NRC Publications Archive
Archives des publications du CNRC

Masking speech in open-plan offices with simulation ventilation noise: noise-level and spectral composition effects on acoustic satisfaction

Veitch, J. A.; Bradley, J. S.; Legault, L. M.; Norcross, S. G.; Svec, J. M.

For the publisher's version, please access the DOI link below./ Pour consulter la version de l'éditeur, utilisez le lien DOI ci-dessous.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/20386334
Internal Report (National Research Council of Canada. Institute for Research in Construction), 2002-04-01

NRC Publications Archive Record / Notice des Archives des publications du CNRC :
https://nrc-publications.canada.ca/eng/view/object/?id=7b46ed82-9360-424c-92f1-47cde0e2620b
https://publications-cnrc.canada.ca/fra/voir/objet/?id=7b46ed82-9360-424c-92f1-47cde0e2620b

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at
https://nrc-publications.canada.ca/eng/copyright
READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site
https://publications-cnrc.canada.ca/fra/droits
LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at
PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

National Research Council Canada   Conseil national de recherches Canada

National Research Council Canada
Conseil national de recherches Canada

NRC · CNRC

Masking Speech in Open-Plan Offices with Simulated Ventilation Noise: Noise Level and Spectral Composition Effects on Acoustic Satisfaction

Veitch, J.A.; Bradley, J.S.; Legault, L.M.; Norcross, S.; Svec, J.M.

IRC-IR-846

www.nrc.ca/irc/ircpubs

Institute for Research in Construction
Institut de recherche en construction
IRC

National Research Council Canada
Conseil national de recherches Canada

Institute for Research in Construction
Institut de recherche en construction

Masking Speech in Open-Plan Offices with Simulated Ventilation Noise: Noise Level and Spectral Composition Effects on Acoustic Satisfaction

by **Jennifer A. Veitch, John S. Bradley, Louise M. Legault, Scott Norcross, & Jana M. Svec**

Internal Report No. IRC-IR-846

Date of issue: April 2002

This internal report, while not intended for general distribution, may be cited or referenced in other publications.

Canada

Masking Speech in Open-Plan Offices with Simulated Ventilation Noise: Noise Level and Spectral Composition Effects on Acoustic Satisfaction

Jennifer A. Veitch
John S. Bradley
Louise M. Legault
Scott Norcross
Jana M. Svec

Institute for Research in Construction
National Research Council Canada
Montreal Road, Ottawa, Ontario
CANADA, K1A 0R6

Internal Report No. IRC-IR-846

April 2002

Acknowledgements

These experiments form part of the Acoustics sub-task for the NRC/IRC project Cost-effective Open-Plan Environments (COPE) (NRCC Project # B3205), supported by Public Works and Government Services Canada, Natural Resources Canada, the Building Technology Transfer Forum, Ontario Realty Corp, British Columbia Buildings Corp, USG Corp, and Steelcase, Inc. COPE is a multi-disciplinary project directed towards the development of a decision tool for the design, furnishing, and operation of open-plan offices that are satisfactory to occupants, energy-efficient, and cost-effective. Information about COPE is available at http://www.nrc.ca/irc/ie/cope.html.

The authors are grateful to the following individuals for contributions to these experiments: Guy Newsham, Alf Warnock, David Quirt, and Wing Chu for advice in creating the acoustical conditions; Gordon Bazana for data management; Staffan Hygge (University of Gävle, Sweden, Dept. of Built Environment), for advice on tasks and dependent measures; and, Michael Hunter (University of Victoria, Dept. of Psychology), for advice concerning statistical analyses.

c. 2002 Her Majesty in Right of Canada. National Research Council Canada, Ottawa, Ontario

Masking Speech in Open-Plan Offices with Simulated Ventilation Noise: Noise Level and Spectral Composition Effects on Acoustic Satisfaction

Executive Summary

The Cost-Effective Open-Plan Environments (COPE) project plan identified a need to develop relationships between acoustic conditions in open-plan offices and occupant satisfaction with those conditions. Two experiments were designed to meet this need. In each experiment, participants hired from a staffing agency for one day experienced 15 different simulated ventilation noises in combination with simulated telephone conversations, and provided ratings of their satisfaction with each noise condition. Each exposure consisted of a 15-minute period of work on memory and clerical tasks, followed by 2-3 minutes to complete a questionnaire concerning satisfaction, speech intelligibility, and the characteristics of the noise. This report concerns only the questionnaire data. Memory and clerical task performance in relation to the noise conditions will be reported separately.

- Experiment 1: Noise spectrum effects on satisfaction. In this experiment subjects experienced 15 different simulated noise spectra in combination with the speech from simulated telephone conversations.
- Experiment 2: Noise spectrum and noise level effects on satisfaction. This experiment used three noise spectra at each of five A-weighted noise levels, for a total of 15 different noise conditions in combination with the speech from simulated telephone conversations.

The results of the two experiments provided guidance for identifying acoustical conditions likely to prove satisfactory to occupants:

- Acoustic satisfaction increases as subjectively rated speech intelligibility decreases. This is consistent with our prediction, that speech privacy is what people want.
- The difference between low- and high-frequency A-weighted levels is a good predictor of the effects of masking sound spectrum shape on acoustic satisfaction.
- Acoustic satisfaction decreases as hissiness increases. Thus, sound masking systems must balance the need for high-frequency sound to mask speech, and the need to avoid excessive levels of high-frequency sound.
- Noise spectra that follow the speech spectrum are effective speech maskers.
- Louder masking noise is more effective at making speech less intelligible.
- Louder masking noise does not improve speech masking as much if the spectrum is a poor masker. Simply making the masking noise louder is not a guarantee of improved speech privacy.
- Noise levels much greater than 45 dB(A) are judged to be too loud, even though they are more effective at speech masking.
- Over the range of acoustic conditions in open-plan offices, Speech Intelligibility Index (SII) is a good predictor of acoustic satisfaction and rated speech intelligibility. The findings are consistent with the rule-of-thumb that SII values greater than 0.20 are unacceptable.

These findings will provide the input for modelling acoustic satisfaction in the COPE software tool.

Table of Contents

1.0 Introduction

Occupants of open-plan offices frequently complain about the acoustical environment as a significant problem involving both attention and privacy (Sundstrom, 1987; Sundstrom, Town, Rice, Osborn, & Brill, 1994). Unwanted sound from other people and from equipment is a distraction and can be a source of annoyance. The fact that office workers can hear the conversations of others or that others can hear one's own conversations is an absence of privacy. Despite the frequent reports of dissatisfaction, there is little specific information about the characteristics of the noise that people find most annoying; or, conversely, about the conditions that they find to be most satisfactory. Without this information, it is impossible to design open-plan offices to optimise satisfaction and speech privacy. This is particularly important because open offices are already the norm and there are new trends that could decrease privacy and satisfaction, such as smaller and more open work stations.

Open office acoustical problems can be broken up into two types: annoyance to various noises and a lack of speech privacy. Too much of almost any type of noise can be a source of annoyance in at least some situations. In general the level, spectrum, and variation with time of the noise will influence how disturbing it is found to be. Noise from people talking, telephones ringing, and other intermittent sounds can be more disruptive than more continuous sounds (Sundstrom et al., 1994). The more audible speech sounds from adjacent workstations are, then the less speech privacy there will be. This may be experienced as audible speech from an adjacent workstation or the perception that others can listen to ones own conversations. Generally, the quieter the intruding speech sounds and the louder various ambient noises are, then the greater the speech privacy.

Increasing ambient noise by adding a constant, information-free noise source (called masking noise) can improve the conditions within a workstation by masking speech sounds propagating from adjacent spaces. Masking noise is usually a noise of neutral quality similar to ventilation noise. Masking noise can decrease disturbance (Loewen & Suedfeld, 1992), despite the fact that the overall sound level is increased. There is obviously a limit to how loud the masking noise can be and still be judged a neutral masking sound. Increased noise levels will at some point lead to increased annoyance as well as to increased speech levels, which would further exacerbate the situation.

Unfortunately, these effects are not precisely quantified and most of our knowledge is anecdotal in character (Warnock, 1972; Warnock, Henning, & Northwood, 1972). The fundamentals of how one sound can mask another are well understood (Zwicker & Fastl, 1990) and the Speech Intelligibility Index measure (Acoustical Society of America Standards Secretariat (ASA), 1997) that is used as an indicator of speech privacy is based on our current understanding of the masking of speech sounds by other sounds. There are commercially-available masking noise systems in use in many workplaces. However, there appears to have been no systematic research published on which to base the choice of noise characteristics, either in terms of frequency content or sound level, for open office situations (there might exist proprietary research on this topic, but by definition these are not available publicly).

This report describes a pair of experiments designed to determine the relationship of satisfaction with a range of combinations of speech and noise in an open office work situation. The research was divided into two experiments to more completely consider the many possible variations of noise spectrum and level representative of typical ventilation noises in offices. In the first experiment subjects experienced only different noise spectra at constant noise level, but in the second experiment they experienced a combination of noise spectrum and noise level.

2.0 Experiment 1: Effects of Masking Noise Spectrum on Satisfaction

2.1 Method

2.1.1 Objective. Because of the many possible combinations of noise spectrum shape and noise level, the first experiment was intended to first develop an understanding of the importance of noise spectrum on satisfaction ratings. In this experiment subjects experienced 15 different simulated noise spectra in combination with the speech from simulated telephone conversations.

2.1.2 Participants. Participants were recruited from an office temporary services supplier and paid at the standard rate for a day's clerical work. They were tested by the supplier to ensure a minimum level of English fluency and were experienced in the use of Windows-based word processing and spreadsheet software. The participants knew that the day's work was in support of a research project concerning the effects of the physical environment on office workers. They received advance information from the supplier (Appendix A), and completed an informed consent procedure at the start of the day at NRC (Appendix B).

Complete data were obtained from 35 participants (17 women and 18 men), ranging in age from 18 - 65 years (*M*=32. 9, *SD*=12.8). Other self-rated characteristics are reported in Table 1. Two additional participants did not complete the full day, and their data were excluded from analysis.

Table 1. *Characteristics of Experiment 1 Participants.*

Hearing Impairment	1 = yes 34 = no
Hearing Aid	1 = yes 34 = no
Visual Aids	18 = none 11 = distance glasses 2 = bifocals 3 = contact lenses 1 = no response
Education	21 = High school 5 = community college / CEGEP 7 = undergraduate degree 2 = graduate degree
Years in work force	Range 1 year - 40 years *M* = 12.4 years *SD* = 10.3 years

Participants completed a Hughson Westlake threshold of audibility hearing test at the start of the test day. Their hearing levels relative to threshold values at 500, 1000, 2000, 3000, 4000, and 6000 Hz were summed and subjects with values greater than 20 were classified as having some hearing impairment. The data for Experiment 1 participants, however, was uninterpretable because of an operator error during testing. One participant reported wearing a hearing aid; this person's data were retained for analysis on the basis of the self-reported correction.

2.1.3 Setting. The experiment took place in the Indoor Environment Research Facility (IERF) in Building M-24 on the Montreal Road Campus in Ottawa, Ontario. The IERF is a mocked-up 12.2 x 7.3 m (40 x 24 ft) office designed for acoustics, lighting, ventilation, and indoor air quality research. Interior designers at Public Works and Government Services Canada were hired to lay out the space as a typical mid-level clerical or administrative office similar to those currently being installed in Canadian government buildings (Figure 1). The result is a design having six open-plan workstations of approximately 6 m^2 (65 ft^2) with space for shared file cabinets and printers at the end of the room. The workstations are standard modular systems furniture with computers, storage space, keyboard shelf, and adjustable-height chair. For this experiment, the room was windowless. Temperature, lighting, and ventilation remained unchanged over all experimental sessions and were within normal guidelines for office environments.

Figure 1. *View of NRC's Indoor Environment Research Facility.*

Up to five participants attended on one day; the sixth workstation (workstation 2, in the centre of the back row of workstations) was reserved for the simulated occupant whose speech was masked by the simulated ventilation noise that was the focus of the experiment. The experimental sessions began in the reception/lounge room outside the experimental facility (IERF). This room is equipped with comfortable chairs, a coffee area, and coatroom. The initial instructions, including the signing of the consent form, and all coffee and lunch breaks all occurred in this space. The participants then proceeded to their assigned workstations in the IERF, where the day's work was presented on the computer. The experimenter monitored the participants during the day from the control room using the security monitoring system (video only) in the IERF. The participants were aware that the security cameras were in use and that no permanent record was kept. (Participants were able to contact the experimenter by telephone to the control room; if necessary, the experimenter went to the participant's workstation to answer questions or to resolve problems.)

2.1.4 Independent variable. The experiment included 15 different noise spectra, which masked the speech sounds. These were representative of the range of ventilation noises found in office buildings (Broner, 1993; Tang & Wong, 1998). Each noise spectrum was presented for a total of 18 minutes, in which 12-13 minutes were occupied with performance tasks and approximately 5 minutes were devoted to answering a set of satisfaction questions (see below).

During each trial there was almost continuous speech consisting of a single female voice speaking at a realistic speech level in one workstation (workstation 2, the centre at the back of the IERF). The speech was played back from custom digital recordings of one-sided dialogues simulating one side of telephone conversations. The simulated occupant, "Margo Fontaine", was represented by the voice of an actress reading scripts of telephone conversations in which she called job candidates to arrange for interviews or starting dates, made internal arrangements for new employees, and made personal social calls. The conversations were balanced to maintain approximately the same total length of speech for each trial. The overall level of speech sounds was kept at a constant level of 54.5 dB(A) measured in the same workstation, 1 m from the source, which is consistent with other measured values (Pearsons, Bennett, & Fidel, 1977). When measured at the location of the listener's ear in the other workstations, the mean value was *M*=42.74 dB(A) (*SD*=1.17) for all calls (across workstations, range 41.16 – 44.44 dB(A)).

The 15 noise spectra were created by systematically increasing or decreasing the levels in the low, mid and high frequency regions relative to a –5 dB/octave neutral spectrum shape. The concept that a –5 dB/octave spectrum has a neutral quality and the low mid and high frequency groupings were those suggested in the Room Criterion (RC) rating procedure (American Society for Heating Refrigerating and Air Conditioning Engineers (ASHRAE), 2001; Blazier, 1981). According to this procedure the 16, 31 and 63 Hz octave bands are considered low frequencies; the 125, 250 and 500 Hz bands mid-frequencies and the 1000, 2000, and 4000 Hz bands are high frequencies. Figure 2 illustrates conceptually the increases and decreases in these three frequency ranges that were used to create the experimental noise spectra and gives the two-letter names of each noise spectrum increase (boost) or decrease (cut). The 15 noise spectra were created through trial and error, selecting clearly obvious changes resulting from combinations of the various boosts and cuts to the three frequency ranges.

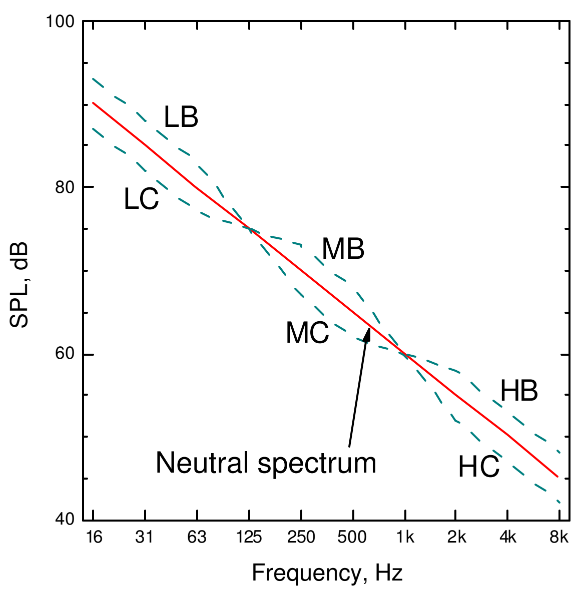


Figure 2. *Symbolic illustration of the noise spectrum shapes used in Experiment 1. LC=low cut, LB=low boost, MC=mid cut, MB=mid boost, HC=high cut, HB=high boost*

After the various increases (boost) and decreases (cut) were made in each frequency range, the overall levels were then adjusted so that all spectra had the same overall loudness level. Thus subjects experienced only changes in noise spectrum and not changes in noise level.

The average measured noise spectra in each workstation are illustrated in Figure 3. This Figure compares the measured noise spectra with the measured average speech spectrum and also with a –5 dB/octave reference line. Each of the 15 spectrum plots also includes the spectrum name and the calculated SII (Speech Intelligibility Index) value. For example LC-MB-HB indicates that the spectrum was created as the combination of a low cut (LC) a mid boost (MB) and a high boost (HB). One spectrum is described as neutral and approximately parallels the –5 dB/octave reference line. Another spectrum is labelled Neutral+3 dB and is the same Neutral spectrum shape but increased in level by 3 dB. This was included to help tie in results to the second experiment in which both noise levels and spectrum shape were varied.

Table 2 describes the noise conditions in terms of a variety of acoustic indices, taking into account the number of participants who occupied each workstation. Appendix E describes the various noise measures included in Table 2. Values in the column L_N(A) show that the total A-weighted noise levels varied a little (42-47 dB(A)), but the range of the overall loudness levels (LL_N) was less than 1 dB (except for the Neutral + 3 spectrum which was deliberately increased in level). These levels are typical of those commonly experienced in office environments (Broner, 1993; Tang & Wong, 1998; Warnock & Chu, 2002).

Figure 3. *The 15 noise spectra (solid lines) from Experiment 1 compared with the measured speech spectrum (dashed line) and a –5 dB/octave reference line (dotted).*

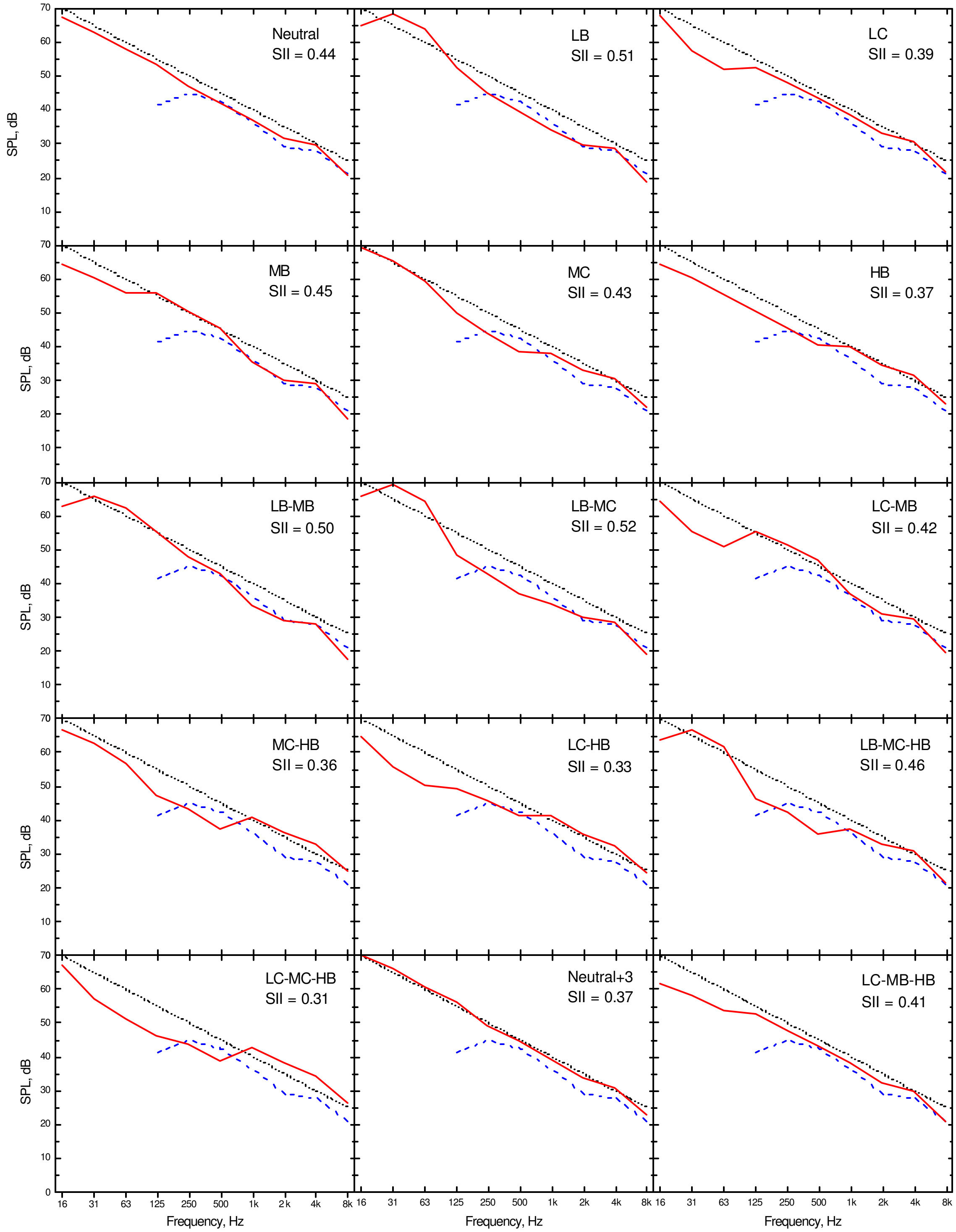


Table 2. *Noise measurements for Experiment 1 conditions, averaged across workstations. (See Appendix E for explanation of these acoustical measures).*

Condition	SII	AI	QAI	s_{16-63}	Low(A)	High(A)	Lo-Hi(A)
Neutral	0.44	0.36	2.81	2.09	42.93	38.76	4.18
LB	0.51	0.43	7.19	2.33	42.44	36.63	5.81
LC	0.39	0.31	1.62	1.84	43.71	40.22	3.49
MB	0.45	0.38	3.76	2.00	45.91	37.49	8.42
MC	0.43	0.35	7.84	2.14	40.40	39.78	0.61
HB	0.37	0.29	5.25	2.06	41.01	41.69	-0.68
LB-MB	0.50	0.43	4.92	2.25	44.53	35.89	8.64
LB-MC	0.52	0.44	10.45	2.33	41.24	36.54	4.70
LC-MB	0.42	0.34	5.46	1.89	46.74	38.50	8.24
MC-HB	0.36	0.28	9.34	2.14	38.64	42.85	-4.22
LC-HB	0.33	0.25	6.63	1.81	41.25	43.05	-1.81
LB-MC-HB	0.46	0.37	9.66	2.41	39.33	39.50	-0.17
LC-MC-HB	0.31	0.23	9.38	1.87	38.66	44.64	-5.97
Neutral+3dB	0.37	0.29	3.21	2.13	45.49	40.95	4.55
LC-MB-HB	0.41	0.33	3.07	1.99	43.55	39.84	3.71

Condition	RNC	RNC_{nf}	RC	PNC	LL_N	L_N(A)	S/N(LL)	S/N(A)
Neutral	45.42	42.18	36.57	38.83	64.43	43.98	-3.74	-1.23
LB	53.50	51.56	33.94	46.03	64.95	42.92	-4.26	-0.17
LC	38.23	38.23	37.97	39.57	64.51	45.04	-3.82	-2.30
MB	40.97	39.98	36.57	42.06	65.07	46.02	-4.38	-3.27
MC	48.27	45.13	36.20	40.63	64.26	42.86	-3.56	-0.11
HB	39.99	38.65	38.20	39.94	64.56	44.18	-3.86	-1.44
LB-MB	51.68	49.54	35.14	42.60	65.00	44.52	-4.31	-1.77
LB-MC	53.85	51.99	33.29	46.83	64.97	42.00	-4.27	0.75
LC-MB	41.28	41.28	37.57	42.37	65.12	46.99	-4.43	-4.24
MC-HB	42.53	40.24	38.00	40.77	64.64	44.13	-3.95	-1.39
LC-HB	39.62	39.62	39.20	41.23	64.68	45.09	-3.99	-2.35
LB-MC-HB	51.80	49.25	34.57	43.40	64.62	42.15	-3.93	0.59
LC-MC-HB	41.12	41.12	39.17	42.40	64.91	45.55	-4.21	-2.80
Neutral+3dB	50.29	47.71	38.97	42.23	67.14	46.37	-6.44	-3.63
LC-MB-HB	37.94	37.94	37.97	39.17	64.41	44.76	-3.72	-2.02

2.1.5 Dependent measures.

The outcome measures encompassed several domains:

Demographic variables. Participants were asked to record their age, sex, education, years of work experience (both overall and experience as a temporary office worker), the state of their vision (corrected or not), and hearing.

Cognitive and clerical performance. Although satisfaction was the principal outcome of interest in these experiments, it was necessary to occupy the participants during their exposure to the noise stimuli. These data will be analysed and reported separately. Environmental noise is known to affect performance of complex cognitive tasks and memory (Banbury & Berry, 1998; Sundstrom, 1987). Complex cognitive tasks are typical of many offices; consequently, these tasks have been chosen to represent the tasks that would be performed in real offices in which masking noise systems were installed.

The memory tasks were word list recognition (in which a participant was shown a list of words on the computer screen at the start of each 15-minute trial, and at the end of the trial was asked to select from a list of words those that were on the original list), recall and recognition of text reading (in which participants read a text about an arbitrary subject, and are subsequently asked a few open-ended and multiple-choice questions about the text), and, grammatical fluency (in which participants are presented with a sentence in which there is a grammatical error, which they must identify). These tasks encompass episodic, semantic, and incidental memory processes; some of these are known to be influenced by noise exposure (e.g., episodic memory), and others not (semantic memory) (Banbury & Berry, 1998).

Participants were also presented with a passage printed on paper in which there were randomly placed typographical errors. They were required to re-type the text into the computer, correcting the errors as they typed. The software into which they typed the text required correct data entry, and recorded both speed and accuracy.

Satisfaction. Judgements about overall satisfaction with the work setting and the acoustic environment were assessed using a questionnaire developed for this study (Appendix C). Overall ratings of environmental satisfaction were based on three questions adapted from Sundstrom, Town, Rice, Osborn, and Brill (1994). Specific ratings of the degree of distraction of the noise, perceived privacy under those noise conditions, and satisfaction with the acoustic conditions were asked on 5-point Likert scales; some of these were adapted from Sundstrom, Burt, and Kamp (1980) and Sundstrom, Town, Brown, Forman, & McGee (1982). All questionnaires were presented on the computer screen using questionnaire software developed at NRC (Newsham & Tiller, 1995).

Noise sensitivity. Sensitivity to environmental noise is a personality trait that has been considered to help explain responses. To explore such individual differences we asked participants to complete Weinstein's (1978) noise sensitivity scale (Appendix D). Minor changes in wording were made to bring the phrasing up-to-date.

Workday experiences questionnaire. As a standard practice, we ask participants to report on their experiences during the session using open-ended questions about their beliefs concerning the nature of the study and factors that might have affected them during the day.

2.1.6 Procedure. The schedule for each testing day is depicted in Table 3. Activities in italics took place in the reception room. Those in plain type occurred in the experimental facility (IERF).

The participants, scheduled in groups of up to 5 (all male or all female) were asked to arrive at 8:30 a.m. and were greeted by the experimenters. They assembled in the reception area outside the IERF for the initial explanation (based on the information outlined in Appendix A), which was presented on videotape to ensure consistency from one testing day to another, and signed the consent form following a question period. While individuals had their hearing sensitivity tested, the rest of the group waited in the reception room. After all had completed this test, each was assigned a workstation in the IERF, which was theirs for the day.

Computer prompts guided the participants through the experimental session. The session began with a demographic questionnaire, which was followed by a set of satisfaction ratings of the neutral-spectrum masking sound, to provide a baseline, and a series of instructions concerning the tasks in each trial. Then, there were fifteen 15-min periods of noise exposure with concurrent speech, cognitive and clerical tasks, and satisfaction questions, and a final questionnaire about their experiences. The session was punctuated by a 45-min lunch break and a 15-min break in the afternoon, taken in the reception room or in the NRC cafeteria in building M-21, across the road.

Table 3. *Schedule for Testing Day. Activities in italic text took place in the reception room; activities in plain text took place in the IERF.*

Approx. Time	Task	Duration (min)
8:45 a.m.	*Arrival, greeting, instructions, consent*	*15*
9:00 a.m.	Hearing threshold test (individual testing, approx. 10 min each)	*50*
10:00	Begin session in IERF - Demographics, task practice	10
	Baseline satisfaction questions	5

10:15	6 – 18 min trials (exposures to different masking sounds and speech)
	During each trial participants completed:
	• Word List Presentation - 20 sec
	  • Reading Text - 2 min
	  • Grammar Fluency (10 ques.) - 3 min
	  • Reading Comprehension (10 ques.) - 3 min
	  • Text Editing/Typing - 3.5 min
	  These 4 tasks occurred in 4 orders so that at least one person was doing the editing task at any time (to maintain the same degree of distraction from keyboard noise).
	• Word List Recognition - 40 sec
	• Environmental Satisfaction (16 items) - 5 min
		108

12:00	*Lunch*	*45*
12:45	5 – 18 min exposures to different masking sounds	90
14:15	*Break*	*15*
14:30	4 - 18 min exposures to different masking sounds	72
15:45	Workday experiences questionnaire	15
16:15 p.m.	*Debriefing and farewell*	*15*

With 15 experimental conditions, a Latin Square approach to controlling for order effects was not feasible. Instead, there were six different randomised orders of the 15 sound conditions, one for each day of testing. Six sessions were originally planned, but eight were required to reach the desired sample size. Therefore two of the orders were used twice.

There was also a partial control for the order of presentation of the reading texts and grammar questions; a different order was installed in each of the five workstations occupied by participants. Thus, the content of the tasks and the noise conditions were not confounded (although there was some overlap because of the extra testing days). In addition, within trials there were four orders of the reading, grammar, and editing tasks (between the word list presentation and recall test), so that at any time at least one person did the editing task and the level of keyboard noise distraction was approximately constant.

2.2 Results

2.2.1 Descriptive statistics. The ratings of satisfaction (Appendix C) consisted of 9 acoustic satisfaction questions rated on 5-point scales, three items rating the characteristics of the noise on 5-point scales (rumble, hiss, and loudness), one 7-point scale rating of self-rated productivity, and one 0-100 sliding scale question concerning the intelligibility of the speech sounds. There were also two open-ended questions, responses to which are discussed below.

The responses to three acoustic satisfaction questions (numbers 5, 6, and 13 in Appendix C) were reverse-scored so that low scores always reflect lower satisfaction, and high scores relate to greater satisfaction. All scales are from 0-4. Several attempts were made to reduce the nine items to a smaller subset of interpretable subscales, but the factor structure was not stable (i.e., the results varied depending on noise conditions being rated). Consequently, it was decided to form one overall rating of acoustic satisfaction for each experimental condition, by averaging the responses to the nine items.

Thus, there were six dependent variables, which were labelled: Acoustic Satisfaction, Productivity, Speech Intelligibility, Rumble, Hiss, and Loudness. Table 4 shows the descriptive statistics for the six variables for each of the 15 experimental conditions, and overall.

Table 4. *Experiment 1 Descriptive Statistics for Satisfaction Measures.*

Condition Statistic	Acoustic Satisfaction	Productivity	Speech Intelligibility	Rumble	Hiss	Loudness
OVERALL	a = .88					
Range	0.11 – 3.33	0 – 5	0 – 100	0 – 4	0 – 4	0 - 4
Median	1.67	2	64	1	1	2
Mean (SD)	1.68 (0.70)	2.32 (1.10)	60.14 (28.07)	1.28 (1.05)	1.58 (1.13)	2.14 (0.88)
Neutral						
Range	0.33 – 3.00	0 - 4	9 - 100	0 - 4	0 - 4	1 - 4
Median	1.78	2	51	1	1	2
Mean (SD)	1.74 (0.65)	2.50 (0.96)	58.80 (27.20)	1.18 (1.00)	1.51 (0.92)	2.09 (0.78)
LB						
Range	0.33 - 3.00	0 - 5	10 - 100	0 - 4	0 - 4	1 - 4
Median	1.78	2	77	1	1	2
Mean (SD)	1.66 (0.70)	2.46 (1.31)	71.51 (23.19)	1.31 (0.93)	0.97 (1.01)	1.86 (0.81)
LC						
Range	0.33 – 3.00	0 - 5	0 - 100	0 - 4	0 - 4	1 - 4
Median	1.89	2	67	1	1	2
Mean (SD)	1.71 (0.70)	2.37 (1.17	58.37 (27.63)	1.26 (1.12)	1.57 (1.12)	2.17 (0.86)
MB						
Range	0.33 - 3.11	0 - 5	10 - 95	0 - 4	0 - 4	1 - 4
Median	1.78	3	63	1	1	2
Mean (SD)	1.77 (0.68)	2.60 (1.09)	59.09 (25.68)	1.54 (0.98)	1.23 (0.94)	2.00 (0.80)
MC						
Range	0.33 - 3.11	0 - 4	12 - 100	0 - 4	0 - 4	1 - 4
Median	1.67	2	65	1	1	2
Mean (SD)	1.58 (0.68)	2.11 (1.02)	64.46 (27.94)	1.26 (0.99)	1.46 (1.04)	2.14 (0.88)
HB						
Range	0.33 - 2.89	0 - 5	15 - 100	0 - 4	0 - 4	1 - 4
Median	1.78	2	52	1	2	2
Mean (SD)	1.72 (0.72)	2.41 (0.99)	54.11 (26.34)	1.14 (0.91)	1.91 (1.09)	2.09 (0.89)
LB-MB						
Range	0.11 - 3.33	0 - 5	12 - 99	0 - 4	0 - 4	1 - 4
Median	1.67	2	80	1	1	2
Mean (SD)	1.69 (0.75)	2.11 (1.18)	68.14 (25.28)	1.32 (0.91)	1.03 (1.01)	1.91 (0.78)
LB-MC						
Range	0.56 - 3.11	1 - 5	10 - 100	0 - 3	0 - 3	0 - 3
Median	1.67	2	80	1	1	1
Mean (SD)	1.69 (0.70)	2.46 (1.15)	72.00 (27.67)	1.20 (0.96)	0.74 (0.78)	1.63 (0.84)
LC-MB						
Range	0.56 - 3.11	0 - 4	7 - 99	0 - 4	0 - 4	1 - 4
Median	1.89	2	67	1	1	2
Mean (SD)	1.77 (0.72)	2.23 (0.97)	61.11 (26.63	1.54 (1.17)	1.26 (1.01)	2.03 (0.86)
MC-HB						
Range	0.33 - 2.89	0 - 4	9 - 99	0 - 4	1 - 4	1 - 4
Median	1.67	2	64	1	2	3
Mean (SD)	1.65 (0.64)	2.24 (1.02)	57.71 (26.87)	1.03 (1.10)	2.26 (1.01)	2.43 (0.74)

Condition Statistic	Acoustic Satisfaction	Productivity	Speech Intelligibility	Rumble	Hiss	Loudness
LC-HB						
Range	0.33 - 3.11	0 - 5	1 - 98	0 - 4	1 - 4	1 - 4
Median	1.67	2	66	1	2	2
Mean (SD)	1.67 (0.73)	2.20 (1.02)	57.14 (29.72)	1.23 (1.19)	2.14 (1.06)	2.37 (0.97)
LB-MC-HB						
Range	0.11 - 3.11	0 - 4	17 - 100	0 - 4	0 - 4	1 - 4
Median	1.67	2	80	1	2	2
Mean (SD)	1.58 (0.72)	2.06 (1.04)	68.69 (27.17)	1.29 (0.99)	1.77 (0.97)	2.23 (0.88)
LC-MC-HB						
Range	0.33 - 2.89	0 - 5	2 - 100	0 - 4	0 - 4	1 - 4
Median	1.44	2	50	1	3	3
Mean (SD)	1.52 (0.69)	2.09 (1.15)	52.57 (30.58)	0.83 (1.07)	2.77 (1.29)	2.71 (0.93)
Neutral +3dB						
Range	0.33 – 3.00	0 - 5	1 - 100	0 - 4	0 - 4	1 - 4
Median	1.78	2	44	1	1)	3
Mean (SD)	1.77 (0.67)	2.56 (1.13)	48.29 (29.20)	1.69 (1.11)	1.60 (0.95	2.46 (0.89)
LC-MB-HB						
Range	0.33 - 3.22	0 - 5	0 - 96	0 - 4	0 - 4	1 - 4
Median	1.78	2	57	1	1	2
Mean (SD)	1.70 (0.75)	2.47 (1.19)	50.06 (30.33)	1.31 (1.16)	1.40 (1.03)	2.03 (0.90)

Figure 4 shows the means and standard deviations for the six dependent variables and 15 noise conditions in graphic form. The effects of masking noise spectrum are clearly larger on the ratings of the noise (speech intelligibility, rumble, hiss, and loudness) than on the satisfaction ratings (acoustic satisfaction and self-rated productivity). This is evident from the greater variability in the means. Moreover, none of the satisfaction or productivity means rise above the midpoints of the scales on which they were measured (2 for satisfaction, and 3 for productivity), indicating that on average the participants found none of the noise conditions to be satisfactory.

Figure 4. *Means and standard deviations for 15 masking noise conditions on the six dependent variables.*

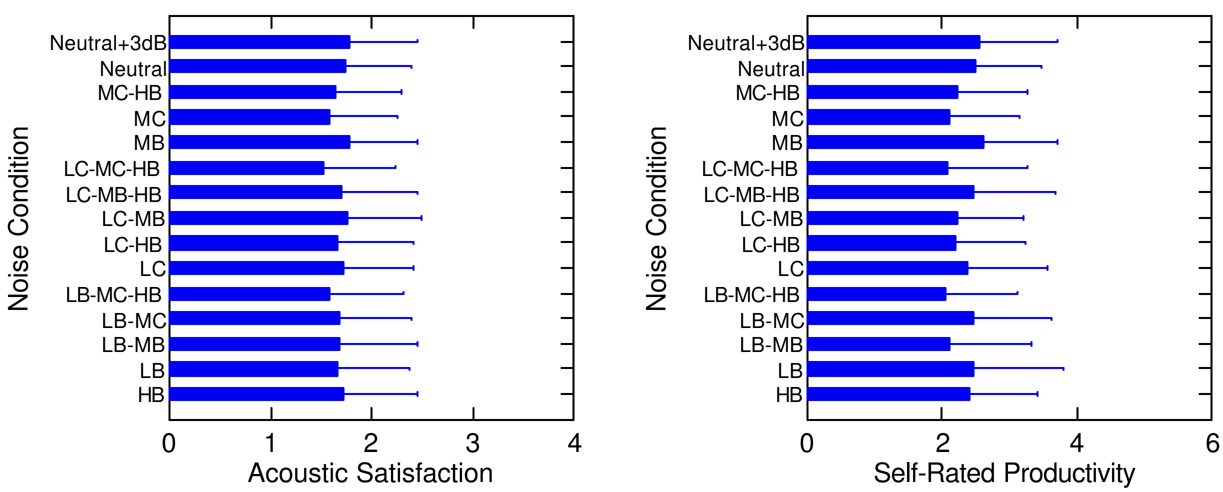
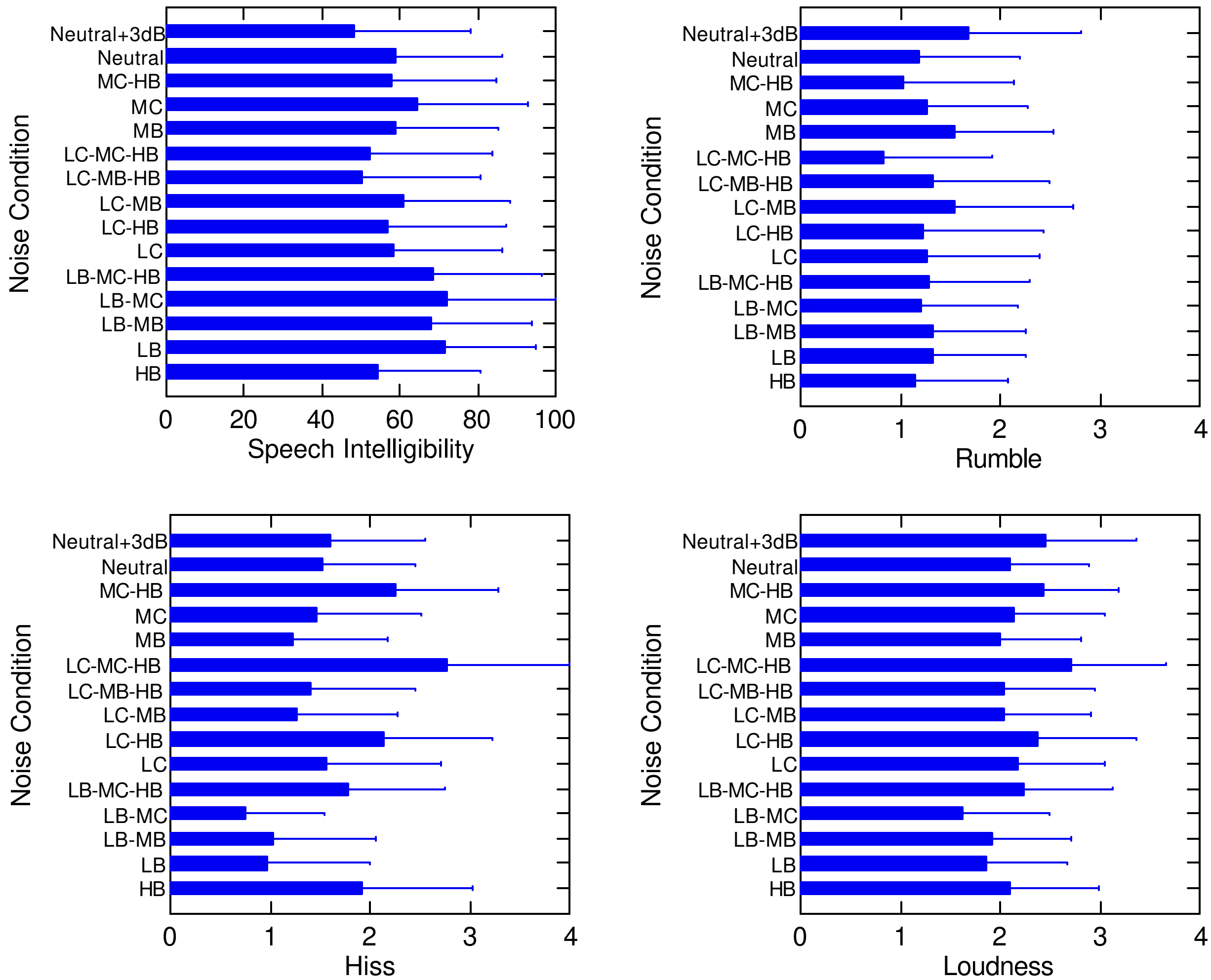


Figure 4. *Means and standard deviations for 15 masking noise conditions on the six dependent variables.*



2.2.2 Overall effects of noise conditions. Prior to proceeding, we performed preliminary statistical tests to determine whether there were overall effects of the noise conditions on the six dependent measures. The omnibus repeated-measures test of Noise Conditions (collapsed across all dependent variables) was statistically significant and moderate to large in size ($F(14, 434) = 5.27$, $p<.001$, *partial* $?^2=.15$)*. The interaction test of Dependent Variable by Noise Condition was also statistically significant (($F(70, 2170) = 6.32$, $p<.001$, *partial* $?^2=.17$). The latter test indicates that the effect of the noise conditions differed across the six dependent variables. We therefore proceeded to examine the exact relationship between the noise conditions and the dependent variables.

2.2.3 Measures of spectral characteristics. Most of the acoustical measures are intended to assess the level of the noise with some particular

* Partial $?^2$ is a measure of the strength of the association between the independent and dependent variables (Tabachnick & Fidell, 2001). It is the proportion of variance in the dependent variable that is uniquely attributable to the effect of interest, after all other non-error sources of variance have been removed [Partial $?^2$ = Sum of Squares_{EFFECT}/(Sum of Squares_{EFFECT} + Sum of Squares_{ERROR})]. It has a theoretical range from 0 to 1. Because partial $?^2$ are based on different denominators, they are not additive (i.e., all the partial $?^2$ for all the effects on a particular dependent variable can sum to more than 1).

weighting of the different frequency components. Only one existing measure (QAI) was found to relate to differences in spectral characteristics. As included in the following section of this report, this was the only acoustical measure found to be significantly related to satisfaction ratings in this experiment. The importance of particular frequency components of the noise was therefore investigated in more detail. This was done initially in terms of aggregate responses concerning the rating of the rumble, hiss and loudness characteristics of the noises. (Items 2, 3 and 4 in Appendix D). These aggregate response scores were correlated with measured values of octave band noise levels and the resulting correlation coefficients are included in Table 5. Only significant ($p < 0.05$) results are included.

As expected, mean rumble ratings were most strongly correlated with the 125, 250 and 500 Hz octave band noise levels. (The correlations are negative because these responses were reverse coded). The rumble ratings were also significantly related to some higher frequency noise levels but the sign of the correlation was reversed. Thus although rumble ratings increase with increasing low frequency noise levels, they decrease with increasing high frequency noise levels.

Also as expected, the ratings of the hissy character of the noises were very strongly correlated with the higher frequency octave band noise levels and weakly with the measured noise levels in the 63 and 125 Hz octave bands. Judgements of the loudness of the noises were similarly most strongly correlated with the higher frequency octave band levels because the higher frequencies have a greater influence on loudness.

These results do not agree with the RC rating system (ASHRAE, 2001) that suggests that rumble is related to noise levels in the lowest octave bands (i.e. 16 to 63 Hz). Although the sound levels of the noise spectra in Figure 3 were higher in these very low frequency octave bands, they would not be perceived to be as loud as the 125 to 500 Hz octave band levels. Even though they are representative of typical office noises, some of the lowest octave bands may not even be audible. Thus the 125 to 500 Hz octave band levels probably have greater influence on Rumble ratings because they are more noticeable to subjects.

Table 5. *Correlation coefficients for significant ($p<0.05$) correlations of aggregate ratings of rumble, hiss and loudness and the measured octave band levels of the noises.*

Octave noise levels	Rumble	Hiss	Loudness
NL_16			
NL_31			
NL_63		0.56	
NL_125	-0.78	0.55	
NL_250	-0.70		
NL_500	-0.65		
NL_1000		-0.94	-0.88
NL_2000	0.58	-0.95	-0.86
NL_4000	0.59	-0.97	-0.87
NL_8000	0.55	-0.94	-0.88

New measures of the spectral characteristics of the noises were created that included simple approximations to the loudness of the frequency components in various frequency ranges. The loudness estimates were created by A-weighting the individual octave band noise levels and then summing the A-weighted sound levels over groups of octave bands. In one case the octaves were summed in three groups, as in the RC rating procedure, as low (16 to 63 Hz), mid (125 to 500 Hz) and high (1000 to 4000 Hz) frequency groups. In a simpler scheme only two groups were considered, low (16 to 500 Hz) and high (1000 to 8000 Hz). New spectral measures were then created as differences between the A-weighted levels of the 2 or 3 frequency groups. The simple difference between the A-weighted low (16 to 500 Hz) and high (1000 to 8000 Hz) groups was best correlated with the aggregate ratings of rumble and hiss. This level difference between low and high frequency A-weighted levels is referred to as Lo-Hi(A) in this report and was found to be a strong correlate of the aggregate judgements of the rumble (r = 0.859, p< 0.001)and hiss (r = 0.884, p<0.001) characteristics of the noises.

2.2.4 Predictions from noise characteristics.

In this experiment, every participant experienced every noise condition. The noise conditions differed slightly depending on which workstation the participant occupied. We can describe the noise conditions as having been nested within individuals. In such a case, hierarchical linear modelling (HLM) is the appropriate statistical technique to use for predicting dependent variables (acoustic satisfaction, loudness, etc.) from acoustic variables that describe the noise conditions (Bryk & Raudenbush, 1992). Conceptually, this technique creates separate regression lines for each individual, then tests the slopes of the regression lines for statistical significance against the null hypothesis that the average slope is 0. This separates the variance associated with individuals from the variability associated with the noise conditions, providing a good estimate of the likely population effect.

We selected a subset of 15 different acoustic variables for use in these analyses, all derived from detailed measurements of the acoustic conditions. Although each has its own calculation algorithm, most of the values are highly intercorrelated, which prevented these analyses from using more than one of the variables. We repeated the HLM analyses for the 15 predictors on each of the six dependent variables.

The outcome is summarised in Table 6. The table shows, for each dependent measure, the summary statistics for its prediction from the various acoustic variables. The intercept is the average value (across all 35 participants) that the dependent variable (e.g., acoustic satisfaction) would have if the predictor (e.g., SII) were 0. This value differs widely across individuals and consequently is always statistically significant; further examination of these differences was beyond the scope of this project. The B-weight shown in the table is the average slope of the 35 regression lines (that is, it shows the unit increase in the dependent variable associated with a 1-unit increase in the independent variable). The *z* score and associated *p* and partial $?^2$ are those associated with the B-weight. $?^2_{partial}$ is the squared partial correlation coefficient associated with the B-weight for that regression line, and is a measure of effect size, having a theoretical minimum of 0 and maximum of 1 (Tabachnick & Fidell, 2001). This is the unique variance in acoustic satisfaction explained by that predictor variable. It is calculated as $?^2_{partial} = z^2/(z^2+df)$ [for these models, df=34]. The $?^2_{partial}$ values are shown only for those regressions having statistically significant B-weights.

Table 6. *HLM Summary Outcomes*

6.A *Models for Acoustic Satisfaction*

Variable	Mean (SD)	Min-Max	Intercept	B-weight	z_B	*p*	$?^2_{partial}$

Acoustic Satisfaction	1.68 (0.70)	0.111 - 3.333	-	-	-	-	-
SII	0.42 (0.07)	0.26-0.56	1.58*	0.211	0.58	0.56	
AI	0.34 (0.07)	0.17 - 0.48	1.59*	0.245	0.70	.48	
QAI	6.04 (3.06)	0.27-13.19	1.77*	-0.016	-2.54	.01	.16
s_{16-63}	2.09 (0.24)	1.64 - 2.69	1.79*	-0.052	-0.40	.69	
Low(A)	42.39 (2.71)	36.63 - 48.00	~	~	~	~	
High(A)	39.75 (2.57)	34.69 - 45.77	2.14*	-0.01	-1.43	.15	
Lo-HI(A)	2.63 (4.61)	-7.7 - 10.4	1.65*	0.011	3.05	.00	.21
RNC	45.10 (5.76)	37.33-54.91	1.78*	-0.002	-0.51	.61	
RNC_{nf}	43.63 (5.02)	37.33 - 52.75	1.81*	-0.003	-0.51	.56	
RC	36.89 (1.97)	32 - 40	1.62*	0.002	0.14	.89	
PNC	41.87 (2.42)	37 - 48	1.74*	-0.001	-0.16	.87	
LL_N†	64.89 (0.95)	63.07 - 67.92	~	~	~	~	
L_N(A)	44.44 (1.57)	40.37 - 47.84	0.57*	0.025	1.83	.07	
S/N(LL)	-4.19 (1.36)	-8.53 - -2.03	~	~	~	~	
S/N(A)	-1.69 (1.81)	-5.85 - 2.46	1.64*	-0.024	-1.68	.09	

Note. *This intercept estimate was statistically significant, reflective of differences in acoustic satisfaction levels between individuals. ~ This model was unable to be fitted. †In this experiment, LL_N was held constant; therefore, it does not predict any of these outcomes.

6.B. *Models for Self-rated Productivity*

Variable	Mean (SD)	Min-Max	Intercept	B-weight	z_B	*p*	$?^2_{partial}$
Self-rated Productivity	2.32 (1.10)	0 - 5	-	-	-	-	-
SII	0.42 (0.07)	0.26-0.56	2.09*	0.51	0.71	.48	
AI	0.34 (0.07)	0.17 - 0.48	2.12*	0.70	0.80	.43	
QAI	6.04 (3.06)	0.27-13.19	~	~	~	~	
s_{16-63}	2.09 (0.24)	1.64 - 2.69	2.30*	0.02	0.08	.94	
Low(A)	42.39 (2.71)	36.63 - 48.00	~	~	~	~	
High(A)	39.75 (2.57)	34.69 - 45.77	3.21	-0.02	-1.32	.19	
Lo-Hi(A)	2.66 (4.62)	-7.7 - 10.4	2.27*	0.02	2.51	.01	.16
RNC	45.12 (5.77)	37.33-54.91	2.43*	0.01	-0.32	.75	
RNC_{nf}	43.66 (5.02)	37.33 - 52.75	2.46*	-0.00	-0.38	.70	
RC	36.88 (1.98)	32 - 40	2.44*	-0.00	-0.14	.89	
PNC	41.89 (2.41)	37 - 48	2.14*	0.00	0.27	.79	
LL_N†	64.89 (0.95)	63.07 - 67.92	~	~	~	~	
L_N(A)	44.45 (1.57)	40.37 - 47.84	1.27*	0.02	1.02	.31	
S/N(LL)	-4.20 (1.36)	-8.53 - -2.03	~	~	~	~	
S/N(A)	-1.70 (1.81)	-5.85 - 2.46	2.28*	-0.03	-1.11	.27	

6.C. *Models for Speech Intelligibility*

Variable	**Mean (SD)**	**Min-Max**	**Intercept**	**B-weight**	z_B	***p***	$?^{2}_{partial}$
Speech Intelligibility	60.14 (28.07)	0 - 100	-	-	-	-	-
SII	0.42 (0.07)	0.26-0.56	20.78*	95.61	5.25	.00	.45
AI	0.34 (0.07)	0.17 - 0.48	29.60*	92.09	5.12	.00	.44
QAI	6.04 (3.06)	0.27-13.19	~	~	~	~	
s_{16-63}	2.09 (0.24)	1.64 - 2.69	13.96*	22.42	4.18	.00	.34
Low(A)	42.39 (2.71)	36.63 - 48.00	~	~	~	~	
High(A)	39.75 (2.57)	34.69 - 45.77	139.32	-1.99	-4.60	.00	.38
Lo-Hi(A)	2.63 (4.61)	-7.7 - 10.4	58.63*	0.53	2.63	.01	.17
RNC	45.10 (5.76)	37.33-54.91	21.31*	0.86	4.79	.00	.40
RNC_{nf}	43.63 (5.02)	37.33 - 52.75	15.90*	1.01	4.91	.00	.41
RC	36.89 (1.97)	32 - 40	~	~	~	~	
PNC	41.87 (2.42)	37 - 48	-14.20*	1.77	4.29	.00	.35
$LL_N^{\dagger}$	64.89 (0.95)	63.07 - 67.92	~	~	~	~	
L_N(A)	44.44 (1.57)	40.37 - 47.84	221.17*	-3.62	-5.84	.00	.50
S/N(LL)	-4.19 (1.36)	-8.53 - -2.03	78.31*	4.30	3.66	.00	.28
S/N(A)	-1.69 (1.81)	-5.85 - 2.46	66.76*	3.46	5.40	.00	.46

6.D. *Models for Rumble Ratings*

Variable	**Mean (SD)**	**Min-Max**	**Intercept**	**B-weight**	z_B	***p***	$?^{2}_{partial}$
Rumble	1.28 (1.05)	0 - 4	-	-	-	-	-
SII	0.42 (0.07)	0.26-0.56	0.83*	1.07	1.54	.12	
AI	0.34 (0.07)	0.17 - 0.48	0.88*	1.19	1.78	.08	
QAI	6.05 (3.06)	0.27-13.19	~	~	~	~	
s_{16-63}	2.09 (0.24)	1.64 - 2.69	0.99*	0.15	0.65	.51	
Low(A)	42.39 (2.71)	36.63 - 48.00	-1.51	0.07	4.29	.00	.35
High(A)	39.75 (2.57)	34.69 - 45.77	3.01	-0.04	-2.60	.01	.17
Lo-Hi(A)	2.63 (4.61)	-7.7 - 10.4	1.18*	0.04	4.06	.00	.33
RNC	45.08 (5.77)	37.33-54.91	0.95*	0.01	0.90	.37	
RNC_{nf}	43.62 (5.02)	37.33 - 52.75	0.89*	0.01	0.96	.34	
RC	36.89 (1.98)	32 - 40	1.85*	-0.02	-0.69	.49	
PNC	41.88 (2.42)	37 - 48	0.74*	0.01	0.71	.48	
$LL_N^{\dagger}$	64.89 (0.96)	63.07 - 67.92	~	~	~	~	
L_N(A)	44.44 (1.57)	40.37 - 47.84	-1.12*	0.05	2.03	.04	.11
S/N(LL)	-4.19 (1.36)	-8.53 - -2.03	0.61*	-0.15	-2.76	.01	.18
S/N(A)	-1.70 (1.81)	-5.85 - 2.46	1.18*	-0.05	-2.04	.04	.12

6.E. *Models for Hiss Ratings*

Variable	Mean (SD)	Min-Max	Intercept	B-weight	z_B	*p*	?$^{2}_{partial}$
Hiss Ratings	1.58 (1.13)	0 - 4	-	-	-	-	-
SII	0.42 (0.07)	0.26-0.56	4.66*	-7.36	-7.80	.00	.64
AI	0.34 (0.07)	0.17 - 0.48	4.09*	-7.40	-7.82	.00	.64
QAI	6.04 (3.06)	0.27-13.19	~	~	~	~	
s$_{16-63}$	2.09 (0.24)	1.64 - 2.69	~	~	~	~	
Low(A)	42.39 (2.71)	36.63 - 48.00	6.70	-0.12	-5.97	.00	.51
High(A)	39.75 (2.57)	34.69 - 45.77	-6.22	0.20	7.99	.00	.65
Lo-Hi(A)	2.63 (4.61)	-7.7 - 10.4	1.87*	-0.10	-7.43	.00	.62
RNC	45.10 (5.76)	37.33-54.91	~	~	~	~	
RNC$_{nf}$	43.63 (5.02)	37.33 - 52.75	~	~	~	~	
RC	36.89 (1.97)	32 - 40	~	~	~	~	
PNC	41.87 (2.42)	37 - 48	~	~	~	~	
LL_N†	64.89 (0.95)	63.07 - 67.92	~	~	~	~	
L_N(A)	44.44 (1.57)	40.37 - 47.84	~	~	~	~	
S/N(LL)	-4.19 (1.36)	-8.53 - -2.03	~	~	~	~	
S/N(A)	-1.69 (1.81)	-5.85 - 2.46	~	~	~	~	

6.F. *Models for Loudness Ratings*

Variable	Mean (SD)	Min-Max	Intercept	B-weight	z_B	*p*	?$^{2}_{partial}$
Loudness	2.14 (0.88)	0 - 4	-	-	-	-	-
SII	0.42 (0.07)	0.26-0.56	3.69*	-3.66	-5.64	.00	.48
AI	0.34 (0.07)	0.17 - 0.48	3.38*	-3.62	-5.69	.00	.49
QAI	6.05 (3.06)	0.27-13.19	2.11*	0.01	0.64	.52	
s$_{16-63}$	2.09 (0.24)	1.64 - 2.69	3.43*	-0.61	-3.86	.00	.31
Low(A)	42.39 (2.71)	36.63 - 48.00	~	~	~	~	
High(A)	39.75 (2.57)	34.69 - 45.77	-1.56	.09	6.10	.00	.52
Lo-Hi(A)	2.63 (4.61)	-7.7 - 10.4	2.26*	-0.04	-5.58	.00	.48
RNC	45.11 (5.76)	37.33-54.91	2.99*	-0.02	-2.84	.01	.19
RNC$_{nf}$	43.64 (5.01)	37.33 - 52.75	3.12*	-0.02	-2.88	.00	.20
RC	36.89 (1.97)	32 - 40	-1.87*	0.11	5.10	.00	.43
PNC	41.88 (2.41)	37 - 48	4.09*	-0.05	-3.26	.00	.24
LL_N†	64.89 (0.95)	63.07 - 67.92	~	~	~	~	
L_N(A)	44.44 (1.57)	40.37 - 47.84	~	~	~	~	
S/N(LL)	-4.19 (1.36)	-8.53 - -2.03	~	~	~	~	
S/N(A)	-1.69 (1.81)	-5.85 - 2.46	2.04*	-0.06	-2.81	.01	.19

6.G. *Overall HLM Summary.*

Variable	Signficant Predictions	Significant Predictor of	Model Fit Failures
SII	3	Speech Intelligibility, Hiss, Loudness	0
AI	3	Speech Intelligibility, Hiss, Loudness	0
QAI	1	Acoustic Satisfaction	4
$s_{16\text{-}63}$	2	Speech Intelligibility, Loudness	1
Low(A)	2	Rumble, Hiss	4
High(A)	4	Speech Intelligibility, Rumble, Hiss, Loudness	0
Lo-Hi(A)	6	Acoustic Satisfaction, Self-rated Productivity, Speech Intelligibility, Rumble, Hiss, Loudness	0
RNC	2	Speech Intelligibility, Loudness	1
RNC_{nf}	2	Speech Intelligibility, Loudness	1
RC	1	Loudness	2
PNC	2	Speech Intelligibility, Loudness	1
$LL_N^{\dagger}$	0		6
L_N(A)	2	Speech Intelligibility, Rumble	2
S/N(LL)	2	Speech Intelligibility, Rumble	4
S/N(A)	3	Speech Intelligibility, Rumble, Loudness	1

The results confirm the initial impression that the noise conditions had a greater effect on the ratings of speech intelligibility and the noise character (rumble, hiss, and loudness) than on the satisfaction and self-rated productivity ratings. More of the acoustic variables were statistically significant predictors, and the effect sizes were larger. This is also not surprising given that most of the acoustic variables were developed as indices of speech intelligibility, the general level of loudness, or the characteristics of the noise.

The complete failure of loudness levels (LL_n) to fit a prediction model was of course expected. This value was held almost constant (within a range of less than 1 dB) across the fifteen noise conditions, with only one condition ("Neutral+3 dB") having a different level. With no variability in this value, it intentionally had no room in which to predict outcomes.

Overall the most consistent predictor was the difference between A-weighted noise levels in low and high frequencies (Lo-Hi(A). It is the only noise characteristic that predicted all six dependent measures; none of the more common measures were as effective. Figure 5 shows the individual trends and the average trend for the six variables, predicted by this value. The left-hand column shows the sets of individual trends, for each hierarchical equation; the right-hand column shows the observed and predicted values and the average regression line. The individual trends show, as one would expect, marked differences between individuals. The average regression lines show that as the Lo-Hi(A) difference increased (i.e., when the loudness of low frequencies exceeded that of high frequencies), acoustic satisfaction, self-rated productivity, and ratings of hiss and loudness all became more favourable. Ratings of rumble increased, but not above the neutral level for the scale (2).

Speech intelligibility became worse (increased slightly) as Lo-Hi(A) increased, which is predictable, because the shift of the balance to more low frequencies (and hence less high frequency noise) would mask speech sounds less well. The slope of the line is small, but statistically significant: speech intelligibility changes by .53 % for a 1 dB(A) increase in the Lo-Hi(A) value (with speech intelligibility scaled from 0 - 100 the line in the graph looks almost flat, even though the effect explains a moderate amount of variance). This result may seem counterintuitive; in that the same acoustic conditions that improved satisfaction tended to lead to greater speech intelligibility and hence less speech privacy. Thus noise that best masks speech sounds and hence leads to greater speech privacy is not necessarily the most acceptable to the subjects. The relationship between acoustic satisfaction, speech intelligibility, and hiss ratings is further explored below.

Figure 5. *Individual and average trends for dependent variables predicted by Lo-Hi(A)*

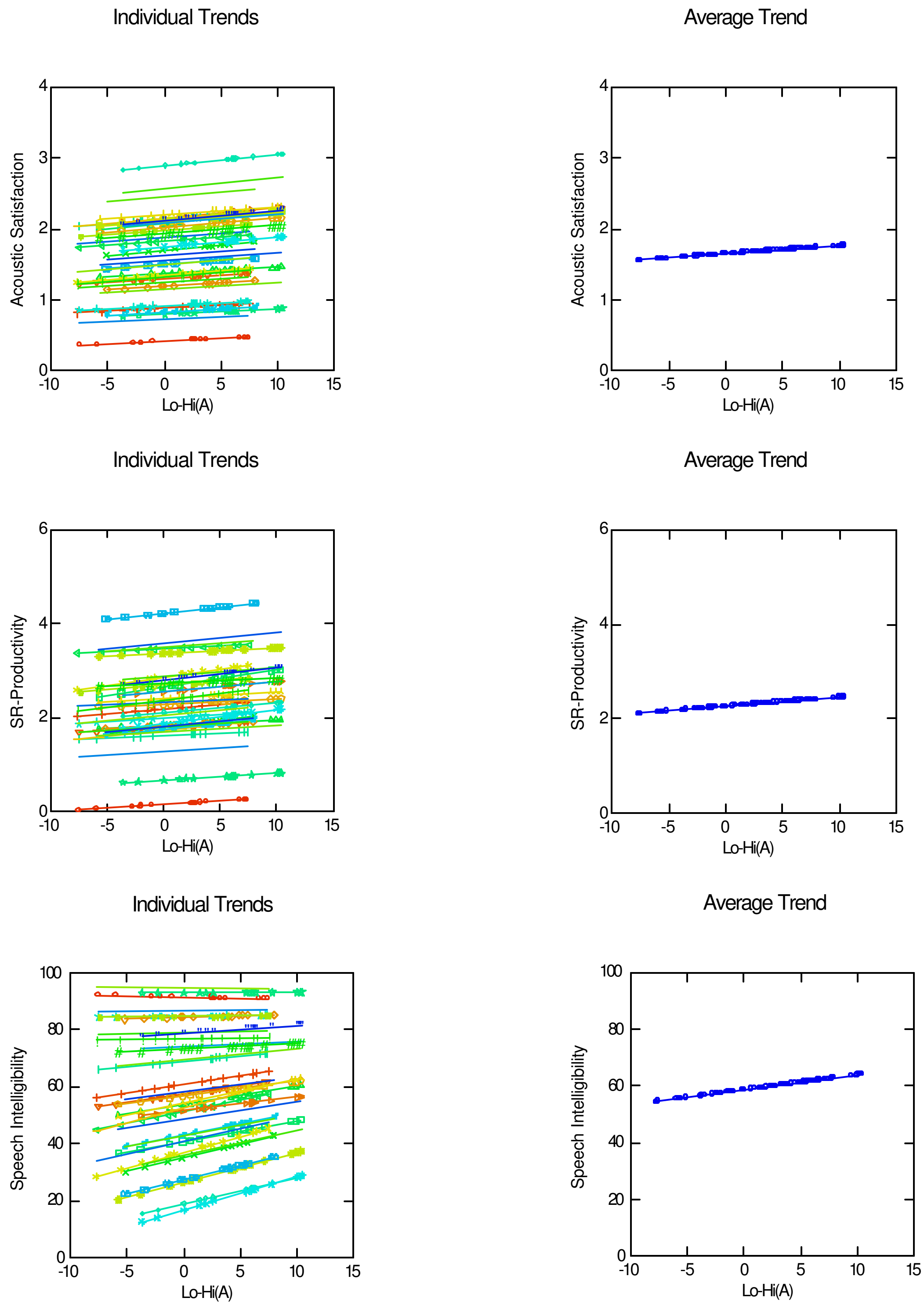
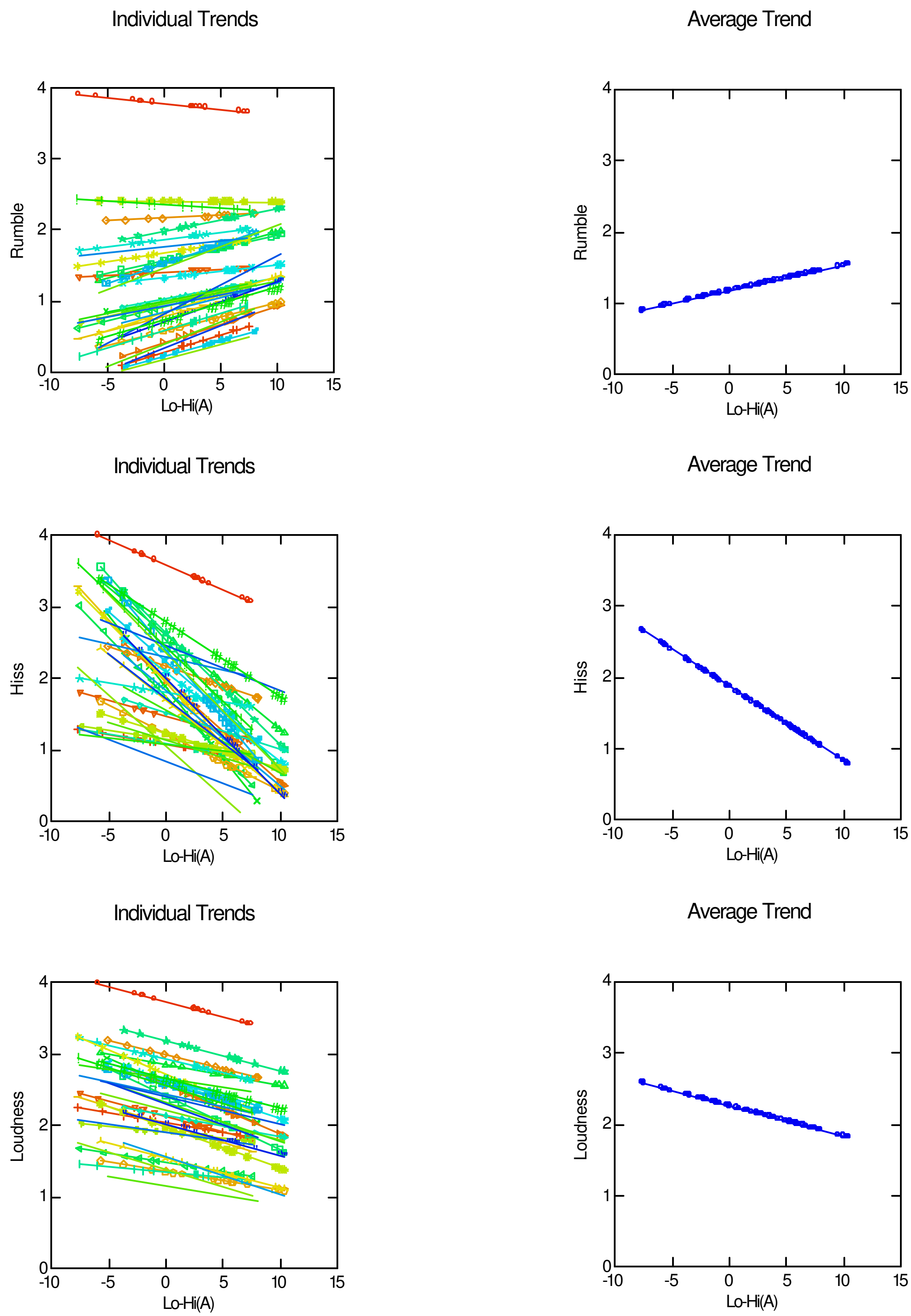


Figure 5. *Individual and average trends for dependent variables predicted by Lo-Hi(A)*



2.2.5 Aspects of acoustic satisfaction. To further explore the relationship between speech intelligibility and hiss ratings in relation to acoustic satisfaction, an HLM model was created with these three variables, in which speech intelligibility and hiss were used to predict acoustic satisfaction. Although the ratings were made simultaneously (as part of one questionnaire), this directional relationship makes theoretical sense. The model combining two predictors was possible because ratings of speech intelligibility and hiss were almost uncorrelated (r=.06 over the entire sample and all noise conditions). The results of the HLM analysis are shown in Table 7. It shows that both speech intelligibility and hiss ratings are strong predictors of acoustic satisfaction: reducing speech intelligibility increases acoustic satisfaction, as does reducing hiss.

Table 7. *HLM Analyses of acoustic satisfaction in relation to perceived conditions.*

Variable	Mean (SD)	Min-Max	Estimate	z_B	*p*	$?^2_{partial}$
Acoustic Satisfaction	1.68 (0.70)	0.11 – 3.33	-	-	-	-
Intercept			2.42	18.34	.00	
Speech Intelligibility	60.14 (28.07)	0 - 100	-0.01	-5.79	.00	.50
Hiss Rating	1.58 (1.13)	0 – 4	-0.12	-5.87	.00	.50
Intercept			1.76	18.61	.00	
Rumble	1.28 (1.05)	0 - 4	0.04	-1.43	.15	

We also attempted the same analysis with ratings of rumble. The model with both rumble and speech intelligibility failed altogether. A model with rumble alone showed that it was not a significant predictor of acoustic satisfaction (independent of speech intelligibility). The bottom section of Table 7 shows the rumble result.

2.2.6 Individual differences in noise sensitivity. We hypothesized that individual differences in noise sensitivity might explain overall ratings of environmental satisfaction and ratings of task difficulty at the end of the experiment. Scores on the 21-item Noise Sensitivity Scale (Weinstein, 1978) were regressed on the end-of-day environmental satisfaction ratings and on the average rating of task difficulty (excluding ratings of the difficulty of the hearing test). The results are summarised in Table 8. Neither regression produced a statistically significant result.

Table 8. *Regression analyses of Noise Sensitivity (Experiment 1).*

Dependent Variable / Predictor	Mean (SD)	Cronbach's a	Min-Max	Estimate	*t*	*p*
ES_End	2.57 (0.82)	.88	0.50 - 4.00			
Intercept				2.49		
NSS	2.50 (0.61)	.91	1.48 - 3.62	0.03	0.14	.89
Difficulty	1.75 (0.55)	.68	0.50 - 2.83			
Intercept				1.38		
NSS	2.50 (0.61)	.91	1.48 - 3.62	0.15	0.95	.35

Note. All scales have theoretical range from 0 - 4. Lower scores indicate less noise sensitivity (NSS), lower ratings for task difficulty (Difficulty), and lower ratings for overall environmental satisfaction at the end of the session (ES_End).

2.3 Discussion: Experiment 1

The results of experiment 1 reveal that people are sensitive to changes in the spectral qualities of simulated ambient noise combined with speech when the overall loudness of the noises is not varied. The difference between the A-weighted level of the low frequencies relative to the high frequencies was seen to be related to judgements of the rumble and hiss characteristics of the noises as well a to the overall satisfaction and the speech intelligibility ratings. Louder levels in the low frequencies than high frequencies were generally preferred (higher values of Lo-Hi(A)). Higher values of this difference were indicative of more rumbly sounds and lower values of this difference less than 0 dB(A) were rated on the "too hissy" side. The low, mid and high frequency divisions used in the ASHRAE RC rating were not appropriate for explaining judgements of the rumbly character of these noises. Ratings of the rumbly character of the noises were most strongly related to the noise levels in the 125, 250 and 500 Hz octave bands.

Examination of the interrelationships between speech intelligibility and hiss ratings and acoustic satisfaction revealed that conditions that decreased speech intelligibility also increased acoustic satisfaction. Such conditions generally require more sound energy in the higher frequencies (cf., Table 6.C, which shows a strong relationship between increasing higher frequency noise levels (High(A)) and decreasing speech intelligibility). The challenge, then, lies in establishing the best balance between conditions that reduce speech intelligibility (i.e. increase speech privacy) without decreasing satisfaction with the character of the noise such as caused by increased hiss.

3.0 Experiment 2: Effects of Noise Level and Spectrum

3.1 Method

3.1.1 Objective. The second experiment assessed the combined effects of varied noise spectrum and level when combined with speech in situations representative of typical open offices.

3.1.2 Participants. All details of the procedures for participant recruitment were the same for experiment 2 as in experiment 1. Data were obtained for 32 participants (38 completed the consent form, but 3 left midway through a session, 2 did not provide valid data, and equipment error invalidated the data from 1 participant). These participants included 15 men and 17 women with age range 19 - 56 years (*M*=32.7, *SD*=11.5). Other characteristics are reported in Table 9; the samples for the two experiments are comparable on the variables collected.

Table 9. *Characteristics of Experiment 2 Participants.*

Hearing Impairment	1 = yes 31 = no
Hearing Aid	0 = yes 32 = no
Visual Aids	15 = none 10 = distance glasses 3 = bifocals 4 = contact lenses
Education	15 = High school 7 = community college / CEGEP 8 = undergraduate degree 2 = graduate degree
Years in work force	Range 0 year - 37 years *M* = 11.9 years *SD* = 11.3 years

The hearing loss data for Experiment 2 subjects was interpretable. Measured hearing levels relative to threshold values at 500, 1000, 2000, 3000, 4000, and 6000 Hz were summed and subjects with values greater than 20 were classified as having some hearing impairment. Table 9 indicates that one subject was classified as hearing impaired and data from that subject was excluded from the analyses.

3.1.3 Setting. All details of the setting were identical to those for Experiment 1.

3.1.4 Independent variables. The constant speech was identical to that in Experiment 1. There were two independent variables in this experiment, which had a factorial within-subjects experimental design: the noise had five levels (approximately 41, 43, 45, 48, and 51 dB(A)) and the noise spectrum had three levels (LB-MB, neutral, and LC-MB-HB). The three spectra were chosen to provide a range of sound masking potential. The ASHRAE neutral spectrum (ASHRAE, 2001; Blazier, 1981) formed the base case; the Low Boost-Mid Boost (LB-MB) spectrum was chosen to provide an example of stronger low frequency noise (but with lower speech masking), and the Low Cut-Mid Boost- High Boost (LC-MB-HB) spectrum was chosen to provide greater speech masking. Based on the results of Experiment 1, LB-MB would be expected to be more satisfactory than the other conditions, despite its lower speech masking qualities.

The average measured noise spectra in each workstation are illustrated in Figure 6. This figure compares the measured noise spectra with the measured average speech spectrum and also with a –5 dB/octave reference line. Each of the 15 spectrum plots also include the spectrum name and the calculated SII (Speech Intelligibility Index) value. (The spectrum naming convention was explained in section 2.1.3).

Table 10 describes the noise conditions in terms of a variety of acoustic indices, taking into account the number of participants who occupied each workstation. The total noise levels experienced by the participants were between 41 and 51 dB(A), which is within the range of noises found in typical work environments (Broner, 1993; Tang & Wong, 1998).

Figure 6. *The 15 noise spectra (solid lines) from Experiment 2 compared with the speech spectrum (dashed line) and a –5 dB/octave reference line (dotted).*

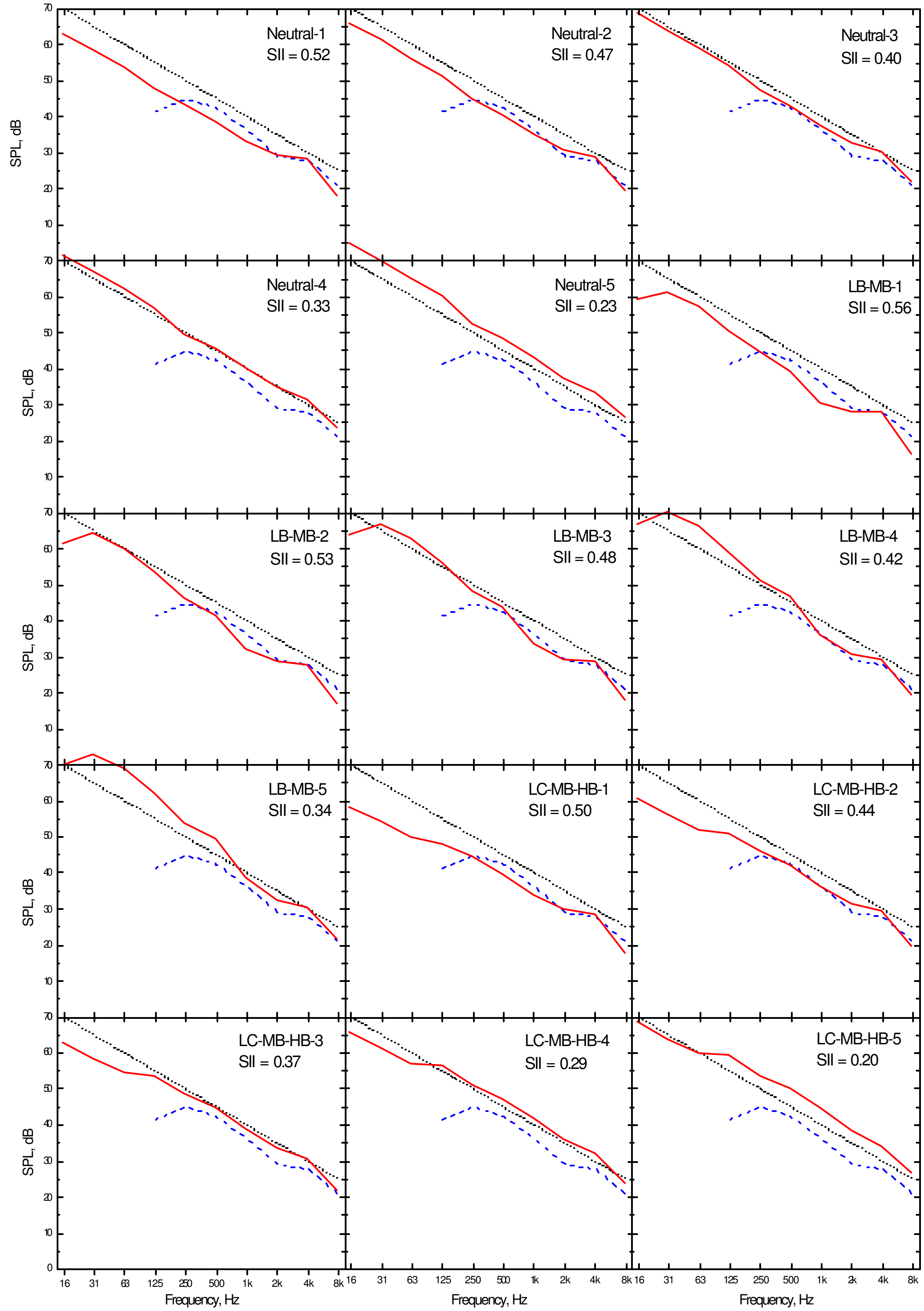


Table 10. *Noise measurements for Experiment 2 conditions, weighted averages across workstations.*

Spectrum	Noise Level	SII	AI	QAI	$s_{16\text{-}63}$	Low(A)	High(A)	Lo-HI(A)
LB-MB	1	0.56	0.48	1.85	2.16	40.90	34.69	6.21
LB-MB	2	0.53	0.45	3.77	2.31	43.23	35.36	7.88
LB-MB	3	0.48	0.40	5.28	2.25	45.85	36.78	9.07
LB-MB	4	0.42	0.34	7.41	2.28	48.73	38.42	10.31
LB-MB	5	0.34	0.28	8.60	2.34	51.62	40.62	11.00
Neutral	1	0.52	0.45	2.46	2.14	39.62	36.27	3.36
Neutral	2	0.47	0.39	2.90	2.12	41.74	37.84	3.89
Neutral	3	0.40	0.33	3.41	2.13	44.15	39.91	4.24
Neutral	4	0.33	0.25	3.90	2.18	46.93	42.27	4.66
Neutral	5	0.24	0.17	4.41	2.10	49.90	44.99	4.90
LC-MB-HB	1	0.50	0.42	5.01	1.89	40.25	36.85	3.40
LC-MB-HB	2	0.44	0.36	4.25	1.98	42.38	38.70	3.67
LC-MB-HB	3	0.37	0.29	4.15	2.08	45.05	40.95	4.10
LC-MB-HB	4	0.29	0.22	3.60	2.10	47.63	43.54	4.10
LC-MB-HB	5	0.20	0.13	3.41	2.09	50.49	46.27	4.22

Spectrum	Noise Level	RNC	RNC_{nf}	RC	PNC	LL_N	$L_N(A)$	S/N(LL)	S/N(A)
LB-MB	1	44.63	41.45	32.53	37.10	61.62	41.40	-0.74	1.56
LB-MB	2	50.05	46.79	34.10	40.87	63.81	43.35	-2.93	-0.40
LB-MB	3	53.05	51.24	35.67	45.07	66.38	45.77	-5.50	-2.82
LB-MB	4	56.11	54.37	37.67	50.07	69.12	48.48	-8.24	-5.53
LB-MB	5	59.19	57.37	40.67	54.23	71.96	51.29	-11.07	-8.34
Neutral	1	37.42	34.96	33.90	35.63	60.82	41.00	0.06	1.95
Neutral	2	42.50	39.27	35.67	37.37	63.18	42.84	-2.30	0.11
Neutral	3	48.15	44.91	37.67	40.40	65.88	45.09	-4.99	-2.14
Neutral	4	52.08	50.21	40.43	44.83	68.73	47.75	-7.85	-4.79
Neutral	5	54.94	53.41	43.03	49.83	71.80	50.64	-10.92	-7.69
LC-MB-HB	1	34.84	34.84	34.67	36.20	60.89	41.62	-0.01	1.33
LC-MB-HB	2	36.65	36.65	36.67	37.83	63.18	43.58	-2.30	-0.63
LC-MB-HB	3	39.47	39.36	39.03	41.00	65.90	46.12	-5.01	-3.17
LC-MB-HB	4	43.95	42.31	41.67	43.87	68.67	48.67	-7.79	-5.72
LC-MB-HB	5	49.35	46.70	44.43	47.27	71.57	51.47	-10.69	-8.52

3.1.5 Dependent measures. The dependent measures were identical to those in Experiment 1.

3.1.6 Procedure. The procedure was identical to that used in Experiment 1, except that the simulated masking noises were as described in section 3.1.3 above.

3.2 Results

3.2.1 Descriptive statistics. Examination of the dependent variables revealed that one participant had failed to answer the acoustic satisfaction questionnaires for four of the 15 noise conditions. This was judged to be excessive, and data from this participant was excluded from further analyses. Eleven other participants had skipped questions in an apparently random fashion; for these participants, we imputed the means of the available data to be the score. Thus, all data reported here is based on 30 participants.

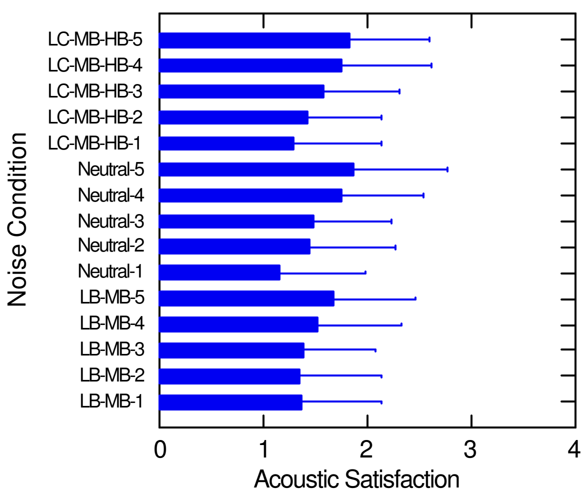
The dependent variables were the same as in Experiment 1, and are shown for the 15 noise conditions in Table 11 and Figure 7. The graphical presentation reveals that the effects of changing noise level are likely to be greater than the effects of changing the spectrum of the masking noise. The means for acoustic satisfaction and self-rated productivity never rise above the midpoints of their respective scales, suggesting that none of the sound masking conditions is considered particularly good.

Table 11. *Experiment 2 Descriptive Statistics for Satisfaction Measures (N=30)*

Condition Statistic	**Acoustic Satisfaction**	**Productivity**	**Speech Intelligibility**	**Rumble**	**Hiss**	**Loudness**
OVERALL	a = .90					
Range	0.00 - 3.89	0.00 - 6.00	0.00 - 100.00	0.00 - 4.00	0.00 - 4.00	0.00 - 4.000
Median	1.44	2.00	80.00	1.00	1.00	2.00
Mean (SD)	1.52 (0.80)	2.37 (1.26)	69.10 (31.88)	1.38 (1.08)	1.44 (1.11)	2.06 (0.97)
LB-MB -1						
Range	0.11 - 3.00	0.00 - 5.00	6.00 - 100.00	0.00 - 2.00	0.00 - 3.00	0.00 - 3.00
Median	1.33	2.00	91.50	1.00	0.00	1.00
Mean (SD)	1.37 (0.76)	2.43 (1.25)	80.70 (28.50)	0.67 (0.71)	0.67 (0.84)	1.37 (0.85)
LB-MB-2						
Range	0.11 - 2.89	0.00 - 5.00	14.00 - 100.00	0.00 - 3.00	0.00 - 3.00	0.00 - 3.00
Median	1.28	2.00	95.50	1.00	1.00	1.50
Mean (SD)	1.35 (0.78)	2.13 (1.36)	84.70 (21.65)	1.13 (0.78)	0.73 (0.83)	1.53 (0.94)
LB-MB-3						
Range	0.22 - 2.89	0.00 - 5.00	16.00 - 100.00	0.00 - 3.00	0.00 - 3.00	1.00 - 3.00
Median	1.33	2.00	80.50	1.50	1.00	2.00
Mean (SD)	1.39 (0.69)	2.27 (1.11)	78.43 (24.19)	1.53 (0.68)	1.10 (0.92)	2.03 (0.72)
LB-MB-4						
Range	0.22 - 3.89	0.00 - 5.00	0.00 - 100.00	1.00 - 4.00	0.00 - 3.00	1.00 - 3.00
Median	1.44	2.00	83.00	2.00	1.00	2.50
Mean (SD)	1.51 (0.81)	2.43 (1.22)	70.53 (31.00)	2.10 (1.09)	1.20 (0.89)	2.40 (0.67)
LB-MB-5						
Range	0.56 - 3.11	1.00 - 6.00	1.00 - 100.00	0.00 - 4.00	0.00 - 4.00	1.00 - 4.00
Median	1.72	2.00	51.50	2.50	2.00	3.00
Mean (SD)	1.67 (0.77)	2.53 (1.20)	54.70 (31.70)	2.27 (1.11)	1.70 (1.02)	2.57 (0.73)
Neutral-1						
Range	0.00 - 2.67	0.00 - 6.00	11.00 - 100.00	0.00 - 2.00	0.00 - 2.00	0.00 - 3.00
Median	1.17	2.00	98.50	0.00	0.81	1.00
Mean (SD)	1.16 (0.81)	2.13 (1.57)	87.73 (20.90)	0.53 (0.63)	0.62 (0.67)	1.17 (0.83)
Neutral-2						
Range	0.22 - 2.67	1.00 - 4.00	21.00 - 100.00	0.00 - 3.00	0.00 - 3.00	1.00 - 3.00
Median	1.41	2.00	89.50	1.00	1.00	2.00
Mean (SD)	1.45 (0.82)	2.35 (1.06)	79.17 (23.41)	1.03 (0.76)	1.10 (0.80)	1.62 (0.61)
Neutral-3						
Range	0.44 - 3.11	1.00 - 6.00	2.00 - 100.00	0.00 - 2.00	0.00 - 3.00	0.00 - 3.00
Median	1.28	2.00	86.00	1.00	2.00	2.00
Mean (SD)	1.48 (0.73)	2.50 (1.20)	71.73 (33.94)	1.07 (0.69)	1.53 (0.90)	2.10 (0.92)
Neutral-4						
Range	0.33 - 3.11	1.00 - 6.00	1.00 - 100.00	0.00 - 4.00	0.00 - 4.00	1.00 - 4.00
Median	1.67	2.00	55.00	1.00	2.00	2.50
Mean (SD)	1.75 (0.78	2.53 (1.14)	57.57 (32.67)	1.60 (1.04)	2.07 (0.98)	2.43 (0.82)
Neutral-5						
Range	0.33 - 3.44	1.00 - 6.00	0.00 - 100.00	0.00 - 4.00	0.00 - 4.00	2.00 - 4.00
Median	1.78	2.34	29.50	2.00	2.50	3.00
Mean (SD)	1.87 (0.90)	2.62 (1.22)	44.57 (35.59)	2.33 (1.03)	2.40 (1.22)	2.90 (0.61)
LC-MB-HB-1						

Condition Statistic	**Acoustic Satisfaction**	**Productivity**	**Speech Intelligibility**	**Rumble**	**Hiss**	**Loudness**
Range	0.11 - 3.00	0.00 - 6.00	10.00 - 100.00	0.00 - 2.00	0.00 - 2.00	0.00 - 3.00
Median	1.06	2.00	91.50	0.00	1.00	1.00
Mean (SD)	1.28 (0.84)	2.18 (1.46)	81.20 (25.07)	0.50 (0.63)	0.87 (0.68)	1.37 (0.93)
LC-MB-HB-2						
Range	0.13 - 2.89	0.00 - 5.00	16.00 - 100.00	0.00 - 3.00	0.00 - 3.00	0.00 - 3.00
Median	1.39	2.29	93.00	1.00	1.00	1.50
Mean (SD)	1.42 (0.71)	2.26 (1.28)	83.10 (21.25)	1.03 (0.93)	1.30 (0.88)	1.57 (1.04)
LC-MB-HB-3						
Range	0.56 - 3.22	0.00 - 6.00	7.00 - 100.00	0.00 - 4.00	0.00 - 4.00	1.00 - 3.00
Median	1.56	2.00	79.00	1.00	1.00	2.00
Mean (SD)	1.59 (0.71)	2.31 (1.32)	69.30 (31.11)	1.33 (0.92)	1.55 (0.89)	2.20 (0.71)
LC-MB-HB-4						
Range	0.67 - 3.67	1.00 - 6.00	0.00 - 100.00	0.00 - 4.00	0.00 - 4.00	1.00 - 4.00
Median	1.50	2.00	60.50	1.00	2.25	3.00
Mean (SD)	1.75 (0.87)	2.50 (1.22)	53.97 (32.95)	1.57 (1.17)	2.25 (1.16)	2.70 (0.79)
LC-MB-HB-5						
Range	0.44 - 3.22	0.00 - 5.00	0.00 - 100.00	0.00 - 4.00	0.00 - 4.00	1.00 - 4.00
Median	1.83	2.50	29.50	2.00	2.50	3.00
Mean (SD)	1.82 (0.76)	2.37 (1.43)	39.10 (29.05)	2.07 (1.28)	2.53 (1.20)	2.90 (0.76)

Figure 7. *Experiment 2: Means and standard deviations for 15 masking noise conditions on the six dependent variables (N=30).*



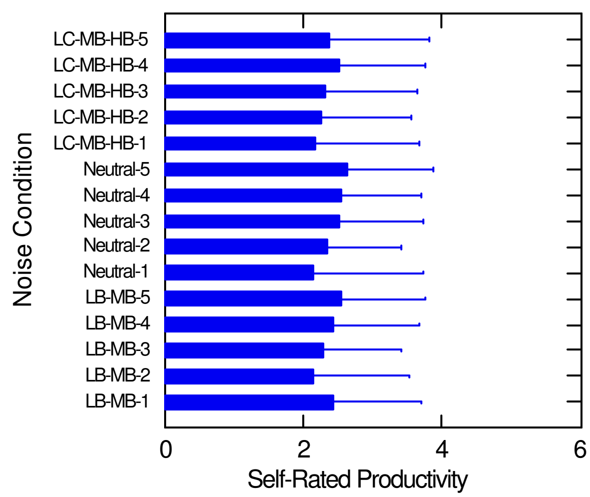
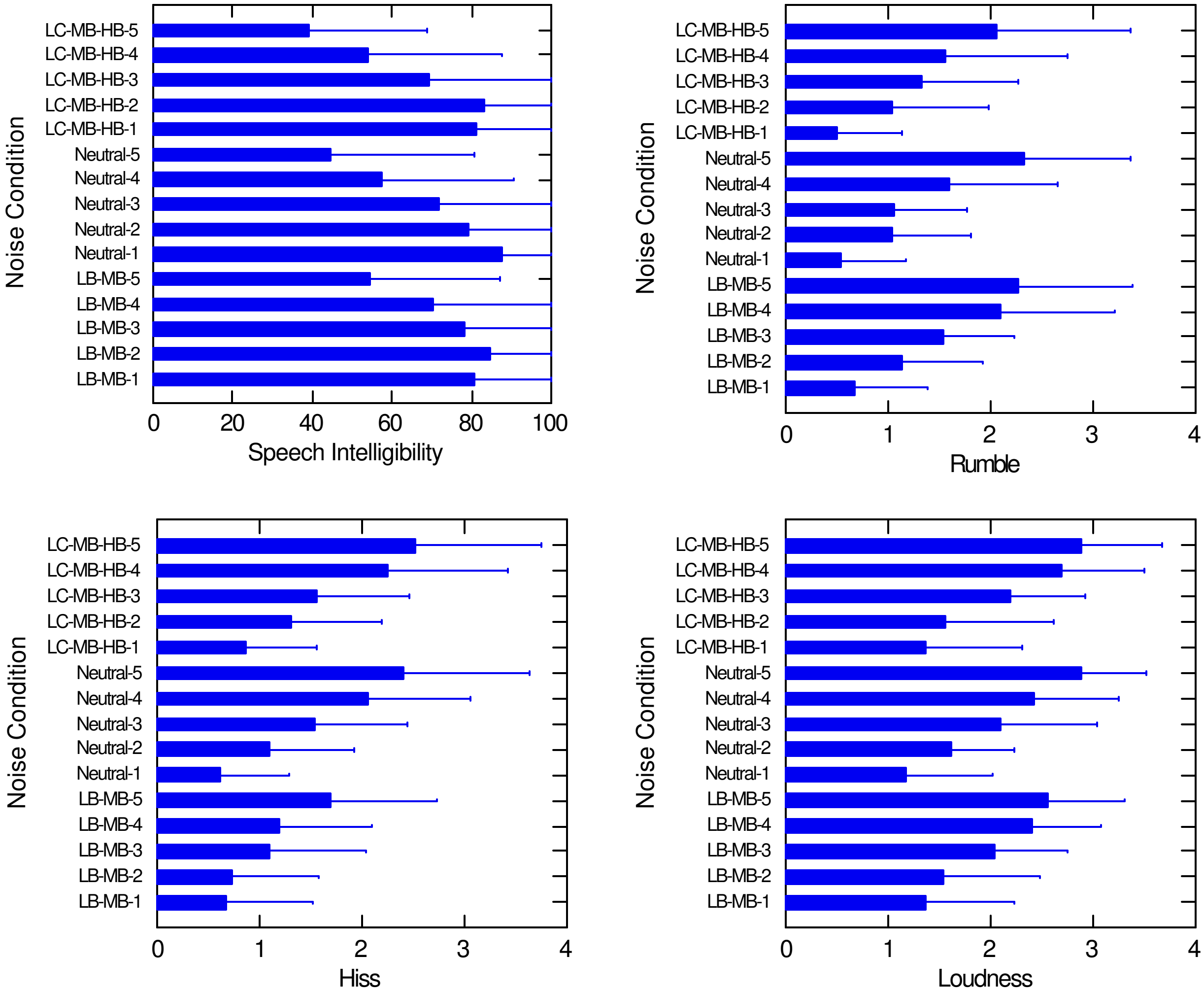


Figure 7. *Experiment 2: Means and standard deviations for 15 masking noise conditions on the six dependent variables (N=30).*



3.2.2 Noise level and spectrum effects. The experiment used a 5 x 3 (noise level x spectrum) factorial within-subjects design that allowed a straightforward multivariate analysis of variance (MANOVA) approach to data analysis. There were six dependent variables, as described above. Table 12 shows the single-degree-of-freedom planned comparisons that were examined. Although it would have been possible to examine cubic and quartic effects of noise levels, this was not done because the graphs of the effects showed no evidence that the curves took either shape (Figure 8).

Table 12. *Planned Comparisons for Experiment 2 MANOVA.*

Spectrum main effects (collapsed across noise levels):
LC-MB-HB in comparison to Neutral [S1]
LB-MB compared to Neutral [S2]
Noise main effects (collapsed across spectrum levels)
Linear [NL]
Quadratic [NQ]
Interaction effects
S1 x NL

S1 x NQ
S2 x NL
S2 x NQ

The results of the MANOVA analysis are displayed in Table 13. Statistically significant (p<.05) univariate tests were interpreted only if the multivariate test for that hypothesis was also statistically significant. Effect sizes (partial $?^2$) were interpreted using Cohen's (1988) guidelines for behavioural research.

Of the main effects for spectrum, only S2 reached multivariate statistical significance, and its univariate tests involve speech intelligibility and the ratings of the noise. The effects are medium-sized. As expected, LB-MB provided less speech masking (highest speech intelligibility). LB-MB was also perceived as being more rumbly and less hissy than the Neutral spectrum (see Figure 8, below). The Neutral and LC-MB-HB spectra did not differ on any of the six dependent measures [S1 contrast].

The linear noise effects, statistically significant for 5 of the 6 dependent variables, are very large by the standards of behavioural research. Only self-rated productivity ratings showed no effect of noise level. Acoustic satisfaction increased with noise level; speech intelligibility declined (see Figure 9). Ratings of rumble, hiss, and loudness all increased as noise level increased.

Table 13. *Summary of MANOVA Analysis for Experiment 2.*

Effect	Dependent Variable	Wilks' ?	*F*	*df*	*p*	$?^2_{partial}$
S1		0.71	1.66	6,24	.17	Average = .07
	Acoustic Satisfaction		3.45	1,29	.07	.11
	Self-Rated Productivity		1.56	1,29	.22	.05
	Speech Intelligibility		1.72	1,29	.20	.06
	Rumble		0.02	1,29	.88	.00
	Hiss		5.08	1,29	.03	.15
	Loudness		2.52	1,29	.12	.08
S2 *		0.57	3.00	6, 24	.02	Average = .12
	Acoustic Satisfaction		0.17	1, 29	.69	.01
	Self-Rated Productivity		0.55	1, 29	.46	.02
	Speech Intelligibility *		6.49	1, 29	.02	.18
	Rumble *		4.87	1, 29	.04	.14
	Hiss **		14.64	1, 29	.00	.34
	Loudness		0.66	1, 29	.42	.02
NL *		.13	26.40	6, 24	.00	Average = .57
	Acoustic Satisfaction **		16.71	1, 29	.00	.37
	Self-Rated Productivity		2.47	1, 29	.13	.08
	Speech Intelligibility **		55.34	1, 29	.00	.66
	Rumble **		104.4	1, 29	.00	.78
	Hiss **		87.76	1, 29	.00	.75
	Loudness **		121.11	1, 29	.00	.81
NQ		0.64	2.20	6, 24	.08	Average = .07
	Acoustic Satisfaction		0.78	1, 29	.38	.03
	Self-Rated Productivity		0.04	1, 29	.84	.00
	Speech Intelligibility		13.36	1, 29	.00	.32
	Rumble		0.41	1, 29	.53	.01
	Hiss		0.70	1, 29	.41	.02
	Loudness		0.29	1, 29	.60	.01

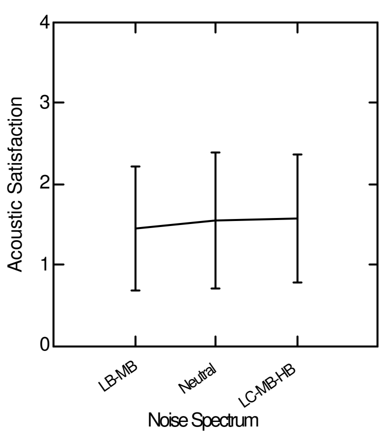
Table 13. *Summary of MANOVA Analysis for Experiment 2.*

Effect / **Dependent Variable**	**Wilks' ?**	***F***	***df***	***p***	$?^2_{partial}$
S1 x NL	.95	0.23	6,24	.96	Average = .01
Acoustic Satisfaction		0.00	1,29		.00
Self-Rated Productivity		0.74	1,29		.03
Speech Intelligibility		0.20	1,29		.01
Rumble		0.69	1,29		.02
Hiss *		0.37	1,29		.01
Loudness		0.02	1,29		.00
S1 x NQ	.63	2.38	6,24	.06	Average = .04
Acoustic Satisfaction		0.47	1,29	.50	.02
Self-Rated Productivity		0.01	1,29	.94	.00
Speech Intelligibility		1.50	1,29	.23	.05
Rumble		6.63	1,29	.02	.19
Hiss		0.35	1,29	.56	.01
Loudness		0.00	1,29	.97	.00
S2 x NL **	0.40	6.07	6, 24	.00	Average = .16
Acoustic Satisfaction		2.37	1, 29	.13	.08
Self-Rated Productivity		1.22	1, 29	.28	.04
Speech Intelligibility **		10.77	1, 29	.00	.27
Rumble		0.00	1, 29	1.00	.00
Hiss **		14.64	1, 29	.00	.34
Loudness *		7.61	1, 29	.01	.21
S2 x NQ *	0.60	2.71	6, 24	.04	.07
Acoustic Satisfaction		0.35	1, 29	.56	.01
Self-Rated Productivity		3.44	1, 29	.07	.11
Speech Intelligibility		2.40	1, 29	.13	.08
Rumble *		5.86	1, 29	.02	.17
Hiss		1.77	1, 29	.19	.06
Loudness		0.00	1, 29	.97	.00

Note. * $p < .05$. ** $p < .01$.

.

Figure 8 *Means and Standard Deviations by Spectrum*



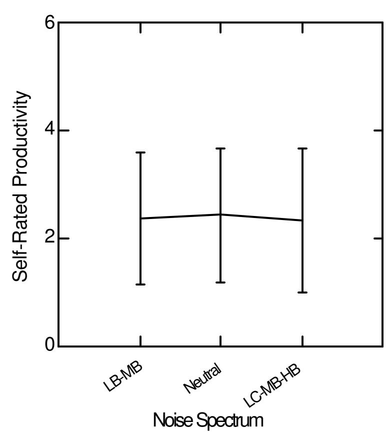


Figure 8 *Means and Standard Deviations by Spectrum*

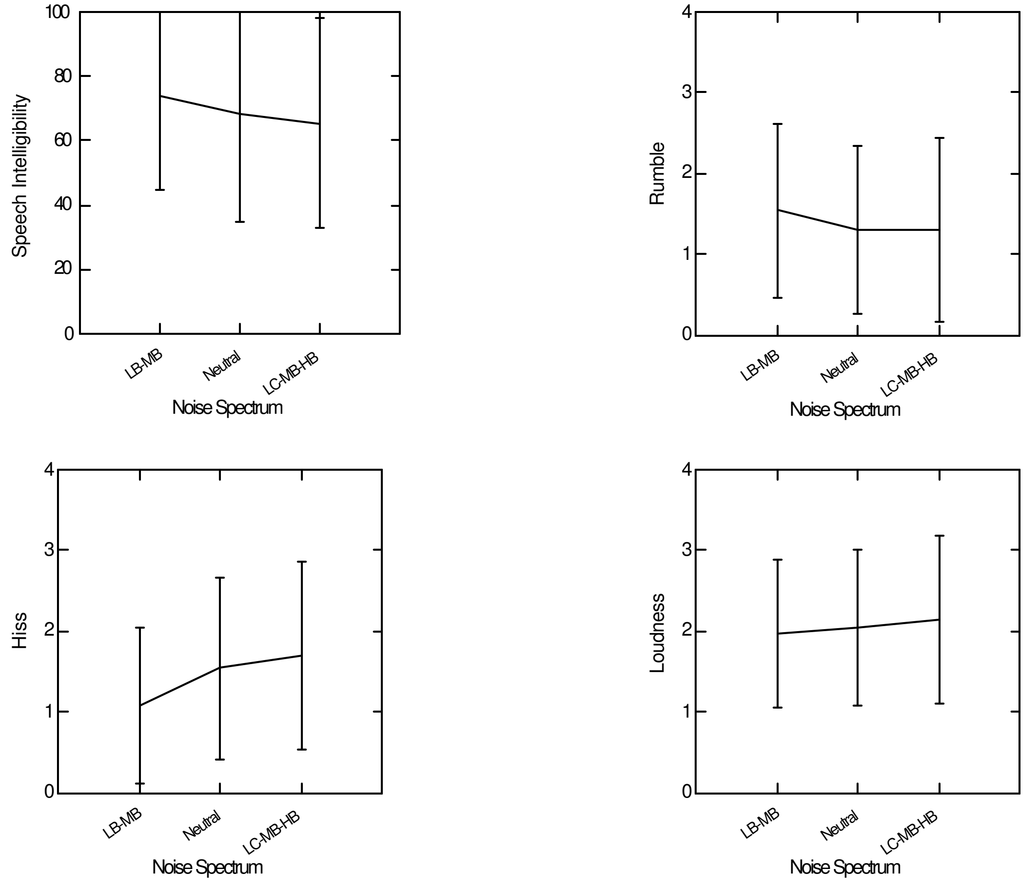


Figure 9. *Means and Standard Deviations by Noise.*

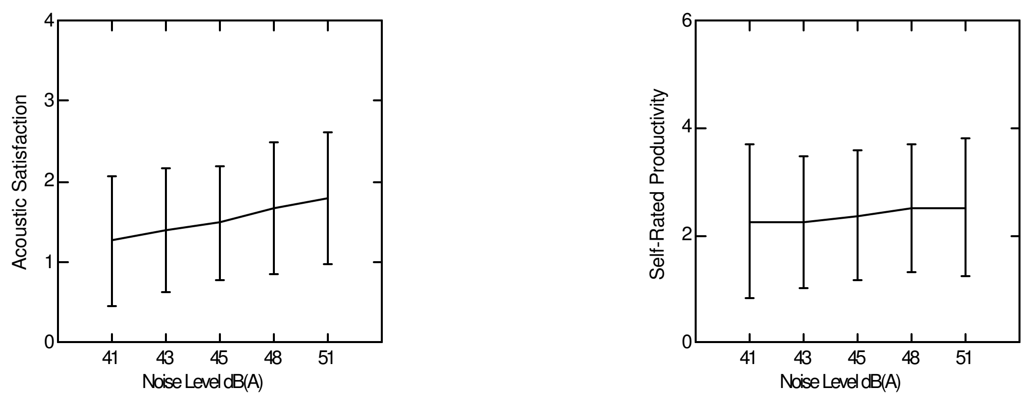
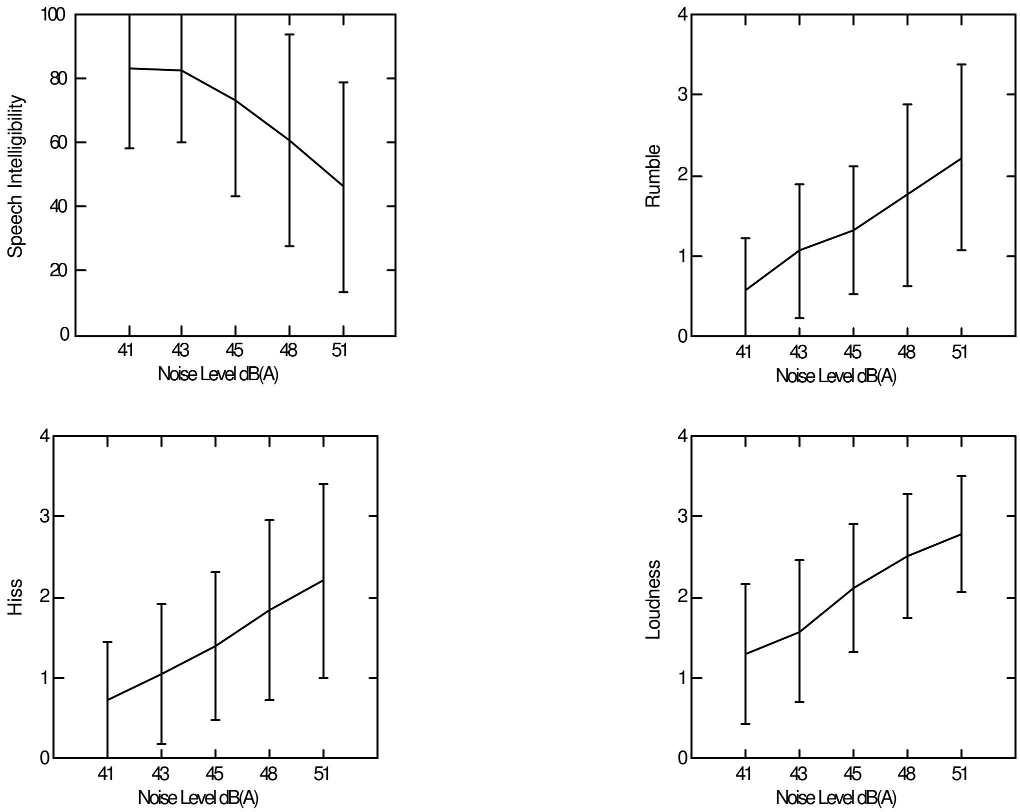


Figure 9. *Means and Standard Deviations by Noise.*



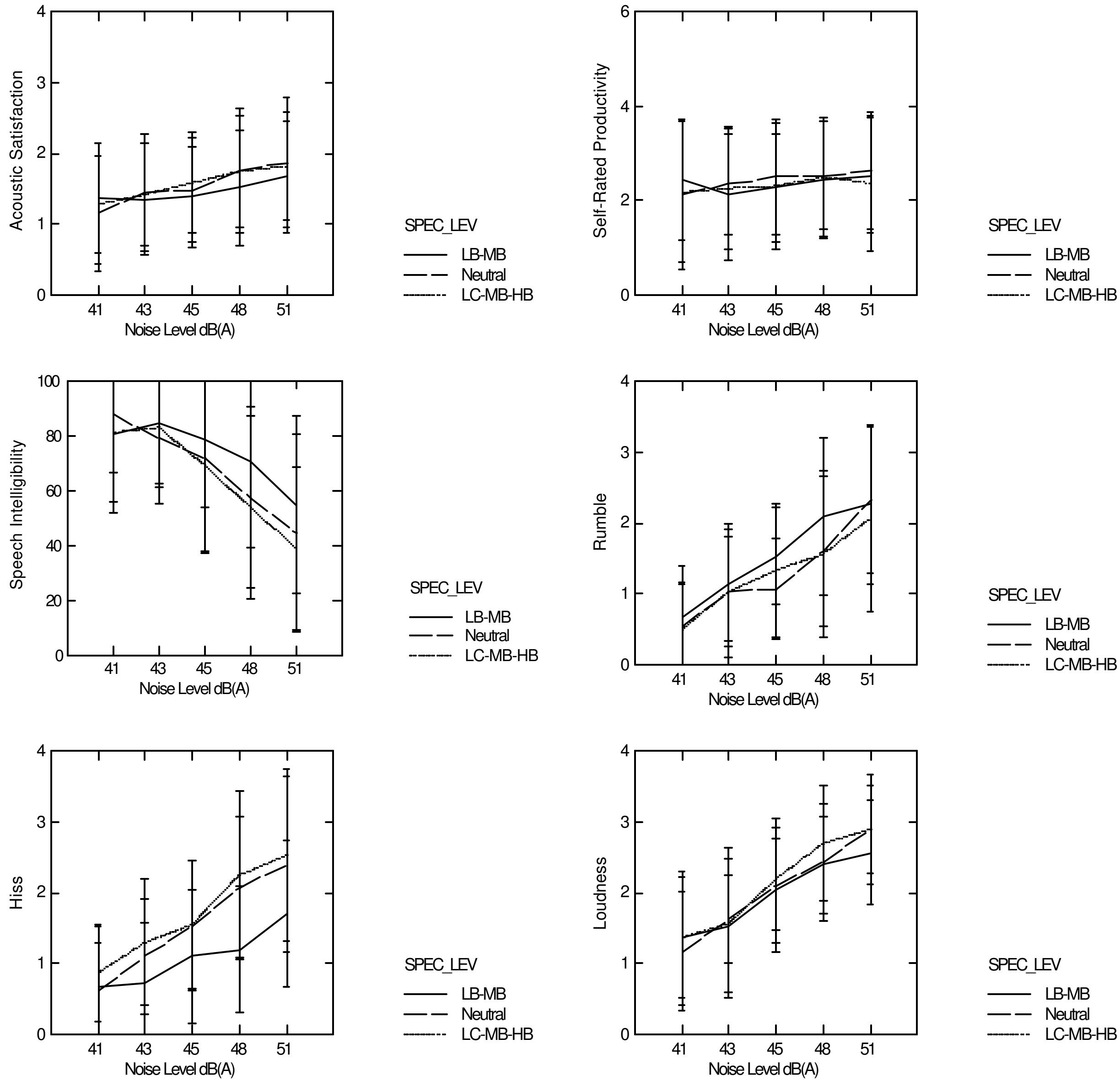
The more interesting results are the interactions of spectrum and noise, which moderate the main effects. Figure 10 plots the means and standard deviations by spectrum and noise level. There are statistically significant interactions of S2 x NL for speech intelligibility, hiss, and loudness. In this case, increasing the noise level has a smaller effect for LB-MB than for the Neutral spectrum. That is to say, that speech intelligibility decreases with noise more slowly for LB-MB than for Neutral, whereas hiss and loudness increase more slowly as noise increases for LB-MB than for Neutral. These effects are generally predictable. Increasing the level of noise of a masking noise spectrum that has less high-frequency sound should have less effect on speech intelligibility - the increased level cannot compensate for what is lacking in the spectrum. Similarly for the hiss and loudness ratings, the difference is accountable by the absence of high-frequency sound in the LB-MB spectrum.

For Rumble there is a statistically significant interaction of S2 x NQ that is more difficult to explain. At moderate noise levels relative to higher or lower levels, LB-MB shows an increase in rumble ratings, whereas the Neutral spectrum shows a decline, although (as indicated by the statistically significant main effect) LB-MB is always more perceived as more rumbly than Neutral. The reason for this quadratic interaction with noise levels is not clear.

There were no statistically significant multivariate interactions for S1 x NL or S1 x NQ. Changing noise levels did not differentially affect responses to Neutral versus LC-MB-HB. One explanation for this is that the two spectra were not sufficiently different, particularly with respect to the new Lo-Hi(A) measure (see also the measured spectrum levels in Figure 6).

Figure 10 *Means and standard deviations by Spectrum and Noise.*

Figure 10 *Means and standard deviations by Spectrum and Noise.*



3.2.3 Predictions from acoustic measures. Using hierarchical linear modelling, as for experiment 1, we examined the data from a different perspective, using physical measures of acoustical conditions instead of categorical variables for spectrum and noise level. Originally we had wanted to test the main effects and interactions, using variables to stand in for spectrum, noise, and their interaction. This proved to be impossible because the acoustic variables were too highly intercorrelated.

Instead, we selected three acoustic variables as possible predictors, and tested them in relation to the six dependent measures. The selection of predictors was based on theory and on the results of experiment 1. The predictors were Speech Intelligibility Index (SII), chosen because it developed to be an index of the degree of speech privacy afforded in an environment; Lo-Hi(A), chosen because of its explanatory strength in experiment 1, and A-weighted noise levels [Ln(A)], chosen because of the importance of the linear effect of noise levels in the MANOVA analyses.

The HLM results are presented in Table 14.A - 14.F. Generally speaking, both SII and Ln(A) were very good predictors, explaining large amounts of variance in 5 of the 6 dependent measures (all but self-rated productivity). The new variable, Lo-Hi(A), was not a good predictor in Experiment 2, most likely because it had a much smaller range (-7.7 to +10.4 in experiment 1, and 0.78 to 12.98 in Experiment 2). Similarly, the improvement in predictive ability for SII is probably related to its increased range across Experiment 2 conditions (.26 to .56 in Experiment 1, .14 to .61 in Experiment 2). The good agreement between results for SII and Ln(A) is consistent with the high correlation between these predictors (-.84; louder masking noise provides greater speech privacy). For interpretive purposes we have chosen to focus on SII only (see Figure 11, below).

Table 14. *HLM Summary Outcomes for Experiment 2*

14.A *Models for Acoustic Satisfaction*

Variable	**Mean (SD)**	**Min-Max**	**Intercept**	**B-weight**	z_B	p	$?^2_{partial}$
Acoustic Satisfaction	1.52 (0.80)	0-3.89	-	-	-	-	-
SII	0.41 (0.11)	0.14 - 0.61	2.25*	-1.80	-4.57	.00	.42
Lo-Hi(A)	5.67 (2.87)	0.78 - 12.98	1.52	0.00	0.03	.98	
Ln(A)	45.94 (3.55)	40.13 - 52.02	-0.83	0.05	4.01	.00	.36

Note. *This intercept estimate was statistically significant, reflective of differences in acoustic satisfaction levels between individuals. These were of no theoretical significance here, and were not further interpreted. ~ This model was unable to be fit.

14.B. *Models for Self-rated Productivity*

Variable	**Mean (SD)**	**Min-Max**	**Intercept**	**B-weight**	z_B	p	$?^2_{partial}$
Self-rated Productivity	2.37 (1.26)	0 - 6	-	-	-	-	-
SII	0.41 (0.11)	0.14 - 0.61	2.73*	-0.90	-1.52	.13	
Lo-Hi(A)	5.67 (2.87)	0.78 - 12.98	~	~	~	~	
Ln(A)	45.94 (3.55)	40.13 - 52.02	1.04	0.03	1.51	.13	

14.C. *Models for Speech Intelligibility*

Variable	**Mean (SD)**	**Min-Max**	**Intercept**	**B-weight**	z_B	p	$?^2_{partial}$
Speech Intelligibility	69.10 (31.88)	0 - 100	-	-	-	-	-
SII	0.41 (0.11)	0.14 - 0.61	15.14	133.36	7.96	.00	.69
Lo-Hi(A)	5.67 (2.87)	0.78 - 12.98	~	~	~	~	
Ln(A)	45.94 (3.55)	40.13 - 52.02	248.41*	-3.90	-7.68	.00	.67

14.D. *Models for Rumble Ratings*

Variable	**Mean (SD)**	**Min-Max**	**Intercept**	**B-weight**	z_B	p	$?^2_{partial}$
Rumble	1.38 (1.08)	0 - 4	-	-	-	-	-
SII	0.41 (0.11)	0.14 - 0.61	3.14	-4.27	-8.25	.00	.70
Lo-Hi(A)	5.67 (2.87)	0.78 - 12.98	0.73*	0.12	5.53	.00	.51
Ln(A)	45.94 (3.55)	40.13 - 52.02	-5.98*	0.16	10.28	.00	.79

14.E. *Models for Hiss Ratings*

Variable	Mean (SD)	Min-Max	Intercept	B-weight	z_B	*p*	$?^2_{partial}$
Hiss Ratings	1.44 (1.11)	0 - 4	-	-	-	-	-
SII	0.41 (0.11)	0.14 - 0.61	3.74	-5.65	-9.02	.00	.74
Lo-Hi(A)	5.67 (2.87)	0.78 - 12.98	1.60	-0.03	-1.42	.15	
Ln(A)	45.94 (3.55)	40.13 - 52.02	-5.52	0.15	9.52	.00	.76

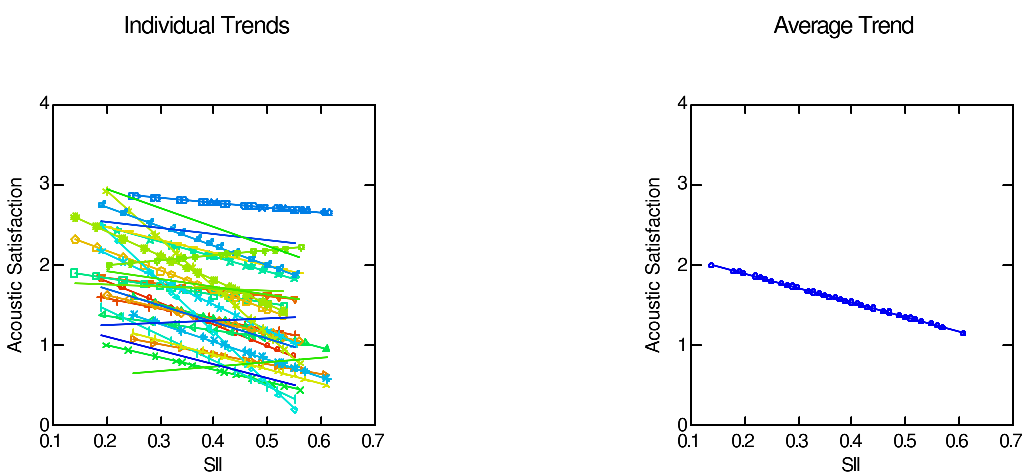
14.F. *Models for Loudness Ratings*

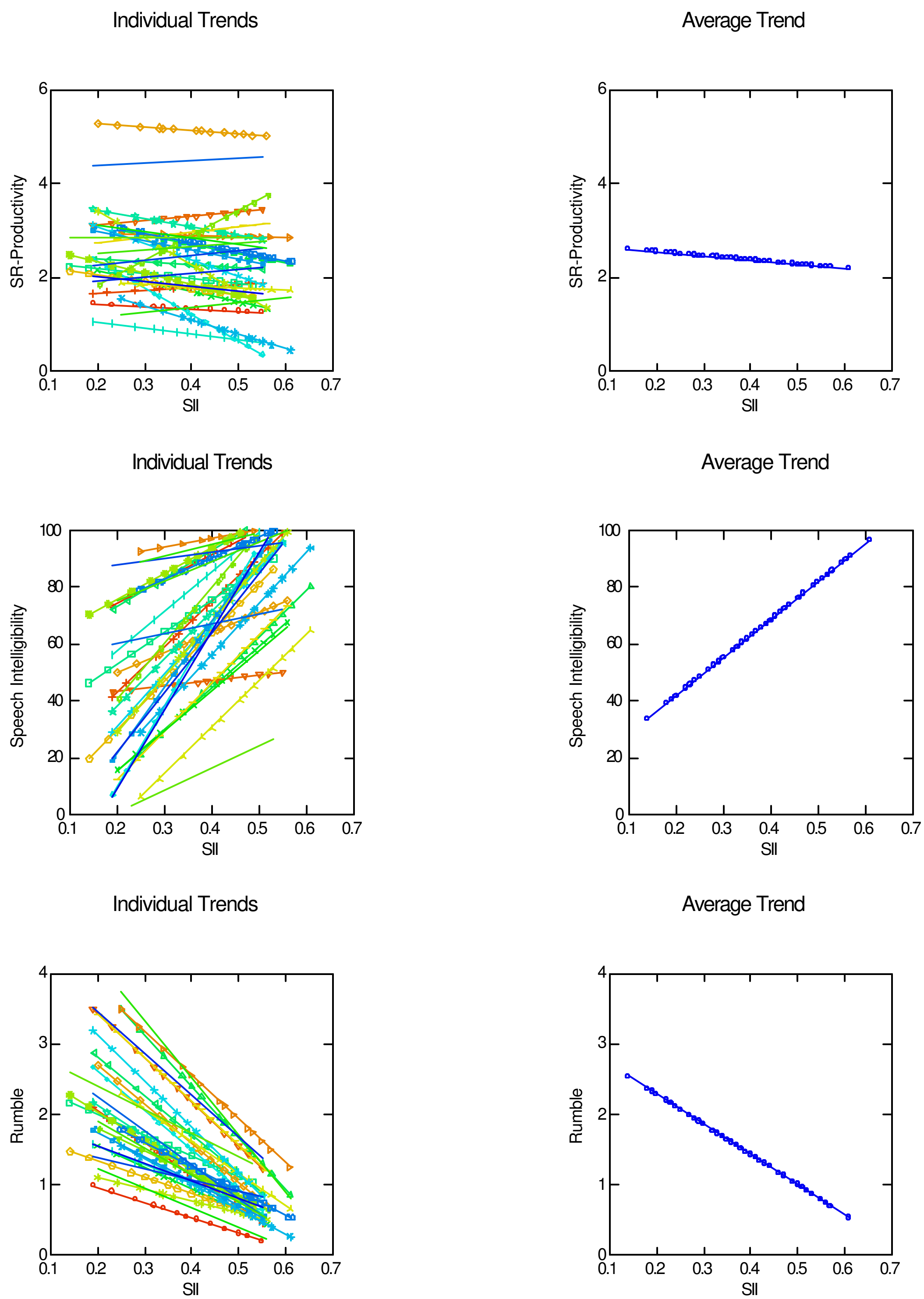
Variable	Mean (SD)	Min-Max	Intercept	B-weight	z_B	*p*	$?^2_{partial}$
Loudness	2.06 (0.97)	0 - 4	-	-	-	-	-
SII	0.41 (0.11)	0.14 - 0.61	4.06	-4.90	-10.74	.00	.80
Lo-Hi(A)	5.67 (2.87)	0.78 - 12.98	*8	~	~	~	
Ln(A)	45.94 (3.55)	40.13 - 52.02	-5.13	0.16	11.09	.00	.81

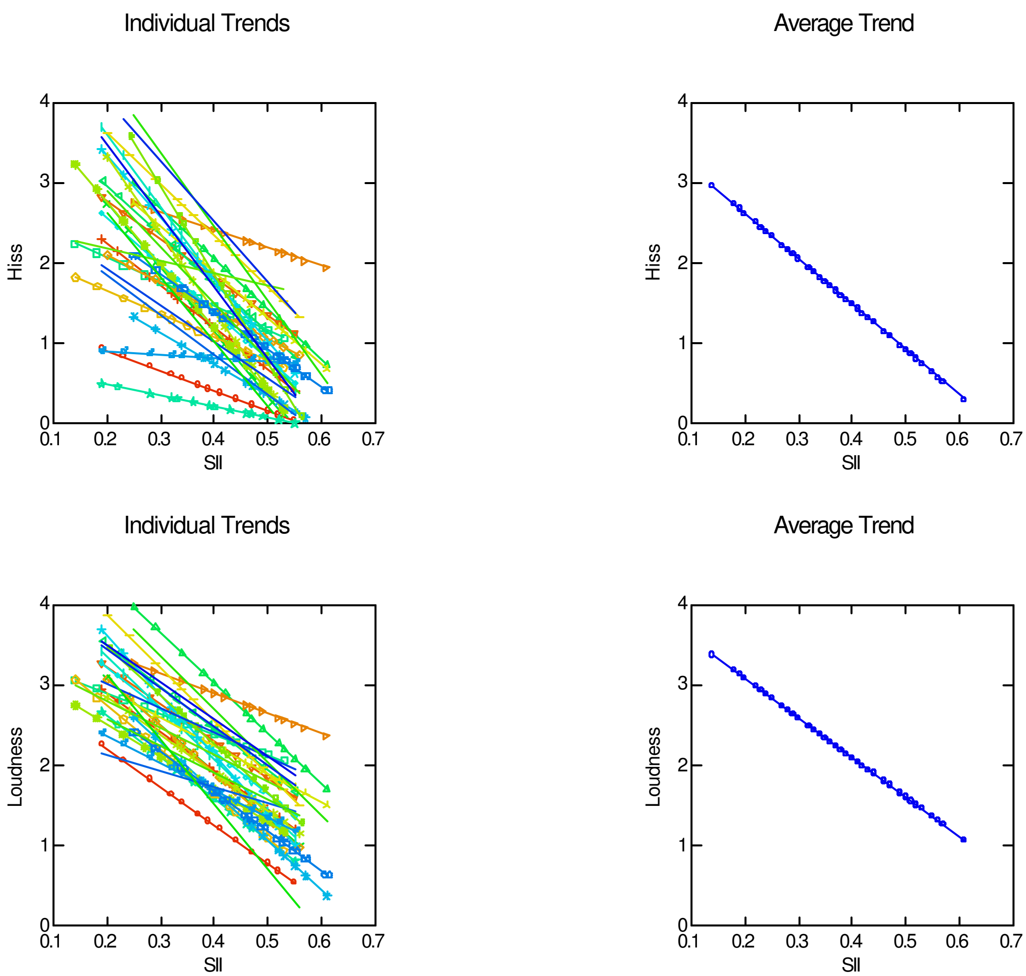
14.G. *Overall HLM Summary.*

Variable	Signficant Predictions	Significant Predictor of	Model Fit Failures
SII	5	Acoustic Satisfaction, Speech Intelligibility, Rumble, Hiss, Loudness	0
Lo-Hi(A)	1	Rumble	3
Ln(A)	5	Acoustic Satisfaction, Speech Intelligibility, Rumble, Hiss, Loudness	0

Figure 11. *Individual and Average Trends for HLM Prediction by SII.*




Individual Trends
SR-Productivity
SII
Average Trend
SR-Productivity
SII
Individual Trends
Speech Intelligibility
SII
Average Trend
Speech Intelligibility
SII
Individual Trends
Rumble
SII
Average Trend
Rumble
SII



The average results (right-hand column) show that as SII increases, acoustic satisfaction declines and speech intelligibility increases.

Figure 12 shows the results for predictions based on Ln(A) values, for all six dependent variables. Consistent with the hypothesis that acoustic satisfaction is provided by improving speech privacy, acoustic satisfaction increased with increasing loudness, while speech intelligibility declined. However, consistent with the MANOVA results, ratings of loudness crossed over towards "too loud" when Ln(A) exceeded 45 dB(A).

Figure 12. *Individual and Average Trends for HLM Prediction by Ln(A).*

Figure 12. *Individual and Average Trends for HLM Prediction by Ln(A).*

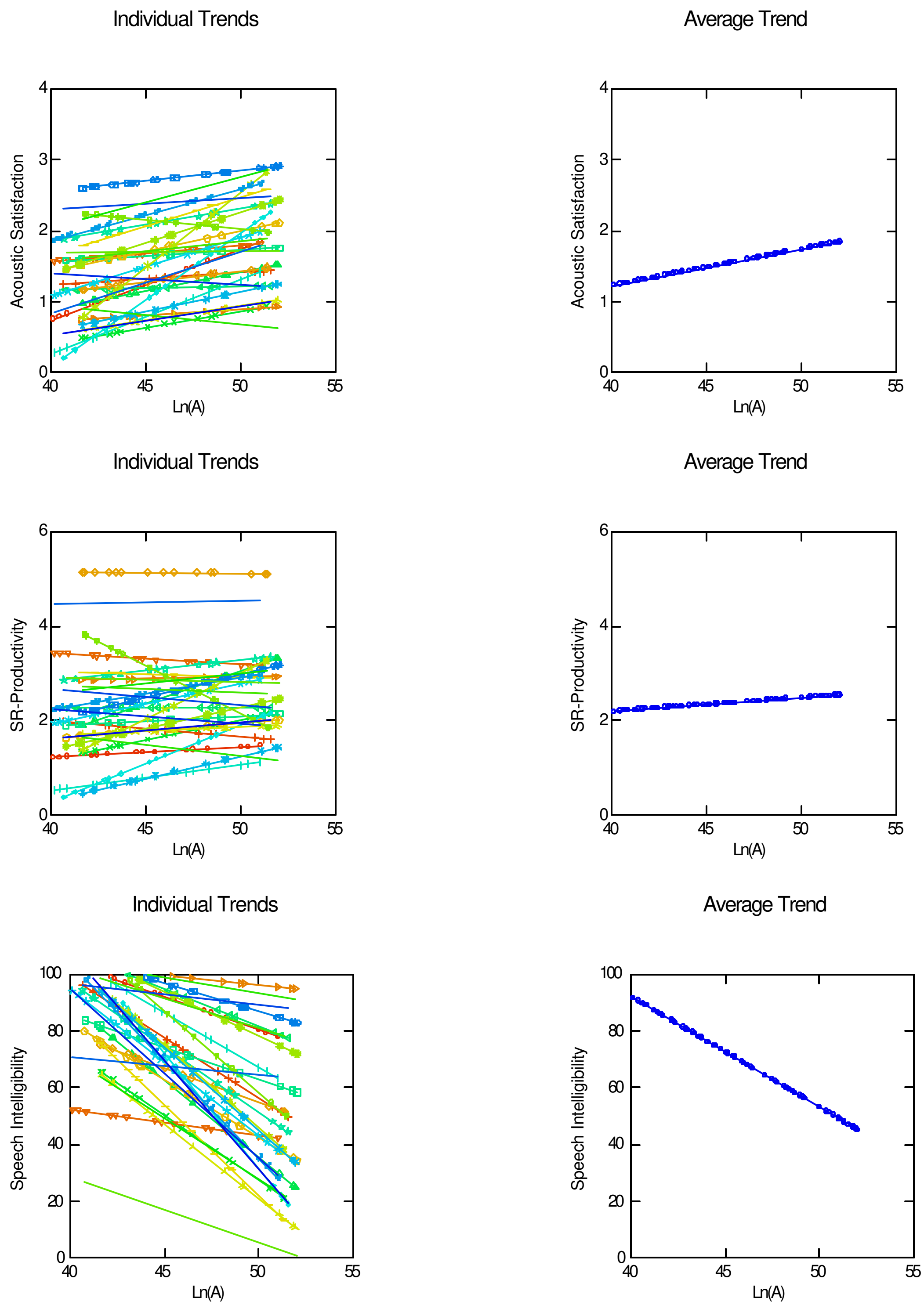
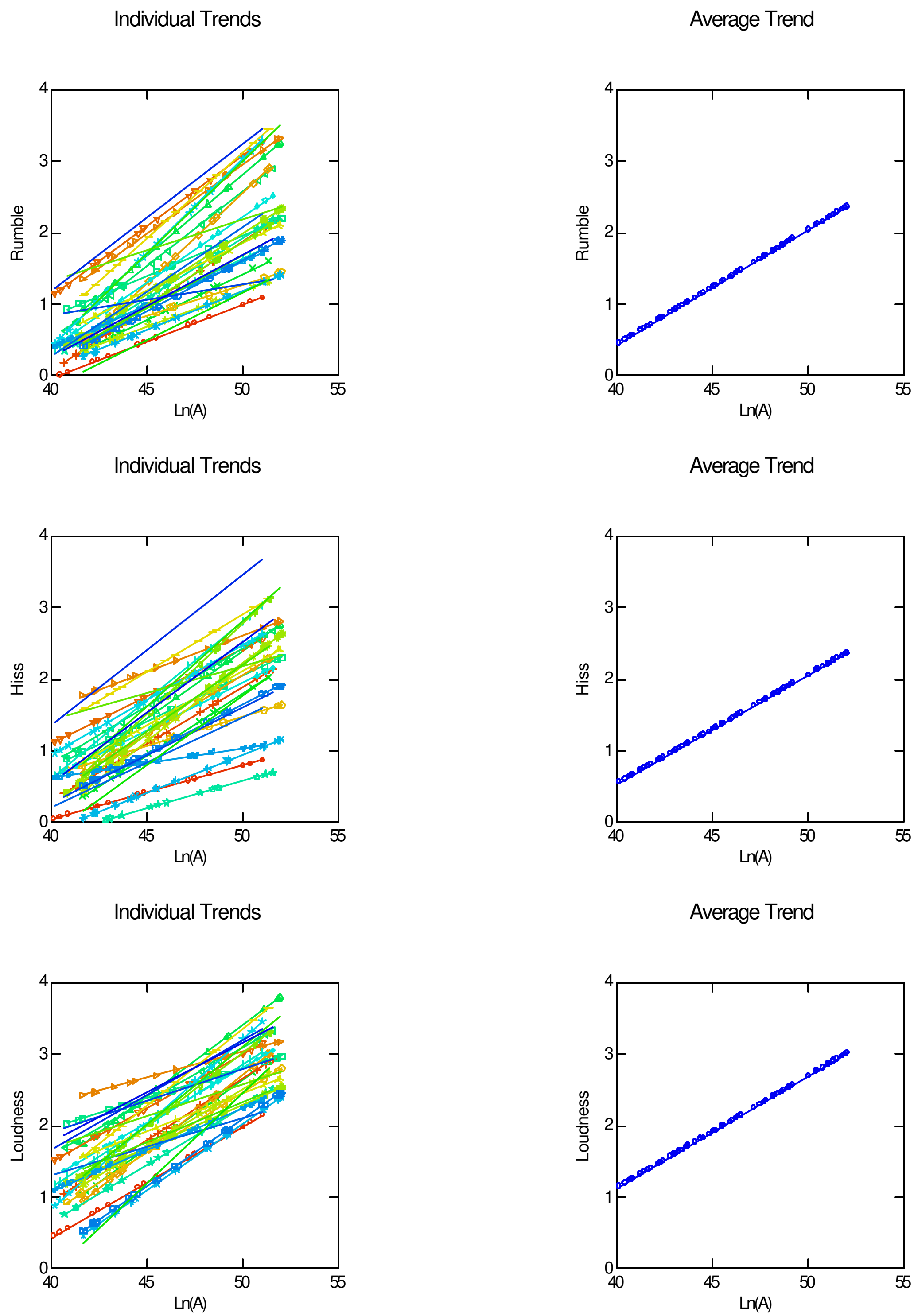


Figure 12. *Individual and Average Trends for HLM Prediction by Ln(A).*



We also attempted to run models predicting acoustic satisfaction from Lo-Hi(A) and Ln(A) together, and with SII and Ln(A) together. However, the distributions of these variables caused the models to fail; this procedure is very sensitive to non-normality and to multicollinearity.

3.2.4 Aspects of acoustic satisfaction. In experiment 2, unlike experiment 1, the more satisfactory acoustic conditions (lower SII) were also rated as more hissy. Nonetheless, we sought to replicate the relationships between acoustic satisfaction, speech intelligibility, and hiss that were seen in experiment 1. Consistent with the observations above, the two predictors (speech intelligibility and hiss) were correlated for experiment 2 (r = -.28 over the entire sample and all noise conditions). Nonetheless, we ran the model that we had observed for experiment 1: acoustic satisfaction predicted from speech intelligibility and hiss. The results are shown in Table 15. In experiment 2, the hissiness of the masking sound does not predict acoustic satisfaction. One reason for this could be that none of the conditions in experiment two were as highly weighted in high frequencies as in experiment 1 (as seen in the range of values for the Lo-Hi(A) index). The strong relationship between speech intelligibility and acoustic satisfaction, however did replicate.

We also repeated the analysis of acoustic satisfaction in relation to rumble. In this experiment, rumble was a significant predictor of acoustic satisfaction: as rumble increased, so did acoustic satisfaction. In the reverse direction, this suggests that the balance between high and low frequencies is an important consideration.

Table 15. *HLM Analysis of acoustic satisfaction in relation to perceived conditions.*

Variable	Mean (SD)	Min-Max	Estimate	z_B	*p*	?$^2_{partial}$
Acoustic Satisfaction	1.52 (0.80)	0.00 - 3.89				
Intercept			2.33			
Speech Intelligibility	69.10 (31.88)	0 - 100	-0.01	-5.17	.00	.48
Hiss Rating	1.44 (1.11)	0 - 4	-0.03	-1.03	.30	
Intercept						
Rumble	1.38 (1.08)	0 - 4	0.04	2.51	.01	.18

3.2.5 Individual differences in noise sensitivity. As in experiment 1, we tested the hypotheses that individual differences in noise sensitivity might explain overall ratings of environmental satisfaction and ratings of task difficulty at the end of the experiment. Scores on the 21-item Noise Sensitivity Scale (Weinstein, 1978) were regressed on the end-of-day environmental satisfaction ratings and on the average rating of task difficulty (excluding ratings of the difficulty of the hearing test). The results are summarised in Table 16. In Experiment 2, there was a statistically significant relationship between noise sensitivity and environmental satisfaction, but it was contrary to the prediction: people who were more noise-sensitive reported higher satisfaction with the environment at the end of the experimental session.

Table 16. *Regression analyses of Noise Sensitivity (Experiment 2).*

Dependent Variable / Predictor	Mean (SD)	Cronbach's a	Min-Max	Estimate	*t*	*p*	R^2
ES_End	2.40 (0.75)	.79	1.00 - 3.50				
Intercept				1.31			
NSS	1.95 (0.52)	.88	0.81 - 2.76	0.63	2.26	.03	.20
Difficulty	1.56 (0.57)	.64	0.33 - 2.67				
Intercept				2.22			
NSS	1.95 (0.52)	.88	0.81 - 2.76	-0.36	-1.48	.15	

Note. All scales have theoretical range from 0 - 4. Lower scores indicate less noise sensitivity (NSS), lower ratings for task difficulty (Difficulty), and lower ratings for overall environmental satisfaction at the end of the session (ES_End).

3.3 Discussion: Experiment 2

The conventional MANOVA model for Experiment 2 revealed that both spectrum and sound pressure level are important to the achievement of speech masking. The results are in predicted directions, although the effects of spectrum are not as strong as those of noise level. LB-MB was less effective for speech masking, and did not improve as much in masking as it became louder as did the Neutral spectrum. The absence of the predicted effects for LC-MB-HB in comparison to the Neutral spectrum might be explained by their similarity in terms of the Lo-Hi(A) characteristic (see Table 10). Across the LC-MB-HB and Neutral conditions, Lo-Hi(A) values range only between 3.36 and 4.90, whereas LB-MB is very different. To maximise this difference, a better choice of spectrum might have been LC-HB (Lo-Hi(A) around -1.8) or LC-MC-HB (Lo-Hi(A) around -5).

Effects of noise level across spectra were large, with higher noise levels generally leading to more extreme evaluations of the sound quality (lower speech intelligibility, more hissy, more rumbly, and louder). Overall loudness crossed the neutral point on its scale at level 3 (approx. 45 dB(A)). Thus given typical tolerances of ± 3 dB(A), this suggests that acceptable noise levels are 45 ± 3dB(A). This would be in agreement with suggestions that ambient noise levels in open offices should not exceed 48 dB(A) (Warnock et al., 1972).

Examining the data in a different way, using HLM, the data revealed that Speech Intelligibility Index (SII) is a good predictor of acoustic satisfaction and noise conditions, producing effect sizes that are large in behavioural research terms. Most notably, higher SII values reduce acoustic satisfaction and speech intelligibility. SII values above approximately 0.20 resulted in satisfaction falling below the neutral point on the its scale, which is close to the rule-of-thumb value that is used for acceptable speech privacy (i.e., SII should be less than 0.20) (American Society for Testing and Materials (ASTM), 1993). The high sound pressure levels (48 and 51 dB(A)) that created the low SII conditions in this experiment probably attenuated this relationship.

Also of note are the predictions for rumble, hiss and loudness, all of which decline with SII. These are also as predicted, in that quieter sounds are poorer at masking speech.

As in experiment 1, rated speech intelligibility strongly predicted acoustic satisfaction. However, rated hiss did not. The more limited range of spectral conditions probably underlies this absence of effect. Another difference between the results of experiments 1 and 2 is the presence in experiment 2 of a relationship between noise sensitivity and environmental satisfaction.

4.0 General Discussion

Speech and noise propagation are inevitable in open-plan spaces, where there are few or no barriers to sound transmission from one cubicle to another. This is the source of long-standing dissatisfaction with open-plan spaces (e.g., Sundstrom et al., 1994). Although sound masking equipment has been available for decades, marketed as a solution for masking speech sounds, there has been little empirical evidence to guide the choice of masking spectrum or level. These two experiments provide such guidance, both qualitatively and quantitatively.

Considering the results of the two experiments, we can extract the following general principles concerning acoustic satisfaction in relation to office noise conditions:

Acoustic satisfaction increases as subjectively rated speech intelligibility decreases. This finding was observed in both experiments, and makes intuitive sense. Distraction from overheard speech is a common complaint (Sailer & Hassenzahl, 2000; Sundstrom et al., 1994) and also causes poorer task performance (Banbury & Berry, 1998).

The difference between low- and high-frequency A-weighted levels is a good predictor of the effects of masking sound spectrum shape on acoustic satisfaction. This new way to characterise spectrum shape was the only predictor that predicted all six dependent measures in Experiment 1. It merits further attention to replicate this finding.

Acoustic satisfaction decreases as hissiness increases. This finding occurred only in Experiment 1, where the range of spectra was greater. Excessive hiss [Lo-Hi(A) < 0 dB(A)] can compromise acoustic satisfaction. This has consequences for selecting an effective masking spectrum, requiring balance between speech intelligibility and hiss.

Noise spectra that follow the speech spectrum are effective speech maskers. This is consistent with predictions from the basic psychoacoustics (Zwicker & Fastl, 1990), in experiment 2, LB-MB was less effective than either the Neutral or LC-MB-HB spectra.

Louder masking noise does not improve speech masking as much if the spectrum is a poor masker. Although increasing the loudness of the masking noise does provide some improvement in speech masking, the effect is diminished if the spectrum itself is weak in the frequencies needed for speech masking (Experiment 2).

Noise levels much greater than 45 dB(A) are judged to be too loud. Although higher levels provide greater speech masking and improved acoustic satisfaction (experiment 2), the effect on loudness ratings is much larger. Higher levels could trigger physiological stress responses, even in individuals not reporting that they perceive being stressed (Evans & Johnson, 2000). If one assumes a tolerance of ± 3dB(A), this suggests that a noise level of 45 dB(A) is optimum and noise levels should not exceed about 48 dB(A) as suggested previously (Warnock et al., 1972).

Over the range of acoustic conditions in open-plan offices, SII is a good predictor of acoustic satisfaction and rated speech intelligibility. Since speech intelligibility is the inverse of speech privacy, we can conclude that SII is a good predictor of speech privacy. . The HLM results for experiment 2 generally validate the rule-of-thumb that SII should be below 0.2 in open-plan offices and that satisfaction and speech privacy will increase further for lower SII values. The fact that all the conditions with SII<.20 were very loud probably attenuated the acoustic satisfaction with conditions of very low speech intelligibility. Future research should investigate the effects of reducing SII by reducing sound transmission between workstations (e.g., using higher partitions, insulating material in partitions, or improved ceiling materials), so that masking sound levels at low SII values can be lower.

Every investigation has its limitations. Two important limitations of these experiments are the very short exposure times (15-18 minutes) to each noise condition, and the limited range of acoustic conditions (even in experiment 2, the only conditions with SII < .20 were very loud). In addition, the acoustic conditions were varied by changing simulated ventilation sound, holding the office furnishings and layout constant. Further investigation, likely in field settings, is required to determine that these conclusions are widely applicable over the range of conditions commonly experienced in real open-plan offices.

5.0 References

Acoustical Society of America Standards Secretariat (ASA). (1997). *Methods for calculation of the speech intelligibility index* (ANSI S3.5-1997). New York: ASA.

American Society for Heating Refrigerating and Air Conditioning Engineers (ASHRAE). (2001). *ASHRAE fundamentals handbook*. Atlanta, GA: ASHRAE.

American Society for Testing and Materials (ASTM). (1993). *Standard guide for open offices acoustics and applicable ASTM standards* (ASTM E1374). Philadelphia, PA: ASTM.

Banbury, S., & Berry, D. C. (1998). Disruption of office-related tasks by speech and office noise. *British Journal of Psychology, 89*, 499-517.

Beranek, L. L. (1971). *Noise and vibration control.* New York: McGraw Hill.

Blazier, W. E. (1981). Revised noise criteria for application in the acoustical design and rating of HVAC systems. *Noise Control Engineering Journal, 16*(2), 64-73.

Blazier, W. E. (1997). RC Mark II; A refined procedure for rating the noise of heating ventilating and air-conditioning (HVAC) systems in buildings. *Noise Control Engineering Journal, 45*(6), 243-250.

Broner, N. (1993). *Determination of the relationship between low frequency HVAC noise and comfort in occupied spaces*. Atlanta, GA: American Society for Heating, Refrigerating, and Air-Conditioning Engineers.

Bryk, A. S., & Raudenbush, S. W. (1992). *Hierarchical linear models: Applications and data analysis methods*. Newbury Park, CA: Sage.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

Evans, G. W., & Johnson, D. (2000). Stress and open-office noise. *Journal of Applied Psychology, 85*, 779-783.

Loewen, L. J., & Suedfeld, P. (1992). Cognitive and arousal effects of masking office noise. *Environment and Behavior, 24*, 381-395.

Newsham, G. R., & Tiller, D. K. (1995, March). *Questionnaire software to enable study of short-term changes in subjective reactions to the indoor environment.* Paper presented at the 26th Annual Convention of the Environmental Design Research Association, Boston, MA.

Pearsons, K. S., Bennett, R. L., & Fidel, S. (1977). *Speech levels in various noise environments* Report No. EPA-6001-77-025 (NTIS PB-270 053). Washington, D.C.: U. S. Environmental Protection Agency.

Sailer, U., & Hassenzahl, M. (2000). Assessing noise annoyance: An improvement-oriented approach. *Ergonomics, 43*, 1920-1938.

Schomer, P. D., & Bradley, J. S. (2000). A test of proposed revisions to room noise criteria curves. *Noise Control Engineering Journal, 48*(4), 124-129.

Sundstrom, E. (1987). Work environments: Offices and factories. In D. Stokols, & I. Altman (Eds.), *Handbook of Environmental Psychology* (Vol. 1, pp. 733-782). New York: Wiley.

Sundstrom, E., Burt, R. E., & Kamp, D. (1980). Privacy at work: Architectural correlates of job satisfaction and job performance. *Academy of Management Journal, 23*, 101-117.

Sundstrom, E., Town, J. P., Brown, D. W., Forman, A., & McGee, C. (1982). Physical enclosure, type of job, and privacy in the office. *Environment and Behavior, 14*, 543-559.

Sundstrom, E., Town, J. P., Rice, R. W., Osborn, D. P., & Brill, M. (1994). Office noise, satisfaction, and performance. *Environment and Behavior, 26*, 195-222.

Tabachnick, B. G., & Fidell, L. S. (2001). *Using multivariate statistics* (4th ed.). Boston, MA: Allyn & Bacon.

Tang, S. K., & Wong, C. T. (1998). Performance of noise indices in office environment dominated by noise from human speech. *Applied Acoustics, 55*(4), 293-305.

Warnock, A. C. C. (1972). *Acoustical studies in open plan offices - Summary report.* (Technical Note No. 567). Ottawa, ON: National Research Council of Canada, Division of Building Research.

Warnock, A. C. C., & Chu, W. T. (2002). *Voice and background noise levels measured in open offices* (IRC-IR-837). Ottawa, ON: National Research Council of Canada, Institute for Research in Construction.

Warnock, A. C. C., Henning, D. N., & Northwood, T. D. (1972). *Acoustical survey of an open-plan landscaped office*. (DBR Internal Report No. 400). Ottawa, ON: National Research Council of Canada, Division of Building Research.

Weinstein, N. D. (1978). Individual differences in reactions to noise: A longitudinal study in a college dormitory. *Journal of Applied Psychology, 63*, 458-466.

Zwicker, E., & Fastl, H. (1990). *Psychoacoustics*. Berlin, Germany: Springer-Verlag.

Zwicker, E., Fastl, H., & Dallmayr, C. (1984). BASIC-Program for calculating the loudness of sounds from their 1/3-octave band spectra according to ISO 532B. *Acoustica, 55* , 63.

Appendix A

Information for Participants: NRC Project B3205 (Protocol 1999-35)

You have been invited to participate in a research project at the National Research Council of Canada's Institute for Research in Construction. The project is part of our Indoor Environment program, in which we study the relationships between the building physical conditions and the experiences and opinions of the people who work in buildings. Some of our investigations are field studies in organisations; others, like this one, take place in the laboratory.

We are working to develop guidelines for the design and maintenance of offices that enable people to work effectively and efficiently while being comfortable and healthy workplaces. To accomplish this we will require good behavioural tools to measure the outcomes that matter to employees and employers. We want to collect data from a large number of people to get an idea of the average performance and opinions of office workers before we proceed to try out these tools in the field.

At this stage, we are seeking your agreement in principle to participate. For this study, we are hiring 85 office temporaries from **<name of firm here>** to work for one day at a set of tasks that cover the elements of office work. This page describes the study. Please read it carefully, and then tell your supervisor if you are willing to be considered for this job. You must be at least 18 to participate in this study. You must also have normal or corrected-to-normal vision, normal hearing, no mobility impairments, and the required level on your agency's word fluency test. Because some people have hearing problems of which they might not be aware, everyone who arrives at our facility to participate will have a short hearing test to determine their hearing sensitivity before the session starts.

If you are willing to act as a research subject, your name will be added to the pool of participants for this study. Each week, 16-20 people of various ages will be selected randomly from the pool and scheduled for a day's work as a participant. People who are not chosen will remain part of the pool, and may be chosen at a later time.

If you choose to participate in this study, it will involve spending one day in the Indoor Environment Research Facility (IERF) in Building M-24 on our Montreal Road Campus. The IERF is a specially-constructed open-plan office where we conduct the laboratory portion of our work. The office was designed according to standard federal government practice for open-plan offices, and has six workstations. It is monitored from a separate room using a security camera so that the researchers can leave employees to work on their own.

The day will include reading tests, word completion, and memory tests. We will also ask you to complete a variety of questionnaires to assess your opinions of the office. Most of the work and the questionnaires will be completed on a PC using Windows-based software.

There is a separate lounge area for your lunch (45 minutes). Coffee and tea will be provided. We encourage all participants to bring a lunch; however, there is a cafeteria in a nearby building if you prefer.

You will be paid for the day's work at your standard rate for a 7.5-hour day. The start time is 8:30 a.m. You will probably finish at about 4:30 p.m. Pay will be managed in the usual way by your employer. However, because the work is in the service of a research project, you have additional rights. You have the right to end your participation at any time during the day should you desire. There will be no penalty for doing so, nor will we inform your employer of your decision.

All of the information that we receive from you will remain strictly confidential. It will be recorded anonymously, using a code based on your initials and month and day of birth. Your name will appear only on the consent form that you will be asked to sign; these forms will be held in a locked file cabinet controlled by the principal investigators. Your name will never appear in any report or document based on this research. Your employer will not have access to any information that you provide during the day. Although we cannot provide feedback during the day, you can access the data you provide by contacting the principal investigator.

There are no known risks or hazards associated with participating in this investigation. Prior to beginning the work session you will be offered an opportunity to ask questions about the investigation and the work, and you will be asked to read and sign a form to indicate that you have consented to participate in the study.

The principal investigators for this study are Dr. Jennifer Veitch and Dr. John S. Bradley. You can reach Dr. Veitch at 993-9671 should you have any questions to direct to her, or Dr. Bradley at 993-9747.

Appendix B

Initials	**Birth Month & Day**
e.g. KDG	*e.g. 0930*

CONSENT TO SERVE AS A SUBJECT IN RESEARCH AT THE NATIONAL RESEARCH COUNCIL OF CANADA

I have been asked to participate in a study of office work performance and satisfaction. I understand that I will receive no benefits from participation in this experiment other than the regular pay for one day's work, administered by my employer <name of temporary services firm>.

I understand my hearing sensitivity will be tested. My employer will not be informed about the results of the hearing test nor any other data I provide.

I have had satisfactory answers to all my questions. I understand that there are no known risks or hazards involved in this experiment.

I have been informed that I may withdraw my consent and discontinue my service as a research subject at any time I so desire.

I have been informed that my identity will not be revealed in any publication or document resulting from this research.

At the end of the experiment I will be entitled to a full explanation of the nature of the experiment, and to know the results from my participation.

Based on this information, I freely and voluntarily consent to serve as a subject in the research investigation for NRC project 44-B3205 (Protocol No. 1999-35).

Signed this __________ day of ___________, 200__

in the City of Ottawa, in the Province of Ontario.

____
Signature of Subject

____
Printed Name of Subject

Principal Investigators:
Jennifer A. Veitch, Ph.D. and John S. Bradley, Ph.D.
National Research Council of Canada
Ottawa, Ontario K1A 0R6

Appendix C
Acoustic Satisfaction Measures

Please tell us your opinion about all aspects of the office conditions in the last few minutes. When responding, think about the total effect of those conditions on you if they were the conditions of your everyday office. Please click on the radio button which best indicates your level of agreement or disagreement with each statement.

Please use the following scale to indicate your agreement or disagreement with each statement:.

strongly disagree	disagree	neutral	agree	strongly agree
❍	❍	❍	❍	❍

1. Considering all the sounds just heard, I am satisfied with sound environment.

2. Please rate the how rumbly you find character of the background sound (ventilation).

Not rumbly at all	A little rumbly	Somewhat rumbly	Rumbly	Too rumbly
❍	❍	❍	❍	❍

3. Please rate the how hissy you find character of the background sound (ventilation).

Not hissy at all	A little hissy	Somewhat hissy	Hissy	Too hissy
❍	❍	❍	❍	❍

4. Please rate your work space for the loudness of background sound (ventilation).

Much too quiet	Somewhat too quiet	Neither quiet nor loud	Somewhat loud	Much too loud
❍	❍	❍	❍	❍

5. How much did conversation from an adjacent work space hinder you from doing the tasks?

Not at all	A little bit	Somewhat	Very much	Completely hindered
❍	❍	❍	❍	❍

6. How would you rate the speech privacy of your office?

Confidential Privacy	Moderate Privacy	Acceptable Privacy	A little Privacy	No Privacy
❍	❍	❍	❍	❍

7. Please use the slider bar to estimate the percentage of speech that you could understand during this session.

0% 100%

8. Please click on the radio button that best represents how much you think your personal productivity during this work session was increased or decreased by the sound conditions as compared to what you usually achieve.

❍	❍	❍	❍	❍	❍	❍
-30%	-20%	-10%	0%	+10%	+20%	+30%

For the next statements, please think what it would be like if you had to work all the time in conditions similar to those experienced in the last few minutes....

strongly disagree	disagree	Neutral	agree	Strongly agree
❍	❍	❍	❍	❍

If I had to work all the time in conditions similar to those experienced in the last work session (15 minutes):

9. I could have meetings in my office without distracting others.
10. I could work uninterrupted for long periods.
11. The noise in my office would not be distracting.
12. I could easily have confidential conversations.
13. This constant level of office sound around me would annoy me.
14. I could work effectively with this constant level of office sounds around me.

15. Please describe, in your own words, the background ventilation noise.

16. Please describe how this background ventilation noise would affect you if you had to work on something requiring a lot of concentration.

Appendix D
Noise Sensitivity Scale

(Weinstein, 1978 with editorial changes)

The following questions relate to *your typical response to everyday sounds*. There are no right or wrong answers. We simply to know your opinions. Please indicate your level of agreement or disagreement for each of the following statements.

strongly disagree	disagree	neutral	agree	strongly agree
❍	❍	❍	❍	❍

1. I wouldn't mind living on a noisy street if I had a nice home.
2. I am more aware of noise than I used to be.*
3. No one should mind much if someone turns up the stereo full blast once in a while.
4. At movies, whispering and crinkling candy wrappers disturb me.*
5. I am easily awakened by noise.*
6. If it's noisy where I'm working, I try to close the door or window or move someplace else.*
7. I get annoyed when my neighbours are noisy.*
8. I get used to most noises without much difficulty.
9. It would matter to me if an apartment or house I wanted were located across from a fire station.*
10. Sometimes noises get on my nerves and get me irritated.*
11. Even music I normally like will bother me if I'm trying to concentrate.*
12. It wouldn't bother me to hear the sounds of everyday living from neighbours (footsteps, running water, etc.).
13. When I want to be alone, it disturbs me to hear outside noises.*
14. I'm good at concentrating no matter what is going on around me.
15. In a library, I don't mind if people carry on a conversation if they do it quietly.
16. There are often times when I want complete silence.*
17. Motorcycles ought to be required to have better mufflers.*
18. I find it hard to relax in a place that's noisy.*
19. I get mad at people who make noise that keeps me from falling asleep or getting work done.*
20. I wouldn't mind living in a house or apartment with thin walls.
21. I am sensitive to noise.*

* Item scored in opposite direction before responses are summed.

Appendix E
Explanation of Acoustical Measures

Three types of acoustical measures were included in the analyses of this report. These are: measures of the overall level of noise with various frequency weightings, measures of speech-to-noise ratios and measures of the spectral characteristics of the noises. The measures that rate the overall levels of noises can be divided into two types, those that compare a measured noise spectrum with a set of rating contours and those that sum up the contributions of the weighted importance of difference frequency components of the noise.

Measures of overall noise level

(a) Measures using frequency weighted sums.

L_N(A) The A-weighted overall sound level. This is the overall level of the noise in decibels after the signal has been passed through an A-weighting filter. This filter has a shape that approximates the frequency response of our hearing system and is derived from a particular equal loudness contour. A-weighted sound levels are an approximate indication of the loudness of sounds and are the most commonly used single number rating of noise levels.

LL_N The loudness level. The loudness level is a more precise indicator of the perceived loudness of sounds. The calculations were based on Zwicker's method (Zwicker & Fastl, 1990) that sums up the weighted importance of each frequency component of the noise and also includes estimates of the masking of one component on another. In this study LL_N values were calculated from 1/3 octave band measurements of the noises using a published computer program (Zwicker, Fastl, & Dallmayr, 1984).

(b) Measures based on rating contours.

NC Noise Criterion. The Noise Criterion rating is the oldest of the octave-band noise rating systems using sets of rating contours. Measured octave band sound levels for the standard octave bands from 63 to 8000 Hz are plotted on the ratings contours. The highest contour that the measured levels just touch is the NC rating of the noise. (Beranek, 1971). NC values are not included in the current analyses because they don't include the lowest frequencies, but are described here because they are the basis of the other systems described below.

PNC Preferred Noise Criterion. The Preferred Noise Criterion rating is a revision to the NC system that extends one octave lower (31 to 8000 Hz) and includes slightly different rating contours (Beranek, 1971).

RC Room Criterion. The Room Criterion rating was devised to rate ventilation noise (Blazier, 1981) and is recommended for indoor ventilation noise (ASHRAE, 2001). The rating contours consist of straight lines decreasing at 5 dB/octave because this shape of spectrum was thought to produce a spectrally neutral sound. The RC rating consists of both a number and a letter such as RC 35(N). The numerical part is simply the average of the octave band levels at 500, 1000 and 2000 Hz. The letter indicates whether the spectral quality is neutral (N), has greater low frequency sound (LF), has greater mid-frequency sound (MF), or has greater high frequency sound (HF). Low frequencies were defined as the 16, 31 and 63 Hz octave bands, mid-frequencies as the 125, 250 and 500 Hz octave bands, and high frequencies as the 1000, 2000 and 4000 Hz octave bands. The RC Mark II procedure (Blazier, 1997) added the calculation of the Quality Assessment Index (QAI). QAI is intended to numerically assess the deviation of the spectral quality from a neutral spectrum case by measuring the maximum range of deviations from the neutral case over the three frequency regions corresponding to low mid and high frequency sounds.

RNC Room Noise Criterion. The Room Noise Criterion is the most recent octave band noise rating procedure (Schomer & Bradley, 2000). It is based more closely on our understanding of the psychoacoustics of the loudness of noises and includes an estimate of the additional loudness caused by fluctuating low frequency sounds. In this work RNC values were calculated both with (RNC) and without (RNC_{nf}) noise level fluctuations. The added effect of low frequency level fluctuations is based on the standard deviation of the levels in the 16 to 63 Hz octave bands, $\sigma_{16\text{-}63}$. This low frequency level fluctuation component of the measure, $\sigma_{16\text{-}63}$, was also considered separately in the analyses of this report.

RNC_{nf} Room Noise Criterion without low frequency level fluctuations. The Room Noise Criterion was also calculated without the low frequency level fluctuation term to enable the evaluation of both components of the RNC measure. RNC_{nf} allows the evaluation of the rating contours used in the RNC measure and $\sigma_{16\text{-}63}$ makes it possible to evaluate the level fluctuation component.

Measures of speech-to-noise ratio

Three different weighted-signal-to-noise ratio type measures were included in the analyses of this report. Here the signal refers to the speech sounds and the noise to the simulated ventilation noise. Increasing signal-to-noise ratios relate to increasing speech intelligibility and hence to decreasing speech privacy.

S/N(A) A-weighted speech-to-noise ratio. S/N(A) is simply the ratio of the A-weighted speech and noise sound energies expressed in decibels.

AI Articulation Index. The Articulation Index is a weighted-speech-to-noise ratio measure that resulted from extensive psychoacoustics research. The frequency weightings included in the measure are intended to accurately estimate the masking effects of noise on the intelligibility of speech sounds. AI is defined in ANSI S3.5 1969.

SII Speech Intelligibility Index. The Speech Intelligibility Index is defined in ANSI S3.5 (ASA, 1997) and is intended to be an improvement on the earlier Articulation Index measure. SII is a weighted-speech-to-noise ratio similar to the AI measure. SII includes revised frequency weightings and also includes the effects of masking of one frequency band on nearby frequency bands.

Measures of spectral characteristics

Measures of the spectral characteristics of noises are intended to assess one aspect of the acoustical quality of the sounds. They indicate how the relative strength of different frequency components of the noise will influence how it is perceived.

QAI Quality Assessment Index. The Quality Assessment Index is a component of the RC rating procedure described above. QAI measures the magnitude of the overall spectral deviations from a neutral spectrum shape.

Lo-Hi(A) Low-High Frequency A-weighted Level Difference. This is a new measure developed as part of this research. It is obtained by subtracting the A-weighted level of the higher frequency sounds High(A) from the A-weighted level of the low frequency sounds Low(A). Low frequency sounds included the octave bands from 16 to 500 Hz and High frequency sounds include the octave bands from 1000 to 8000 Hz. It therefore measures the loudness of the low frequency sounds relative to the high frequency sounds.