#7070

THE EFFECT OF VARYING LEVEL OF OUTDOOR AIR SUPPLY ON NEUROBEHAVIOURAL PERFORMANCE FUNCTION DURING A STUDY OF SICK BUILDING SYNDROME (SBS)[1]

Fatima Nunes[2], Richard Menzies[3], Robyn M Tamblyn[3], Eric Boehm[2], Rick Letz[4]

[2]Respiratory Epidemiology Unit. McGill University, Canada
[3]Respiratory Epidemiology Unit, Depts. of Medecine and Epidemiology and Biostatistics, McGill University, Canada
[4]School of Public Health of Emory University, USA

ABSTRACT

It is generally believed that there exists a relationship between the quality of the indoor office environment, reporting of symptoms of sick building syndrome (SBS) and worker productivity. However, there is no standardized instrument for objective measures, and productivity of most office workers is difficult to measure. 47 workers in one mechanically ventilated office building completed computer-based neurobehavioral performance tests as part of a study of SBS in which the outdoor air supply was experimentally varied. For three weeks workers completed questionnaires regarding symptoms suffered that day, and completed, without supervision, two tests of neurobehavioural function - the continuous performance test (CPT) and the symbol-digit substitution test (SST), while the indoor environment was characterized in detail. Response times, variability, and fatigue for CPT and SST were very similar over all 3 weeks. Personal characteristics such as younger age and clerical work were associated with better performance in CPT. Workers who reported any symptom had significantly higher CPT response times ($P<.001$), and higher SST error rates ($p=.07$). There were modest correlations between higher temperature, lower humidity, and lower air velocity, and slower CPT response times. We conclude that computer-based neurobehavioral tests appear to be a promising tool for determining the impact of symptoms as well as environmental conditions on office workers performance.

INTRODUCTION

Sick building syndrome (SBS) is the term commonly applied to a constellation of symptoms arising among office workers in modern high rise buildings in which all indoor ventilation is supplied by mechanical means. Symptoms associated with SBS include headache, fatigue, difficulty concentrating, and irritation of the mucous membranes such as the eyes, nose and throat (1).

It is generally assumed that there exists a relationship between the quality of the indoor air environment, symptom reporting and worker productivity but there is little objective supportive data. Past studies have been observational, or have relied on self-reported assessments of productivity by workers (2,3). Productivity is difficult to measure for most types of office work, except for clerical work that involves repetitive actions such as data entry. Decreased productivity is important because the economic loss affects not only the individual but also the employer and the community.

Neurobehavioral tests have been used widely to evaluate cognitive function following human exposure to neurotoxic agents (4). The Neurobehavioral Evaluation

System 2 (NES2), is a computer-based series of tests of cognitive, and neural function and has proven useful in a number of epidemiologic investigations and laboratory experiments (4,5). This system of tests can provide quantitative estimates of the effects of toxic exposures on neurobehavioral outcomes.
We have recently completed a study of the effect of changes of outdoor air supply on symptoms of SBS (7). Each week the indoor environment was measured in detail and workers completed a questionnaire regarding symptoms considered typical of SBS. At the same time, a sample of workers completed the NES2 tests -- providing repeated measures of neurobehavioral function under varying environmental conditions.

SUBJECTS AND METHODS

Overall design - main experimental study

This study was conducted among a sub-sample of individuals in one building who participated in a study of the effect of changes in outdoor air on symptoms of SBS (6). The experimental study conducted in four office buildings in downtown Montreal, was a randomized, double blind multiple cross-over trial. For 3 consecutive two-week blocks, building ventilation systems were manipulated to deliver an intended 9 or 24 L/sec/person of outdoor air to the indoor environment, corresponding to indoor CO_2 concentrations of 1,000 and 600 ppm, respectively (ASHRAE 1989). Within each two-week block, the ventilation level was increased for one week and decreased for the other. The ventilation level was changed every week on Friday afternoon. On Wednesday or Thursday of the following week, the participants were asked to rate the environment and to report any symptoms experienced on that day. Temperature, humidity, air velocity, and CO_2 were measured at 8 to 12 worksites on each floor, twice during the day of the questionnaire administration, each week. In addition airborne fungal spores (colony forming units), total volatile organic compounds, dust, nitrogen dioxide, and formaldehyde were measured at 1 to 3 sites per floor each week.

Study population for NES2

A sample of 47 participants in one building of the experimental study, who used a personal computer regularly at work were selected.

Administration of Neurobehavioural Tests

Two tests from the battery of NES2 were used: the Continuous Performance test (CPT) to measure sustained visual attention and the Symbol-digit substitution task (SST) to measure speed and coding ability.
In the CPT test the subject presses a button upon seeing a large letter "S" when it is projected onto a video display terminal. Letters flash briefly (for about 50 msec) on the screen at a rate of one per second for five minutes. Individual response latencies, omission and commission errors are recorded. Using this data, indices of speed, task learning and attention can be calculated.
The SST test is similar to the Digit-Symbol Substitution test from the Wechsler Adult Intelligence Scale. Nine symbols and digits are paired at the top of the screen and the subject has to press the digit keys corresponding to a reordered test set of the nine symbols. Five sets of nine symbol-digit pairs are presented in succession. The pairing of symbols with digits is varied between sets to avoid learning. The time required to complete each symbol-digit set and the number of digits incorrectly matched are recorded.

Participants completed practice trials of both tests while supervised to ensure that the tests were understood. Recorded tests were performed without supervision, each week for the final three weeks of the experimental study.

Statistical methods

The learning effect for week 2 for CPT and SST was calculated by subtracting mean response times of weeks 2 and 1. This was expressed as a percent of the average response times in both weeks. The learning effect for week 3 was calculated from results of weeks 2 and 3.
Fatigue for CPT and SST was calculated for by subtracting mean response time of trials 4 and 5 from mean response time of trials 1 and 2. This was expressed in the same units as the response times.

RESULTS

The participants included 14 (29%) males and 34 (71%) females. There were 31% individuals under 30 years of age and 45% and 24% aged 30-40 and over 40 years respectively. Thirty seven (79%) individuals completed the test in all 3 weeks; 9 completed tests in 2 weeks and 1 person completed only 1 test.
As seen in Table 1 mean response time for CPT were similar over the 3 week period whereas SST coding speed improved slightly. This improvement may be explained by the learning effect over time encountered in SST but not in CPT. Mean percent error rates for both tests remained stable throughout. Within subject variability was comparable between weeks and good correlations were noted between week 1 performance and subsequent testing for both tests. There was no fatigue seen in CPT responses over trials; if anything responses were faster in the final trials particularly in week 1. Fatigue was seen in SST performance, although this diminished over the 3 weeks.

Table 1. Mean CPT and SST results per week.

	CPT			SST		
	Wk1	Wk2	Wk3	Wk1	Wk2	Wk3
n	47	39	47	47	39	47
Response time[1]	389	397	392	2.3	2.2	2.1
(S.D.)	(58)	(67)	(54)	(.90)	(.92)	(.83)
Error rate (%)	1.3	1.3	1.1	1.2	1.4	1.0
Coefficient of Var.[2]	.15	.17	.14	.39	.40	.37
Correlation with Wk1	--	.81	.73	--	.78	.81
Learning effect[3] (%)	--	-1.9	1.6	--	6.0	2.8
Fatigue[3]	-15	- 4	- 5	.09	.03	.02

[1] CPT = msec (s.d); SST = sec/digit (s.d.)
[2] Coefficient of variation = s.d. / mean
[3] Statistical calculations described in Research Methods.

As shown in Table 2, performance time in CPT and SSt increased with increasing age.

A clerical position seems to be associated with better CPT response time. This difference may be explained by the fact that clerical workers were younger. Slightly better performances were noted by males and participants in open area offices for CPT.

Table 2. Overall average CPT and SST performance by personal characteristics.

	CPT				SST			
	Time[1]	Error rate %	C of Var.	Fat.[2]	Time[1]	Error rate %	C of Var	Fat.[2]
Gender								
Males	388	1.0	.14	-9	2.20	.7	.36	.14
Females	394	1.3	.15	-8	2.20	1.3	.39	.02
Age (yrs)								
< 30	376	1.4	.14	-13	2.05	1.0	.42	.08
30-40	398	0.9	.13	-9	2.18	1.1	.32	.03
> 40	401	1.6	.16	1	2.43	1.1	.40	.05
Job type								
Clerical	383	1.4	.16	-5	2.20	1.2	.37	.08
Other	400	1.0	.14	-8	2.19	1.1	.38	.02
Office type								
Closed	390	1.1	.13	-7	2.22	1.2	.37	.03
Open	394	1.3	.15	-8	2.19	1.2	.39	.06

[1] Time = Response time for CPT in msec; SST sec/digit
[2] Fatigue units for CPT in msec; for SST in sec/digit.

As shown in Table 3, among participants who reported any symptoms, CPT response time was significantly longer ($p<.001$) and SST error rates were higher. Fatigue in CPT response was not associated with symptom status, but fatigue in SST response was greater among those with symptoms. Males had greater fatigue in SST performance than females ($p<.01$).
As seen in table 4, all correlations with environmental measurements are low, although increased temperature (overall average of 22.5°C) was correlated with longer CPT response time ($p<.01$) and more fatigue in CPT response ($p=.07$) respectively). Relative humidity (overall mean of 30.4%) was negatively related to CPT response time and CPT fatigue but positively related to percent error rate ($p<.01$). CO_2 (mean of 754 ppm) was positively correlated with percent error rate.

Table 3. Overall average CPT and SST performance by symptom status.

	CPT				SST			
	Time[1]	Error rate %	C of Var.	Fat.[2]	Time[1]	Error rate %	C of Var	Fat.[2]
Any Symptoms								
Yes	404	1.3	.15	-11	2.21	1.3	.36	.038
No	377	1.1	.14	- 5	2.21	1.0	.41	.066
Headache								
Yes	410	1.4	.17	5	2.17	1.7	.36	.004
No	389	1.2	.14	-11	2.22	1.1	.39	.059
Difficulty concentrating								
Yes	411	1.2	.16	- 9	2.29	1.5	.36	.001
No	389	1.2	.14	- 8	2.19	1.1	.38	.059
Fatigue								
Yes	408	1.1	.14	-10	2.23	1.5	.36	.008
No	388	1.2	.14	- 8	2.20	1.1	.39	.059

[1] Time = Response time for CPT in msec; SST sec/digit.
[2] Fatigue units for CPT msec; for SST sec/digit.

Table 4. Correlation of CPT and SST performance with environmental measures.

	CPT			SST		
	Time[1]	Error Rate %	Fatigue	Time[1]	Error Rate %	Fatigue
Temperature	.22	-.08	.16	-.10	.09	-.01
Humidity	-.11	.21	-.13	.18	-.14	.11
Air Velocity	-.15	.12	.03	.04	.09	.04
CO_2	.05	.26	.02	-.04	.03	.01
Mean TVOC	.03	.12	.04	.15	-.01	.14

[1] Time: Response time : CPT (msec); SST (sec/digit)

DISCUSSION

The 47 office workers who participated in this pilot study were able to complete these neurobehavioural tests without direct supervision at their worksite, in a repeated measures design. Estimates of coefficients of variation, were similar in all weeks, learning effects and fatigue were relatively small, while correlations in performance of tests between weeks were similar to those reported when the tests were performed

under direct supervision. (5)
In this study symptomatic workers had significantly worse neurobehavioral performance, especially for sustained visual attention (CPT). Symptomatic workers usually report reduced productivity (2). This study provides evidence that symptoms considered typical of SBS are associated with reduced performance on objective tests of neurobehavioral performance.
In this study there were modest correlations between environmental parameters and test performance, particularly for CPT. CPT performance was adversely affected by increased temperature, lowered humidity and lowered air velocity although CPT performance was not correlated with any of the contaminant measures. In experimental exposures studies, moderate heat stress was found to reduce reading and typewriting skills by as much as 30% (7). These comfort measures are well known to associated with symptoms of SBS (6); this study provides evidence that they may also affect objectively measured performance.
We conclude that computer-based neurobehavioral testing appears to be a promising technique for assessing the impact of symptoms as well as environmental conditions on workers performance. This test appears to be reliable when administered to office workers, already familiar with personal computers, in unsupervised fashion. These computer-based neurobehavioral tests may provide a standardized instrument to objectively measure the effect of the office environment on worker productivity.

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