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EFFECTS OF NOISE, HEAT AND INDOOR LIGHTING ON COGNITIVE PERFORMANCE AND SELF-REPORTED AFFECT

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Abstract

Theoretical and practical concerns guided the design of an experiment on how ventilation noise (38 and 58 dBA), air temperature (21 and 27°C), and illuminance (300 and 1500 lx) combine or interact in their effects on cognitive performance. Self-reports of affective states were taken with an affect circumplex measure (Larsen & Diener, 1992; Knez & Hygge, in press) to study the mediation from the environmental variables over affect to cognitive performance.

Arousal models (e.g., Broadbent, 1971) would predict that increased levels of noise and illuminance increase activation and/or affect levels and that mild heat decreases it. The inverted U-hypothesis would further predict that intermediate levels of perceived arousal improve attention, memory and problem solving performance. A distinction was made between synergetic and antagonistic interactions in order to differentiate arousal and nonarousal mediated effects on cognitive performance.

The results showed that attention worked faster in noise but at the cost of lesser accuracy, which supports the Speed-Accuracy-Trade-Off hypothesis (Hockey, 1984). Interactions were found between noise and heat on the long-term recall of a text, and between noise and light on the free recall of emotionally toned words. These effects on cognitive performance could not be explained as mediated by the affective states, and were not consistent with an arousal model and the inverted-U hypothesis.

Effects of Noise, Heat and Indoor Lighting on Affect and Cognitive Performance

There is both a theoretical and a practical value in knowing how the physical parameters of the indoor environment may combine or interact in producing effects on affect and a cognition. Broadbent (1971) phrased the basic idea behind a synergetic (ordinal) interaction, where the combined effect is more than the sum of its parts, in the following way:

> If condition A gives a 10 per cent increase in errors, and condition B a 10 per cent increase, then the two together should give 20 per cent. If on the other hand both stresses are affecting the same mechanism, the more drastic impairment may well appear: If each condition on its own lowers performance from a perfect level to one of 10 per cent error, then the addition of the second stress to the first may produce far more than 20 per cent of error. This is to be expected because the effect of one stress alone will be partly taken up in overcoming the safety margin of the mechanism concerned. When the second stress is applied, there is no longer any margin left within the mechanism, which is being effected. (p. 405 f.)

The theoretical significance of the argument can be probed also for situations where the combination of conditions A and B cancel each other to produce no net change in result (antagonistic interaction, cross-over interaction). Such a result would indicate that the two conditions antagonistically counteract each other at some level of analysis, which is different from a synergetic interaction indicating a depletion of available processing resources. An arousal model in combination with the inverted-U hypothesis is the major tool to explain a counteracting mediation between environmental influences and performance (Broadbent, 1971; Easterbrook, 1959; Hebb, 1972; Lindsley, 1951; Malmo, 1959).

The empirical support for the two kinds of interactions is scarce since there are very few studies devoted to interactive effects of noise, temperature and indoor lighting on intellectual work of the kind that takes place in schools or offices. There is no study that varied all the three parameters noise, heat and lighting simultaneously. The most common combination of variables has been that between noise and heat, and the second most common between noise and lighting.

Viteles and Smith (1946) reported no interaction between noise (72, 80 and 90 dB fan noise) and heat (corresponding to a range of 22·7–34·4°C, corrected for humidity), on psychomotor and attention tasks. However, in a re-analysis of the same data Wilkinson (1969) stated that there was an antagonistic interaction between noise and heat. Wyon *et al.* (1978) reported an antagonistic interaction between noise (85 dBA industrial noise, 50 dBA quiet) and heat (22 and 30°C) on a five-choice serial reactions task, and on a creativity test (noise from children playing, temperatures 20·0, 23·5, 27·0°C).

Hygge (1991) also reported an antagonistic interaction between continuous fan noise (37 and 58 dBA) and temperature (20 and 27°C) on a problem-solving task (embedded figures), but there were no interactions or main effects for other tasks.

Hancock and Pierce (1985) reviewed 13 studies where both noise and heat were independent variables and concluded that the majority of studies neither showed synergetic nor antagonistic interactions.

Veitch (1990) studied the effects of illuminance (200, 400, and 600 lx) and intermittent office noise (model levels of noise 50 and 70 dBA) on reading comprehension (recognition), but found no interactions or main effects. Löfberg *et al.* (1975) varied illuminance (60, 250 and 1000 lx) and temperature (corresponding to 22 and 27°C) for school children. One of their tasks was an addition test written on paper sheets with different contrasts. For that test there was an interaction between illuminance level, temperature and time-of-day. The high illuminance level improved performance in the warmer condition in the afternoon. In the morning at the lower temperature, performance on the addition test improved with increased illuminance. Nelson *et al.*, (1984) varied air temperatures between 13, 23 and 30°C and illuminance between 100 and 300 lx, and reported productivity increases in cool air but no interaction with illuminance.

Thus, there is some support for an antagonistic interaction between noise and mild heat, meaning that on attentional and problem solving tasks an increased noise level can be counteracted by a slight increase in temperature. There is no support for an antagonistic interactions between noise and pronounced heat, or illuminance and noise, or illuminance and heat.

To account for antagonistic interactions, the arousal model needs to be supplemented with the inverted-U relationship (Broadbent, 1971; Easterbrook, 1959; Hebb, 1972; Lindsley, 1951; Malmo, 1959) between arousal and performance. Performance is assumed to be at its peak in the region of intermediate arousal. For easy tasks the optimum level of performance is in the region of high arousal; for difficult tasks the optimum is on the lower arousal regions. Too low arousal impedes performance by drowsiness and too high arousal produces impaired performance by over-activation. Increases in noise and illumination levels have been assumed to increase arousal, and mild heat (up to ~27°C) to decrease it.

Mere depletion of cognitive processing resources in the mediation of performance would show up as a synergetic interaction, and counteracted arousal as an antagonistic (statistical) interaction between environmental variables in their effects on performance. If an interaction is present, concurrent measures of arousal, affect or activation would provide information about their plausibility as mediators of behavior and cognition. A synergetic interaction between environmental variables in their effects on cognitive performance does not necessitate an inverted-U arousal model. An antagonistic interaction, however, would.

Arousal models have been severely criticized. The uni-dimensional and general nature of the arousal concept has been questioned. The hopes to find physiological correlates of arousal have so far not been successful. Already three decades ago Broadbent (1971, p. 413) explicitly suggested that 'in the present state of knowledge we are defining (the arousal concept) on the basis purely of behaviour and not of physiology'.

Other theorists denounce activation theories and suggest that there are no interactions between e.g., noise and heat (Hockey & Hamilton, 1983, pp. 383 ff.). Still others e.g., Cohen *et al.* (1986, pp. 161 ff.) propose that so called arousal effects rather are decisional or perceptual in nature.

The present experiment was designed to study the interaction effects between noise, heat and illuminance levels on attention, memory and problem solving. To evaluate affective states as mediators between environmental impact and performance, a self-report affect circumplex measure was employed (Larsen & Diener, 1992; Knez & Hygge, in press).

It was predicted that increased levels of noise and illuminance lighting would increase perceived activation level and that mild heat would decrease it. In line with the inverted U-hypothesis, intermediate levels of perceived activation were predicted to improve attention, memory and problem solving. In accordance with the Speed-Accuracy-Trade-Off (SATO) hypothesis (Hockey, 1984), noise was expected to increase speed at the expense of more errors in attention and working memory.

Method

Participants

A total of 128 participants aged 18–19 years were recruited from local high schools. There was an equal number of men and women. Groups of four participants of the same gender were run simultaneously, and were randomly assigned to the eight experimental conditions (two each of noise, heat, and illuminance).

Experimental conditions and design

The experiment was run in an off-white chamber ($3{\cdot}9\,\mathrm{m} \times 3{\cdot}8\,\mathrm{m} \times 2{\cdot}5\,\mathrm{m}$), furnished as a neutral office. Air temperatures (21 and 27°C) were controlled by a computerized climate system, which also held the humidity at a fixed level. A commercial heat exchanger placed on the floor in a corner of the room produced broadband low-frequency (maximum energy in the octave bands 250 Hz and lower) noise at 38 and 58 dBA as measured in the middle of the room. Six ceiling-mounted luminaires with four fluorescent tubes were used, with a color temperature of 3000 K (light source) and a color-rendering index of 95. Two illuminance levels were employed, 300 and 1500 lx.

Basically, a factorial between-subject design was employed with three independent variables: Noise (38 and 58 dBA), Heat (21 and 27°C), and Illuminance (300 and 1500 lx). In some of the analyses this design was supplemented by Gender as a between-subject factor.

Dependent measures

Attention. Attentional performance was measured by a memory-load search task (Smith & Miles, 1987; Hartig, *et al.* 1996). This task involves searching through lines of 59 random capital letters for five target letters defined at the beginning of each line. A five-page reply form, with each page containing 66 lines was given to the participants. Two dependent measures were scored from the replies: Accuracy (percentage of errors of omission) and Speed (number of letters searched). This task was done twice during the experiment.

Problem solving. An embedded figures task (Hygge, 1991; Smith & Broadbent, 1980) was used as a measure of problem solving performance (Hartley, 1989). The answering sheet consisted of two types of figures. At the top there were five small, simple figures (solutions) and below them there were 16 large, complex figures (the targets). The participants' task was to find out which one of the five solutions was present in the 16 large targets. This task was done twice during the experiment with two different sets of 16 figures run in fixed order.

Long-term recall and recognition. A seven pages text about an ancient culture (Carter, 1982) was read at the beginning of the experiment (see procedure section). Approximately 130 minutes later, the participants were asked to write down their replies to six knowledge questions (recall) and 18 multiple-choice questions (recognition) about the text. The replies were scored in the same way as in a set of classroom experiments on noise and learning (Hygge, 1997).

Short-term recall. Three word-lists with 16 words each were used as a free recall task. Each word-list was made up from words with a positive, a negative or a neutral hedonic tone, and was presented in random orders on a PC-screen. After each list presentation the participants were asked to write down, in no particular order, all the words they recalled from the presented list (Knez, 1995).

Affect. A self-report affect circumplex measure (Larsen & Diener, 1992; Knez & Hygge, in press) was employed. It consisted of 48 adjectives representing eight affect states, (HA high activation, AP activated pleasant affect, P pleasant, UAP unactivated pleasant affect, LA low activation, UAUP unactivated unpleasant affect, UP unpleasant, and AUP activated unpleasant affect). In the present study HA was taken as the main indicator of arousal or activation. Ratings were made on a 5-point scale (from 'little or not at all' to 'very much'), in reply to the question: 'How do you feel now?' The affect questionnaire was administered twice, at the beginning and in the later part of the experiment.

A substantial number of participants did not master all of the words in the 48 items. Means for the eight affect states were therefore calculated on three to four items instead of the original six. The items chosen for this reduced model were those suggested by Knez and Hygge (in press).

Procedure

Groups of four females or males were run at each session. The participants were informed that the experiment was about different kinds of intellectual performance. They were not informed about the manipulations of the physical variables. Participants were also informed there would be enough time to complete most, but not all, subtasks. The tasks were given in the following order and time restraints: Affect test, block 1 (5 min), attention task block 1 (6 min), text reading for subsequent long-term recall and recognition (35 min), problem solving task block 1 (15 min), short-term recall of positive negative and neutral words (5 min), affect test block 2 (5 min), attention task block 2 (6 min), problem solving task block 2 (15 min), and test for long-term recall and recognition (20 min). Thus, the whole session took close to two hours. All experimental sessions started at approx. 3.00 p.m.

Results

Analysis strategy

The data for the cognitive tasks were analysed first to detect main effects and interactions. The results for the affect measures were evaluated later, and in more detail if there were effects of the independent variables on cognitive performance. The rationale for this was to elucidate the role of the affect states as mediators first when any significant effects on cognition had been established.

Two of the cognitive tasks, the attention task and the problem solving tasks, and the affect measure were administered twice during the experiment. To focus the analysis on the course of development in the experiment, to avoid pre-experimental base-line differences, and to reduce between person variance, the units entered into the statistical analyses for these measures were the change scores from the first to the second block.

The experiment was arranged to include Gender as one of the independent variables. In order to simplify the presentation of the results, results with main effects or interactions including Gender are presented in a result section of its own.

Effects of noise, heat and light on cognitive performance

Attention. A multivariate analysis of variance with change scores in both Speed and Accuracy as dependent measures showed a significant effect of Noise, F_{exact} (2111) = 3·45, $p = 0{\cdot}035$, (see Figure 1). Univariate follow-up analyses showed that the Noise effect was significant for Speed only, $F(1,112) = 6{\cdot}45$, $MSE = 19652{\cdot}0$, $p = 0{\cdot}035$, meaning increased speed at the higher noise level (Accuracy $F = 1{\cdot}52$, $p = 0{\cdot}22$). This basically supports the SATO (Speed-Accuracy-Trade-Off) hypothesis suggested by Hockey (1984), stating that working memory and attention would work faster with noise but with lesser accuracy.

Problem solving. No significant effects were obtained.

Long-term recall and recognition. Subjects recalled better in 1500 than in 300 lx, $F(1,112) = 3{\cdot}85$, $MSE = 10{\cdot}53$, $p = 0{\cdot}052$. There was also a Noise × Heat interaction, F $(1,112) = 3{\cdot}85$, $MSE = 10{\cdot}53$, $p = 0{\cdot}052$ (see Figure 2), indicating better recall in lower than in higher noise at 27°C, ($M_{38\,dBA-27^{\circ}C} = 9{\cdot}22$, $M_{58\,dBA-27^{\circ}C} = 7{\cdot}25$, $t(30) = 2{\cdot}47$, $p = 0{\cdot}016$), but no difference at the lower temperature ($t < 1$). For recognition no significant effects were obtained.

Short-term recall. For the free recall of the emotionally toned words, more words were remembered at 21 ($M = 19{\cdot}1$) than at 27°C ($M = 17{\cdot}5$), $F(1,120) = 7{\cdot}08$, $MSE = 3{\cdot}87$, $p = 0{\cdot}009$. A significant Noise × Light interaction (see Figure 3), indicated more words being remembered in the 38 dBA-condition at 1500 lx than at 300 lx ($M_{38\,dBA-1500\,lx} = 19{\cdot}4$,

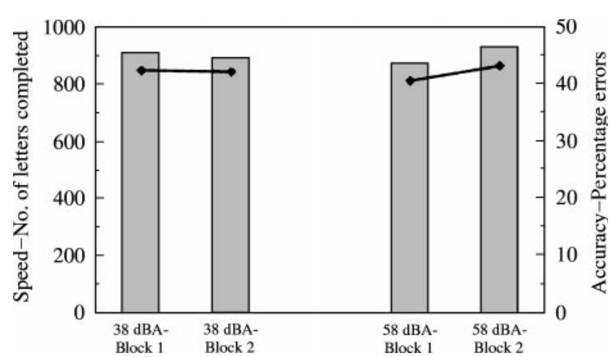

FIGURE 1. Mean speed and accuracy in low and high noise conditions. *Note.* Standard deviations for change scores from Block 1 to 2: Speed 38 dBA=142.7, 58 dBA=143.6, Accuracy 38 dBA=12.91, 58 dBA=13.24. ▭ Speed; —◆— Accuracy.

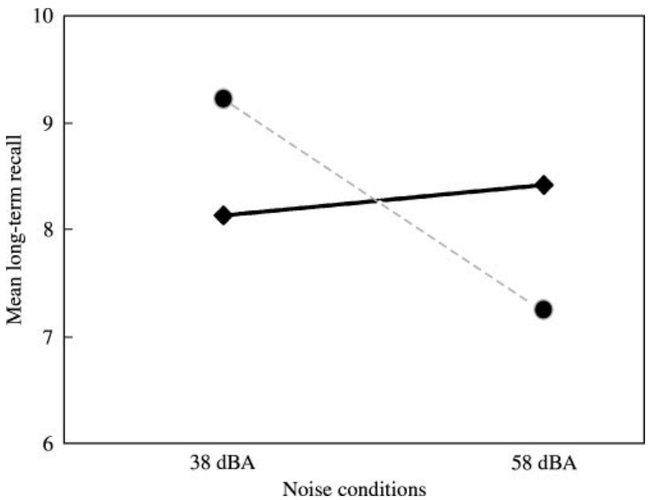

FIGURE 2. Mean long-term recall in low and high noise and heat conditions —◆— 21°C; - - - ●- - - 27°C.

$M_{38\,\text{dBA–300\,lx}} = 17{\cdot}3$, $t(62) = 20$, $p = 0{\cdot}032$), but there was no difference between the lighting conditions at 58 dBA.

Summary of the effects of noise, heat and light. The main findings for the effects of noise, heat and light showed: (1) A trade off between speed and accuracy on attention; (2) better long-term recall in 1500 than in 300 lx, and in the low noise than in the high noise at 27°C; and (3) better free recall in 21 than in 27°C, and in the low noise condition at 1500 lx than at 300 lx.

Effects involving gender on cognitive performance

Attention. The results for the SATO hypothesis were not qualified by Gender. For accuracy the significant Gender × Heat × Light interaction, $F(1,112) = 4{\cdot}22$, $MSE = 84{\cdot}30$, meant that men increased their errors more than women, but this was significant only in the 21°C–300 lx condition, ($M_{\text{women}} = 3{\cdot}69$, $M_{\text{men}} = 6{\cdot}88$, $t(30) = 2{\cdot}73$). The Gender × Noise × Heat interaction, $F(1,112) = 4{\cdot}31$, $MSE = 9825{\cdot}98$, meant that significantly more letters were interaction, $F(1,112) = 4{\cdot}31$, $MSE = 9825{\cdot}98$, meant that significantly more letters were completed for women in the 27°C–58 dBA condition compared to the 21°C–38 dBA condition, than for any other of the three combinations of Gender, Heat and Noise, ($M_{38\,\text{dBA}-21°\text{C}} = 62{\cdot}5$, $M_{58\,\text{dBA–}27°\text{C}} = 95{\cdot}48$, $t(30) = 3{\cdot}35$).

Problem solving. Significant effects of Gender, $F(1,112) = 5{\cdot}25$, $MSE = 4{\cdot}30$, and of Gender × Light, $F(1,112) = 4{\cdot}71$, $MSE = 4{\cdot}30$, showed that women performed better than men in the 1500 lx condition ($M_{\text{women}} = 4{\cdot}66$, $M_{\text{men}} = 2{\cdot}34$, $t(30) = 3{\cdot}37$), but not in the 300 lx condition ($t < 1$).

Long-term recall and recognition. No significant effects involving Gender were obtained.

Short-term recall. A significant effect of Gender, $F(1,112) = 3{\cdot}80$, $MSE = 3{\cdot}70$, $p = 0{\cdot}054$, indicated that women recalled more words than men did. The significant Type × Gender × Light interaction, Exact $F(2,111) = 3{\cdot}14$, $MSE = 3{\cdot}70$, $p = 0{\cdot}047$, indicated that men at 300 lx and women at 1500 lx followed the main effect pattern of remembering significantly more positive and neutral words than negative words. Women at 300 lx and men at 1500 lx did not have significant differences between the types of word they remembered (all $t < 1$).

Summary of effects involving gender. The results showed: (1) Better performance for women than for men in the problem solving task; and (2) more words remembered by women than by men.

Self-reported affect

The change score from the first to the second time of affect measurement was employed in favor of just the second measure, to control for base line differences between groups and to minimize the number of outliers. (Routine check analyses were also done for the values from the second assessment of affect, but as a rule they were less sensitive in picking up significant effects, which indirectly supports the choice of change scores.)

There are two sorts of issues to evaluate for the self-reported affect data. The first is whether there are any effects of noise, heat and light on the eight affect states. The second is whether there are any inverted-U (quadratic component) effects of the affect states, in particular HA as an indicator of activation, on the outcomes of cognitive performance. Resolving these two issues are of particular relevance for the long-term and short-term recall measures found to be sensitive to the environmental conditions in the earlier statistical analyses.

Effects involving HA. The most likely candidate for operationalized arousal is the High Activation (HA) subscale in the circumplex measure. For this scale there was a main effect of Heat, $F(1,120) = 3{\cdot}71$, $MSE = 0{\cdot}657$, $p = 0{\cdot}056$, with more lowering of activation in the 27 than in the 21°C condition, ($M_{21°\text{C}} = -0{\cdot}10$, $M_{27°\text{C}} = -0{\cdot}38$. There was also a Noise × Light interaction, $F(1,120) = 5{\cdot}24$, $MSE = 0{\cdot}657$, $p = 0{\cdot}024$. The corresponding means

Table 1

Change scores for the high activation (HA) and activated pleasure (AP) states by noise and light conditions

Experimental conditions	HA	AP
38 dBA–300 lx	−0·02	−0·05
38 dBA–1500 lx	−0·58	−0·56
58 dBA–300 lx	−0·22	−0·48
58 dBA–1500 lx	−0·13	−0·10
MSE	0·657	0·516
(Standard error	0·143	0·127)

Note. Positive values are increases from the first to the second block.

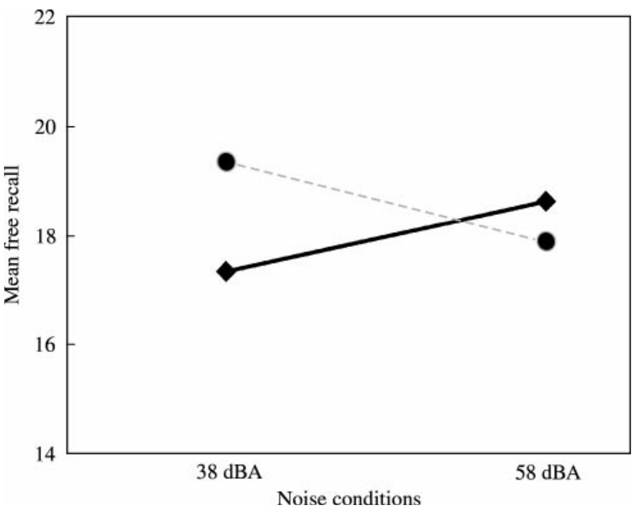

Figure 3. Mean short-term free recall in low and high noise and illuminance conditions —◆— 300 lx; - - - ●- - - 1500 lx.

are shown in left column of Table 1. Adding the Low Activation (LA) scale to the HA-scale strengthened the reported effects and also made the main effect of Light significant, indicating more, not less, activation with 300 lx than 1500 lx.

The effects depicted in Figures 2 and 3, however, can not be explained by the HA-mediation and the inverted U-hypothesis. As evidenced in Figures 4a and 4b, where the performance in the long- and short-term recall tasks in Figure 2 and 3 are plotted against their HA values, neither the form of the function, nor the ordering of activation states fit the arousal model. For instance, in both Figure 4a and 4b the two light and noise conditions do not form expected orderings.

Other affect states. A multivariate analysis of all other affective states than HA pertaining to activation, revealed a significant Noise × Light interaction for the Activated Pleasure (AP) state, $F(1,120) = 12{\cdot}16$, $MSE = 0{\cdot}516$, $p < 0{\cdot}001$. See Table 1, right column. This state was strongly correlated with the HA-state (Pearson $r = 0{\cdot}54$, $p = 0{\cdot}000$) and showed the same pattern of effects.

Quadratic trends for the effects of affect projected on cognitive performance were tested by entering the affect change score values for all the other affect states, regardless of whether they were assumed to tap activation or not, as independent variables in curve-fit analyses of the previously reported significant effects for the different cognitive outcomes. Only one such significant trend with a *maximum* peak performance in the range of the change scores was found. This happened for the UP-state on long-term recall $F(1,125) = 3{\cdot}50$, $p = 0{\cdot}033$. Since this state concerned unpleasantness, and medium change scores were in the region of staying slightly unpleasant (scale value +1), this result does not seem to have any relevance for the arousal inverted-U model.

There were some significant quadratic trends for *minimum* performance (as in Figure 4a) in the range of the change scores. This was true for the free recall of positive words and the AUP-state, the free recall of neutral words and the AUP-state, the free recall of negative words and the P-state, and for the long-term recall measure and the UP-state (All $F > 3{\cdot}40$, df(1,125), all $p < 0{\cdot}037$). None of these trends were consistent with the assumption of noise and heat counteracting each other, with noise increasing activation-arousal and mild heat decreasing it. Nor was it consistent with an inverted-U explanation.

Summary of self-reported affect. Thus, where there were significant interactions between Noise, Heat or Light on cognitive performance (Figure 2 and 4a: Noise × Heat—long-term recall, Figure 3 and 4b: Noise × Light—recall words), there were no corresponding interaction effects on the affective states, and no quadratic trends with peaks in the middle range of the affect measures when plotted against the cognitive performance, to explain the results.

Further, the results for the quadratic fit of the different affective states rather point to intermediate affect levels as minima, not maxima, for the performance functions, which is the opposite to what the inverted U-hypothesis predicts.

Thus, there were no consistent support for the hypotheses that mild heat decreases, and noise and illumination levels increase self-reported affect. Nor is there any strong support for the inverted U-hypothesis about the relationship

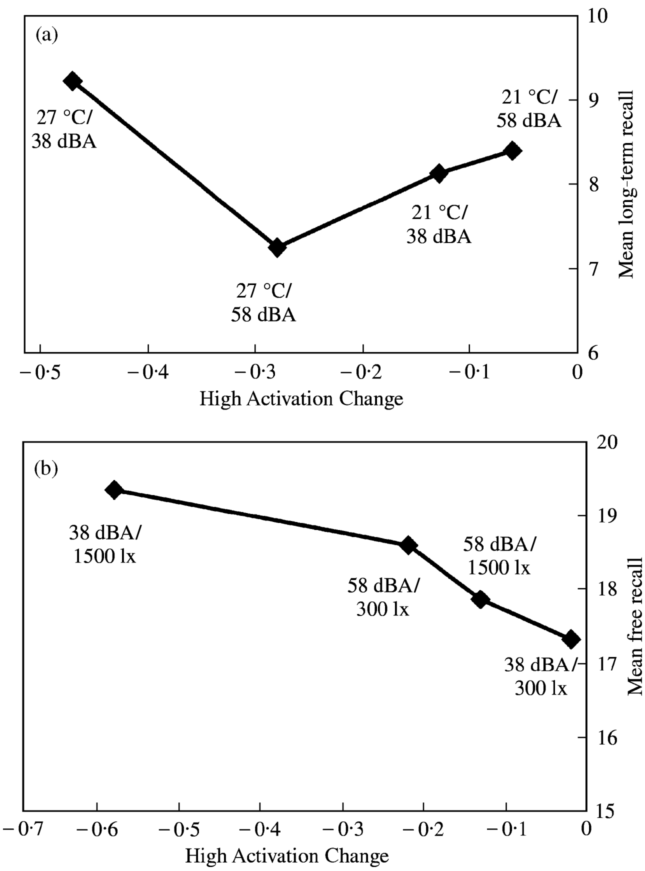

FIGURE 4. Mean long-term recall (4a) and free recall (4b) by High Activation Changes and experimental conditions. *Note:* Negative values are decreases in High Activation from the first to second block.

between self-reported affect and cognitive performance.

The addition of Gender into the analysis of noise, heat and light on the affect measures did not change or add to the reported results.

Discussion

The results showed that the attention task was performed faster in noise but at lesser accuracy. This result supports the SATO-hypothesis suggested by Hockey (1984), stating that working memory increases its speed in noise, but at the expense of increasing errors.

The significant interactions between noise, heat and indoor lighting obtained in the present experiment were on the recall of the text (Noise × Heat, Figure 2 and 4a) and on the free recall of the emotionally toned words (Noise × Light, Figure 3 and 4b). The first interaction, see Figure 2 and 4a, was crossover in nature, meaning impaired recall with heat at the high noise level, but improved recall at the low noise level. As evident from Figure 4b, this is not consistent with the assumption of an optimal performance in the mid-arousal region, but fairly consistent with noise increasing arousal and mild heat decreasing it. The second interaction, see Figure 3 and 4b, was also a crossover interaction but the ordering of the activation states and the lack of an inflection point in Figure 4b, is not consistent with the arousal model's prediction that increased illuminance and noise level would increase activation.

For the affective states other than HA (and the correlated AP) in the circumplex model, there were no indicators of differential main effects of and interactions between noise, heat and lighting. Further, there were no signs of a curve-linear relationship between affect states and cognitive performance peaking in the middle region of the reported affect scores.

It can be argued that an ideal test of the inverted U-hypothesis should have at least three levels each of the independent variables in order to detect any inflection point or peak in performance. Even if there is no task for which we know the relationship between arousal and performance, and at what level arousal performance will peak, we would assume that for several tasks with different degrees of difficulty, some of them, if the inverted-U hypothesis is correct, would show *improvement* in performance with slightly lowered activation and impairment with further lowering of the activation, and an ordering of the activation states from combined experimental conditions (*cf.* Figures 4a and 4b) consistent with earlier research. Lacking this improvement with decreased activation in the present study, and finding performance minima, rather than maxima, in the medium range of activation, does not lend support to the inverted-U hypothesis and the arousal model.

Thus, perceived affect states are not likely mediators of effects on cognition. In particular the arousal and the inverted U–hypotheses are not suitable explanatory models, at least not for the levels of noise, heat and indoor lighting commonly used in dwellings, schools and offices.

As regards the gender effects, the three-way interaction effects between gender, heat and light and gender, heat and noise on attention are not in line with the SATO hypothesis suggesting a speed-accuracy-trade-off effect on working memory and attention. Moreover, compared to men, females performed significantly better in the problem solving task, and especially in the high illuminance condition, which is not consistent with earlier results showing an opposite gender effect in this type of an abstract cognitive task (Knez & Enmarker, 1998; Ussher, 1992). However, in line with earlier results (Knez, 1995; Knez & Kers, 2000), women performed better than men in the free recall task. In addition, men remembered more positive and neutral words in the low illuminance condition and the same effect yielded for women in the high illuminance condition.

Taken together, this experiment reported interactions between noise and heat on the recall of a text, and between noise and light on the free recall of emotionally toned words. These interactive effects were neither mediated by, nor consistent with an arousal model or the inverted-U hypothesis. More generally, this opens up the theoretical possibility that indoor noise, heat and lighting act directly on cognitive performance, without being wholly or partly mediated by affect, and at least, not in the way suggested by the inverted-U hypothesis. That is, cognition and emotion, at least within and close to a comfort zone, may work in parallel rather than intermixed. Further interaction studies should address this issue in more detail.

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