung eine schwere

Kleidungsausrüstung (1·15 clo). Jede Person wurde einzeln in jedem Versuch 2·5 Stunden dem Klima ausgesetzt, wobei die Lufttemperatur fortwährend nach ober und unten dem Verlangen der Versuchsperson angepasst wurde, wie sie es an einem Anzeigegerät angab, um ihren THERMISCHEN KOMFORT aufrecht zu halten. Die Hauttemperatur wurde an 14 Stellen gemessen. Leistungsmessungen erfolgten an einer Zahlen-Addieraufgabe und an zwei Gedächtnisprüfungen. Die Versuchspersonen werteten ihre Anstrengung, Aufmerksamkeit und Ermüdung, und die Frische der Luft an verschiedenen semantischen Skalen. Keine signifikanten Unterschiede der Leistungen konnten zwischen den beiden Bedingungen gefunden werden. Die subjektive Anstrengung, Aufmerksamkeit und Ermüdung unterschieden sich nicht, sondern die Versuchspersonen hielten die Luft unter der Bedingung kühle Luft/schwere Kleidung für frischer. Die Hauttemperatur war unter dieser Bedingung signifikant weniger gleichmässig über die Körperoberfläche verteilt, obwohl die mittlere Hauttemperatur unter beiden Bedingungen die gleiche war. Männliche Personen hielten eine signifikant höhere Hauttemperatur und einen signifikant höheren Verdampfungs-Gewichtsverlust unter beiden Bekleidungsbedingungen aufrecht als weibliche. Es bestanden jedoch keine signifikanten Unterschiede zwischen den Lufttemperaturen, die von Männern und Frauen bevorzugt wurden. Die im Mittle bevorzugten Hauttenperaturen betrugen 32·2° und 18·7°C für 0·6 respektive 1·15 clo.

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Function of the Muscles of the Upper Limb in Car Driving

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The function of (I) the deltoid muscle, (II) the trapezius muscle, and (III) the three main elbow flexors as well as the triceps brachii muscle were tested during driving in a simulator.

I. The anterior and middle portions of the deltoid muscle work during contralateral rotation of the steering wheel, while the posterior portion does not work at all. The deltoid muscle seems to have a purely phasic action in car driving.

II. The upper portion of the trapezius muscle works more or less statically with a weak contraction. There is no correlation between the periods of contraction and the angular movements of the steering wheel. The middle and lower portions of the muscle show much less activity than the upper portion.

III. The three main elbow flexors, i.e. the brachialis, biceps brachii and brachioradialis muscles, and the triceps brachii muscle show some activity during driving, but without any meaningful correlation between the periods of activity and the deviation of the steering wheel.

General Introduction

Very little is known about the function of the muscles of the shoulder and arm during car driving. As a matter of fact, very few electromyographic investigations of car driving have been published. In 1968 Serra discussed the use of EMG in evaluating the ability of a subject to drive a motor vehicle. His two articles mainly concerned the covariation of eye movements with vestibular activity. In 1971 Helander and Söderberg demonstrated the use of EMG on lower limb muscles in determining the drivers' degree of attention in different traffic situations. The same year, Rosemeyer presented the results from a study of the trapezius and the erector spinae muscles in different sitting postures suggestive of those adopted by a car driver. Two similar investigations were published by Andersson *et al.* in 1974. None of these latter three investigations actually concerned any attempts to move a steering wheel. A study of the maximal isometric torque exerted on a handwheel placed in six different positions was reported by Provins in 1955. To the authors' knowledge, no previous electromyographic investigations have been published concerning the function of the upper limb muscles in car driving.

The present investigation is part of a research programme aimed at analysing the function and coordination of the shoulder and arm muscles in car driving. A large number of muscles is being investigated. The main purpose of this programme is to analyse how the shoulder and arm muscles work during simulated driving on a main road and on a country lane, respectively. This presentation deals with six shoulder and arm muscles. Succeeding papers will deal with another seven shoulder muscles.

Methods

General procedure

After the electrodes had been applied and connected to the recording equipment the subject was seated in the car driving simulator. The experiment