Subjective assessment of listening environments in university classrooms: Perceptions of students

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A questionnaire is developed to evaluate perception of the listening environment by university students. The objectives were to develop a questionnaire-based measurement tool, derive a measure of perceived classroom-listening quality, use the questionnaire to investigate factors that enhance, impair, or do not affect perceived listening quality, and consider the implications for classroom design. The questionnaire was administered to over 5700 students in 30 classrooms at one university. Physical and acoustical measurements were also performed in each classroom. The questionnaire included items that recorded aspects of student perception, as well as individual, course-, and instructor-specific factors. Responses to 19 perception items generated a perception of listening ease (PLE) score for each student and a classroom-average score. Decreased PLE was associated with women, English-second-language students, those with hearing impairment, students not interested in the course material, and those who found the material difficult. Increased PLE was associated with higher speech transmission index, acceptable lighting, temperature and seating, better instructor voice, increased visual-aid use, and easier course material. Results indicate that PLE is a useful measure of student perception of the classroom-listening environment, and that optimal classroom acoustical design must take into consideration "in-use" conditions, as well as classroom physical characteristics.
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I. INTRODUCTION

In university classrooms, learning occurs primarily through verbal communication. The physical characteristics of the acoustical environment are key factors in the success of this communication, although other factors, such as the characteristics of the speaker and the listener, and the learning circumstances, also play a role.

Considerable research has demonstrated that successful verbal communication is related to the relative levels of the received speech signal and background noise, and the classroom reverberation.[1] These depend, in part, on the geometry and acoustical characteristics of the classroom surfaces, furnishings, and occupants. One composite measure of the physical characteristics of a room, calculated from the speech-signal level, background-noise level, and reverberation time, is the speech transmission index (STI).[2]

The relationship between these physical parameters and communication success has been studied using various tests of "speech intelligibility" (SI). SI tests are typically performed under controlled conditions, by evaluating the percentage of specific speech material—often single words—correctly understood by a panel of listeners, with or without competing noise.[1,3–5]

Comparisons between SI and STI in the same classroom have indicated good correlation between these composite measures.[2,6,7] However, in these studies considerable effort was directed at minimizing experimental variation due to nonacoustical and typically variable factors such as language, motivation, lighting, etc. However, even in a controlled setting, Cox *et al.*[8] found significant differences in SI in the same room when comparing six different "normal" talkers. Further, of four simulated environments (a quiet living room, a classroom, and social events in two settings) studied by Cox *et al.*, SI was most reduced for all talkers and all speech features in the classroom environment.

Therefore, although STI and SI values provide useful data on the potential influence of objective physical characteristics on classroom communication, the extent to which either approach accurately reflects the total listening experience of students and instructors in a classroom during typical classroom use is not known. Qualitative descriptors (poor, excellent, etc.) of conditions for verbal communication are sometimes associated with various ranges of measured quantities,[2] but they are derived from controlled studies using simple speech material, and their significance to actual classrooms during use is not known.

A possible reason for this gap in the literature is the lack of standardized measurement tools for evaluating the uncontrolled communication experience (including the speaker, room, and listener) during typical classroom use. Questionnaires have been developed to determine the adverse effect of external noise on students and teachers.[4,9] However, until recently, there were few studies that evaluated how classroom users perceive the overall success of the acoustical conditions in the classroom environment, and these generally considered primary- and or secondary-school settings. In order to fill the gap, we developed a questionnaire to measure university-student perception of classroom-listening environments. Details of the questionnaire development, and preliminary results, have been presented (see Ref. 10)—the present journal article describes the work more fully and extends it by using multivariable regression modeling to examine relationships between overall perceptions of classroom-listening quality and both objective and subjective factors that may influence perception.

More recently, several groups of investigators have reported results from studies in which questionnaires were used to assess classroom environments. Wilson *et al.*[11] used a questionnaire to determine the reactions of primary-school teachers to their listening environments and to the addition of ceiling absorption, as well as factors that might affect the reactions. Astolfi *et al.*[12] used teacher and student questionnaires to investigate environmental comfort, including acoustical quality (noise-source intensity and annoyance, consequences of the acoustical environment, teacher voice problems, and student perception of teacher voice clarity and speech comprehension) in secondary-school classrooms. Dockrell and Shield[13] performed a large-scale questionnaire survey of teacher and children perceptions of awareness and annoyance of noise environments in primary schools. Meis *et al.*[14] used a questionnaire to study perception of the quality of the acoustical environments in university classrooms. Respondents rated a number of environmental attributes on scales bounded by opposite-extreme descriptors. Results were correlated with the results of reverberation-time measurements. Hagen *et al.*[15] used a similar questionnaire to measure the reactions of primary-school children to their classroom acoustical environments before and after "improvement" by the addition of sound absorption and/or a sound-field-amplification system.

In the present work, we developed and applied a questionnaire aimed at generating a global measure of the subjective perception of the listening environment by students in university classrooms and at capturing relevant personal and environmental characteristics that may modify this perception. Our specific research objectives were to investigate demographic, instructional, and environmental factors (including physical-acoustical characteristics of the classroom) that enhance, impair, or do not affect perceived classroom-listening quality, and to consider the implications of the work for classroom design.

Here we report results from administering the questionnaire to over 5700 university students from a stratified random sample of university classrooms in which comprehensive measures of the physical-acoustical environments were also made.

II. METHODS

A. Questionnaire development

The questionnaire was developed using standard methods,[16] including a comprehensive literature review, structured interviews with context experts and classroom users, item development, several stages of pilot testing with structured feedback to evaluate construct validity, and reproducibility testing. The final questionnaire contains 73 items, in three parts. Part 1 contains 23 items on student perception of the classroom-listening environment (subsequently used to construct a summary score of "perceived listening ease"); part 2 contains items about potential modifying characteristics of the classroom, the instructor, the course, and where the student typically sat in the room; and part 3 asks demographic information about the respondent. In parts 1 and 2, most items used a five-point response scale bounded at both ends by the words "almost always" and "rarely." One item used a visual analogue scale (i.e., a straight line bounded by descriptive words, on which the subject is asked to place a mark). The complete questionnaire is available from the authors; part 1 is included in the Appendix.

B. Questionnaire administration

A stratified random sample of 30 classrooms was drawn from a list of all classrooms on the University of British Columbia (UBC) campus in which five or more classes were scheduled (with 10 each from classrooms with fewer than 30 seats, between 30 and 80 seats, and between 81 and 300 seats). One of the two UBC classrooms with more than 300 seats was also chosen at random; it replaced one randomly chosen 81–300 seat classroom. For each classroom that was chosen, each instructor scheduled to teach classes in that classroom during one term was contacted for consent to participate in the study. Consent was obtained from all but ten instructors. The final number of participating classes was 107, in 30 classrooms.

Questionnaire administration took place over a two-month period in the Autumn term. Questionnaires were filled out during the first ten minutes of class time and were collected immediately by the researcher. It was not possible to keep a systematic record of refusals; however, the difference between the number of questionnaires distributed and the number returned was less than 5%.

C. Physical measurements, empirical prediction, and STI calculation

Acoustical measurements were made in the classrooms for the purpose of obtaining the values of physical quantities that characterize their acoustical environments physically. It was considered that values relevant to the "in-use" conditions—that is, the occupied classroom—were of most relevance, and had to be obtained. However, since acoustical measurements are difficult in occupied classrooms, classrooms were measured in the unoccupied condition; values of relevant quantities were corrected to the occupied condition by theoretical considerations. Following is a brief description of the measurements performed and the subsequent calculations—full details are found elsewhere.[17–19]

In each classroom, two to nine receiver locations (depending on the size of the room) distributed throughout the student seating area were considered. Measurements were made of 1-kHz octave-band early-decay times using a speech source located at the typical teaching position; for each class, these were then corrected to the occupied condition based on the known number of students in the class. Total A-weighted speech levels associated with a typical male or female instructor (corresponding to the gender of the instructor for each class) were determined using empirical formulas developed in previous work,[19] and these too were corrected to the occupied condition. Total A-weighted occupied-classroom ventilation-system and student-activity noise levels were predicted by previously developed empirical formulas.[19] Total A-weighted background-noise levels were calculated by energetic summation. The resulting 1-kHz early-decay times and A-weighted signal-to-noise level differences were used to calculate values of speech transmission index for each receiver position in the occupied classroom, using a simplified version of the procedure developed by Steeneken and Houtgast.[2] In eight classes, student and instructor questionnaire responses confirmed that a speech-reinforcement system had been used most of the time. In an attempt to account for this in the STI calculations, signal-to-noise level differences were forced to a value of 20 dB on the assumption that the speech-reinforcement system amplified the instructor's speech enough to render the effect of the background noise negligible. Weighted class-average STI values were calculated for each class in each room, using weights based on the proportion of students in each class typically sitting at each of the various receiver positions.

D. Data analysis

A total of 5738 questionnaires were returned. Data analyses used SAS-PC statistical-analysis software (SAS Institute, Cary, NC). Questionnaires missing key demographic variables, more than 50% of the listening-environment response variables, or missing either one of the two composite classroom rating variables were excluded ($n=245$), leaving 5493 analyzable questionnaires. Of these, the proportion with missing values for individual items ranged from less than 0.1 to 1.4%, with no apparent clustering; therefore, missing values were substituted by the mean value for the item from all other questionnaires. One five-item section about classroom activities hampered by a poor listening environment had a large number of "non–applicable" responses; therefore, responses to these items were collapsed into one variable (the number of yes responses divided by the number of applicable responses) and then standardized to a five-point scale. A "perceived listening ease" (PLE) score was calculated as the sum of responses to each of 19 items in Part 1, after each item was standardized to a five-point scale (or rescaled in the case of item 4a) from 0 to 4, in which 4 represents a "better" environment. The final sum was then standardized to a 100-point scale. Prior to settling on a simple additive score for PLE, we tested several different approaches to combining responses to the questions in Part 1, using a randomly selected sample of 500 questionnaires. These included using several different approaches to weighting correlated answers—simply using the answer to question 4a alone or combining 4a and 4b, and using factor analysis instead of an additive (or weighted average) summary score. In brief, we found that weighted average scores gave results similar to those found using a simple additive approach, that using only question 4 responses was not as informative (i.e., less variability was explained by predictive models) as using a score that incorporated all responses in Part 1, and that results from factor analysis were much more difficult to interpret than results using a summary score and they did not appear to provide additional insights into factors associated with subjective perception of the listening environment.

To evaluate factors that may influence PLE, univariable and multivariable linear-regression analyses were carried out with the PLE score as the dependent variable, and classroom-environment variables, course and instructor variables, and personal factors as potential explanatory variables. Environmental variables included the class-average physical measurements (STI, early-decay time, signal-to-noise ratio, and measures of classroom size), seating capacity, the reported level of background noise present due to classroom equipment (e.g., projector, lab equipment), reported suitability of the seating, classroom air, temperature, and lighting, and the ratio of classroom floor area to the number of students (as a measure of crowding). Course and instructor variables included speed, loudness, articulation and accent of the instructor's voice, the normal position of the instructor in the classroom, whether or not a microphone was used, the instructors use of visual aids, the type of material being taught (math and science, language, other), whether the course was an elective or required, whether the course was undergraduate or graduate level, and student report of frequency of attendance, ease of the course material, interest in the material, and whether or not the student typically did required reading prior to class. Personal factors included age, gender, age at which English was first learned, reported hearing impairment, reported uncorrected vision impairment, and the frequency of ear infections and episodes of flu or allergy affecting the ears since the beginning of the course.

Multivariable models were built using a "best subsets" procedure for groups of variables evaluated in the following order: classroom environmental factors, instructor factors, course factors, and personal factors. Model "goodness of fit" was evaluated based on *adjusted* R^2 values and the principle of parsimony (i.e., choosing a simpler model where the change in adjusted R^2 was small). Explanatory factors were only considered for inclusion in the multivariable models if they were associated with PLE in univariate analysis with $p<0.20$. To control for multicollinearity for highly correlated predictor variables (e.g., STI and many of the reported classroom characteristics), the choice of which to include was based on a combination of strength of association in univariable models and on existing theory. Regression diag-

TABLE I. Relevant physical characteristics of 30 UBC classrooms studied.

Quantity	Unit	Mean (standard deviation)	Range
Seating capacity		107 (111)	19–498
Volume	m^3	570 (837)	106–4036
Source/receiver distance	m	6.4 (4.2)	1.0–19.7
Unoccupied 1-kHz early-decay time	s	1.13 (0.41)	0.54–1.83
Number of students		54 (59)	3–279
Occupied 1-kHz early-decay time	s	0.70 (0.24)	0.34–1.31
Occupied A-weighted signal-to-noise ratio	dB	9.0 (5.1)	−0.5 to 20.0
Occupied STI[a] (unweighted)		0.56 (0.06)	0.34–0.71

[a]Speech transmission index, STI (occupied), averaged over $n=9$ receiver positions in each room, adjusted for the total number of students in the class, the gender of the instructor, and microphone use where applicable (but not weighed for the number of students typically sitting in each receiver position)—see Sec. II for details.

nostics (examination of influence and residual plots) were carried out on the final models.

III. RESULTS

A. Characteristics of participants

The participants ranged from first-year to post-graduate students, with a mean age of 21.5 years, and with approximately equal numbers of men and women ($n=2538:2955$, M:F). Typical of our region, one-third of the students reported that English was not their first language, and almost 6% had only learned English after age 16. About 4% of students reported being aware of having a hearing impairment; 1% reported that this was of moderate or greater severity. Almost all students (98%) reported that they attended class most of the time, but 20% found the course material uninteresting, and 24% found the material difficult.

B. Characteristics of the classrooms

The classrooms studied varied from small lecture rooms with volumes around 100 m^3 and as few as 20 seats, to large auditoria with volumes over 3000 m^3 and over 500 seats. The volume-to-surface-area ratios varied from 0.7 to 2.4 m, and classroom shapes varied considerably. Classroom average STI values (weighted for typical student positions in the rooms) ranged from 0.49 to 0.72 with a mean of 0.62 (SD: 0.7). Details are presented in Table I.

C. Subjective perception of the listening environment

Table II presents the responses of the students to the individual questions used to generate the PLE score. "Students talking" was the factor most commonly reported as interfering with listening, followed by intermittent noises in the building, but outside the classroom. In contrast, constant noises within or outside the building, and noise due to the heating and ventilating system, or to projectors or lab equipment, were less likely to be reported as interfering with the listening environment. The most commonly reported adverse consequence of a poor listening environment was the failure to hear questions asked by other students in the class. Individual PLE scores ranged from 1.0 to 94.7 with a mean of 64.2; class-average PLE scores were less variable than the individual scores, ranging from 42.5 to 89.0.

D. Potential modifying factors

Table III records the responses to questions about general characteristics of the classrooms and the instructors that may have influenced the student perception. Almost 33% of respondents rated the level of background noise associated with students as high or very high, whereas only 5% reported high background noise due to teaching or lab equipment. Over 25% of respondents rated temperature, seating, and "classroom air, in general" as unacceptable. The voice of the instructor was rated as fast or very fast by 28% of students, but only 8% reported that they found the instructor's accent or articulation difficult to understand. Visual aids were commonly used and instructors tended to move around, rather than lecture from one fixed position.

E. Perceived listening ease scores

Tables IV and V show class-average and individual PLE scores stratified by selected classroom, class, and personal factors expected *a priori* to influence PLE. PLE score was higher in smaller and less crowded classrooms and in classrooms with measured STI values greater than 0.55. On average, lower PLE scores were reported by women, students whose mother tongue was not English, those with moderate to severe hearing impairment, students not interested in the course material, and those who found the course material difficult.

Table VI shows results from multivariable analyses in which all possible factors that might influence PLE were considered together. The table shows actual and standardized coefficients. The actual coefficients reflect the predicted change in PLE associated with a one unit change in the factor; standardized coefficients reflect the predicted change in PLE for each factor after standardizing for differences in the variance of the factors. Factors associated with a significant reduction in PLE included microphone use in the classroom, math or science course material, and moderate to severe hearing impairment. Increased PLE was associated with

TABLE II. Perception of listening ease (PLE)[a] questionnaire items.

% reporting interference with listening "much of the time or always"	
How often…interferes with ability to hear	%
Students talking in the classroom	26.0
Students moving about in the classroom	19.1
Noise from projectors or lab equipment	4.0
Noise from heating/ventilating systems	10.0
Noises outside the classroom, in the building	
Constant	10.4
Intermittent	22.6
Noises outside the building	
Constant	9.4
Intermittent	17.7
How often experience…as a result of poor listening environment	
Miss points made in class due to noise	13.4
Concentration broken	25.1
Fail to hear questions from other students	55.0
Ask instructor to repeat points	10.8
Increased fatigue	23.5
Leave class feeling frustrated	12.2
Increased effort to hear	23.8
Ask questions for clarification (not understanding)	13.2
% reporting this activity adversely affected (yes/no)	
Activity affected by the listening environment? (yes/no)	%
Lectures (n=5337)	46.0
In class essays, exams, tests (n=4319)	43.6
Question periods (n=3886)	58.0
Class discussions (n=3009)	51.5
Guest speakers (n=2865)	44.5
Overall rating of this classroom:	mean (sd)
compared to other university classrooms (scale: 0 to 4)	2.4 (0.9)
compared to an ideal listening environment (scale: 0 to 100)	60.5 (22.9)
PLE score, individual	64.2 (15.6)
PLE score, class average (n=107)	66.4 (8.9)

[a]PLE is calculated as the sum of responses to each of 19 items (each standardized to scale from 0 to 4, where 4 indicates a better listening environment), then standardized to a 100-point scale.

higher STI values, acceptability of the classroom lighting, temperature, seating, better articulation, easier to understand accent, louder voice from the instructor, increased use of visual aids, and course material that was reported to be easier to understand. Models that considered the individual components of STI (early-decay time and signal-to-noise ratio) instead of STI indicated that both components were significantly associated with PLE, but the model with STI alone was superior to the model with its components (i.e., explained a greater proportion of the overall variance in PLE). Factors tested in the models but *not* associated with PLE in multivarable models included student age, home department and year of study, whether or not the course was required or elective, reported attendance record, whether the student reported doing assigned readings or not, the student's level of interest in the course material, reported visual impairment, reported frequency of ear infections, flu, or allergy, reported mild hearing impairment, loudness of the instructor's voice, and how often the instructor moved around the room or spoke directly facing the class.

IV. DISCUSSION

In summary, a questionnaire to investigate the subjective perception of students to listening environments in university classrooms was developed and applied to a large, heterogeneous population of students. A global measure of perceived listening quality was constructed and factors associated with this subjective perception were evaluated.

Our study population was as heterogeneous as is possible on a single university campus with a large proportion of non-English native speakers and a broad mix of subject matters and levels of interest represented by the courses. The proportion of students reporting a hearing impairment was similar to that expected in a general population of this age range.[20] Therefore, the results from this large study are likely to be well generalized to any similarly aged population of classroom users.

The physical characteristics of the classrooms studied here are similar to those reported at other universities and elsewhere. Other studies have dealt with pre-university classrooms and students with either normal or impaired hearing.[21]

TABLE III. Responses to questionnaire items on factors that may modify student perception of the listening environment.

Questionnaire item	%
Level of background noise (% rating this factor as high or very high)[a]	
from students	32.8
from teaching or lab equipment	4.5
from ventilation, heating, lighting, etc.	12.4
Other environmental factors (% rating this factor as unacceptable)	
lighting	10.7
temperature	26.1
seating	24.6
classroom air	27.8
Voice of instructor	
speed (% fast or very fast)	28.5
loudness (% soft or very soft)	18.7
accent (% difficult/very difficult to understand)	8.1
articulation (% difficult/very difficult to understand)	8.1
Instructor's activities	
speaks toward listeners (% rarely)	3.2
moves about the room while speaking (% rarely)	39.5
uses visual aids (% rarely)	12.7
uses a microphone (% rarely)	72.1

[a]In this part of the questionnaire, respondents were asked to report the *level* of background noise without reference to whether or not they felt it interfered with their ability to hear in this classroom.

TABLE IV. PLE scores—according to class and classroom characteristics.

	Class-average PLE score[a]
	mean (sd)
Classroom size	
<30 seats (n=31 classes/9 rooms)	72.7 (7.1)
30–80 seats (n=33 classes/10 rooms)	67.1 (5.6)
>80 seats (n=43 classes/11 rooms)	64.8 (5.0)
p-value[b]	<0.0001
Room area/number of students	
>3 m^2/student (n=53 classes)	69.8 (6.5)
<3 m^2/ student (n=54 classes)	65.7 (6.2)
p-value	0.001
Course type	
languages (n=16 classes)	69.9 (6.8)
humanities/social sciences (n=47 classes)	68.4 (6.1)
math/physical or biological sciences (n=44 classes)	66.3 (7.0)
p-value	0.1
Microphone used[c]	
No (n=94 classes)	68.6 (6.4)
Yes (n=13 classes)	61.7 (5.6)
p-value	0.0004
STI (occupied)[d]	
>0.60 (n=25 classes)	70.1 (7.4)
0.55–0.60 (n=51 classes)	68.6 (6.3)
<0.55 (n=31 classes)	64.5 (5.4)
p-value	0.003

[a]average of the *classroom*-average PLE values (n=107).
[b]p-value from analysis of variance comparing values across the groups identified.
[c]Microphone used sometimes, often, or always.
[d]STI (occupied), averaged over n=9 receiver positions in each room, adjusted for the total number of students in the class, the gender of the instructor, and microphone use where applicable (but not weighed for the number of students typically sitting in each receiver position); see Sec. II for details.

TABLE V. PLE scores—according to personal characteristics of respondents.

	Individual PLE score
	mean (sd)
Age	
35 or younger ($n=5386$)	64.2 (15.6)
>age35 (107)	67.8 (17.2)
p-value[a]	0.02
Gender	
Men ($n=2538$)	64.8 (15.5)
Women ($n=2955$)	63.8 (15.6)
p-value	0.01
English language fluency	
English mother tongue ($n=3673$)	65.7 (15.3)
Learned English age 15 or earlier ($n=1461$)	61.2 (15.3)
Learned English after age 15 ($n=292$)	61.6 (17.3)
p-value	<0.0001
Hearing impairment (reported)	
None ($n=5203$)	64.3 (15.5)
Mild ($n=135$)[b]	66.4 (15.7)
Moderate, severe, or profound ($n=70$)	57.7 (21.2)
p-value	0.0006
Interest in course material	
Interested or very interested ($n=2831$)	65.8 (15.7)
Neutral or not interested ($n=2662$)	62.5 (15.3)
p-value	<0.0001
Difficulty of course material	
Does not find course material difficult ($n=4151$)	65.1 (15.4)
Finds material difficult or very difficult ($n=1291$)	61.7 (16.0)
p-value	<0.0001
Chooses seat in class in order to hear better	
Rarely ($n=1786$)	72.3 (13.2)
sometimes ($n=1817$)	62.1 (14.4)
always or almost always ($n=1886$)	58.6 (15.6)
p-value	<0.0001

[a]p-value from analysis of variance comparing values across the groups identified.
[b]$p=0.30$ comparing mild hearing impairment to no reported hearing impairment (Scheffé post-hoc test for multiple comparisons).

Results of speech-intelligibility tests ranging from 32% to 93% have been reported;[1,3–5] many classrooms had insufficient signal-to-noise ratios and excessive reverberation. Pekkarinen and Viljanen[22] measured STI values from 0.44 to 0.81 in unoccupied classrooms and from 0.60 to 0.81 in occupied classrooms. Again, classrooms often had excessive noise levels and reverberation.

The objective of the questionnaire-development phase of this study was to create a valid instrument suitable for scoring classroom-user perception of the listening environment during typical classroom use, and for recording environmental and personal factors that may modify this perception. Given the absence of an existing objective gold standard for measuring perception of the listening environment by users, the validity of the questionnaire and of the PLE score can only be assessed indirectly.[23]

In this study, PLE was associated with factors expected to be linked to subjective perception of the quality of the listening environment, including personal factors such as moderate to severe hearing impairment and mother tongue, environmental factors such as room size, crowding, and physical acoustical characteristics (measured by STI), and numerous characteristics of the speaker's voice and the material being delivered. The small but significant gender difference in PLE (with men reporting slightly higher scores) is unexplained by these data, although it should be noted that the size of the difference between women and men was small (1.8 points) compared to other factors. For comparison, since the environmental factors were measured on a scale from 0 to 4, the average difference in PLE between a student rating projector noise as very high compared to very low was about 18 points (i.e., four times the coefficient in the model).

PLE was also associated with student perception of the quality of room lighting, temperature, and seating, factors that are not expected to influence the room acoustics. This suggests that respondents were not completely able to separate their perceptions of overall environmental quality of the classrooms from the "acoustical" quality; however, these more general environmental factors could also contribute to the "listening environment" through indirect pathways (e.g., contributing to increased noise generated by student movement).

Individual components of our results are similar to those found in other studies in which questionnaires have been

TABLE VI. Factors associated with PLE–multivariable models.[a]

	Individual PLE		
Dependent variable:	coefficient (se)	standardized coefficient[b]	p
Intercept	10.3 (2.0)	0	<0.0001
Personal characteristics			
gender (1=female;2=male)	1.8 (0.36)	0.058	<0.0001
English mother tongue (0=no, 1=yes)	3.3 (0.38)	0.098	<0.0001
moderate to severe hearing impairment (0=no, 1=yes)	−3.8 (1.6)	−0.027	0.02
Room characteristics			
crowding: room area/number of students (range: 1.1–11.9 m^2/student)	1.2 (0.14)	0.106	<0.0001
STI,[c] occupied, weighted (range: 0.34–0.71)	17.9 (2.9)	0.073	<0.0001
reported background noise from projectors, other equipment (0 to 4, 4=least noisy)	4.6 (0.21)	0.259	<0.0001
room lighting acceptability (0 to 4, 4=best)	1.7 (0.19)	0.113	<0.0001
room temperature acceptability (0 to 4, 4=best)	1.2 (0.15)	0.095	<0.0001
room seating acceptability (0 to 4, 4=best)	1.3 (0.16)	0.103	<0.0001
Course material/instructor characteristics			
instructor's articulation (0 to 4, 4=easiest to understand)	1.6 (0.26)	0.102	<0.0001
instructor's accent (0 to 4, 4=easiest to understand)	0.76 (0.25)	0.050	0.003
loudness of instructor's voice (0 to 4, 4=loudest)	0.92 (0.21)	0.052	<0.0001
visual aid use (0 to 4, 4=most frequent)	0.43 (0.15)	0.033	0.005
course material ease (0 to 4, 4=easiest to understand)	0.87 (0.20)	0.055	<0.0001
course type: math or physical/biological sciences (0=no, 1=yes)	−1.7 (0.42)	−0.053	<0.0001
microphone used (0=no, 1=sometimes or more often)	−4.1 (0.42)	−0.123	<0.0001
Model R-squared	***0.30***		

[a]Coefficients (standard errors) and p values for the hypothesis that the coefficient=0, from multiple linear-regression models—see Sec. II for details.
[b]Standardized coefficient is computed by dividing the regular regression coefficient by the ratio of PLE standard deviation to the factor standard deviation.
[c]STI (occupied), calculated for $n=2$ to 11 receiver positions in each of 107 classes, weighted according to the number of students reporting typically sitting at each receiver position.

used. Hétu *et al.*[4] found that a high proportion of school teachers find noise to be detrimental to their work. Wilson *et al.*[11] found that while noise outside the classroom was the biggest source of annoyance, in-class student noise was significant. One-third of teachers reported voice strain and the need to raise their voices when teaching. Adding sound absorption to the ceiling improved the perceived classroom quality. Astolfi *et al.*[12] found students in the classroom, and external transportation, to be the biggest sources of noise. The main consequences were reduced teacher-voice perception and reduced concentration. However, the annoyance associated with noise sources was low, apparently because teachers compensated for noise by raising their voices. Thus, many teachers reported hoarse voices and the need to raise their voices while teaching. Dockrell and Shield[13] found that children's ability to hear in class was mainly affected by noise outside the classrooms, and when working in groups. Transportation noise was the most often heard source. Meis *et al.*[14] found that classrooms with the highest reverberation times at low frequencies were judged to be more "reverberant" and "unpleasant." Those with the highest reverberation times at mid-frequencies were rated more "pleasant," "distinct," and "transparent." Hagen *et al.*[15] found that either ceiling absorption, a sound-field amplification system, or both, improved perceived classroom quality.

A strength of our study is that the questionnaire was designed so that the items used to calculate the global PLE score are separate from the items that record potential modifying factors (i.e., the instructor characteristics, the respondent demographics, and the academic level and preparation of the respondent). Therefore, although the questionnaire was designed for university students, it should be possible to modify parts 2 and 3 of the questionnaire to allow it to be applied to other adult populations. Part 1 of the questionnaire (which generates the PLE score) could be used for other adult populations; however, it would be necessary for a modified questionnaire to be subjected to additional verification for face and content validity and reproducibility if it were to be used for a younger age group.

Although previous work at our university[24] found STI values in occupied UBC classrooms ranging from 0.35 to 0.86, the rooms studied here had somewhat less variability in STI values (ranging from 0.34 to 0.71). Based on previously published equations linking STI and SI, this would correspond to predicted SI levels (for controlled situations) of 84–97%.[17] However, the results of multivariable modeling for PLE from this study indicate that, although there was a statistically significant association between PLE and STI in these rooms, if all other factors in the model are held constant (e.g., at their midpoints), predicted PLE varies only from 49.6 to 56.2 when comparing a classroom with STI of 0.34 to one with STI of 0.71. This suggests that, in actual classroom situations, many factors in addition to the physical acoustical characteristics of the classroom play an important role in the user's subjective perception of the quality of the listening environment. For example, predicted PLE from this study would be 31.0 for the challenging environment scenario of a student in a crowded math classroom, who learned English as a second language and who reports difficulty with the course material, who has difficulty understanding the accent and articulation of the instructor, and who rates the classroom lighting, seating, and temperature as poor (for a female student without hearing impairment, holding STI constant at 0.52, and other factors at their midpoint). In contrast, predicted PLE would be 78.6 for the scenario of an English-mother-tongue student in an uncrowded social-science classroom, who reports no difficulty with the course material, no difficulty understanding the instructor's voice, and who rates the classroom lighting, seating, and temperature as excellent (holding STI and other factors constant as above). Since STI quantifies classroom quality with respect to verbal communication, the small variation of PLE with STI could also indicate that verbal communication quality is only a minor component of overall classroom listening quality.

Our results have implications for classroom design. Although it may seem reasonable to design a classroom to optimize verbal communication from a single lecturing position at the front of the class to a group of listeners, our results suggest that this notion of a typical classroom does not capture important components of the listening environment. Fewer than 15% of respondents in this study reported frequent difficulties associated with failure of communication from the instructor to the student—i.e., missing points, asking for points to be repeated, asking questions for clarification due to failure to hear, etc. In contrast, the items identified as most influential with respect to a poor listening environment were those associated with other people—i.e., noise due to students talking and moving about. Noises outside the classroom were also important, especially when they were intermittent. For example, one could anticipate interference from noise due to other students in the hallway, when a classroom door is left open. The most commonly reported activities that were adversely influenced by a poor listening environment were question and discussion periods and over 50% of students reported frequent difficulties with failure to hear questions from other students. Therefore, optimal classroom acoustical design needs to take into consideration the "in-use" (occupied) conditions, as well as the physical and acoustical characteristics of the unoccupied classroom.

According to the results of this study, classroom listening quality can be improved by increasing classroom STI. As discussed in more detail elsewhere,[17,25] this involves controlling external and internal noise, promoting adequate speech levels, and optimizing reverberation. The design optimization of classroom reverberation should take into account typical classroom occupancies and the absorption contributed by the occupants.[26] Classrooms should be designed for effective communication between students, and from students to the instructor, as well as from the instructor to the students. Classrooms should have flexible and accessible seating, and not be overcrowded. They should be designed to avoid the need for a speech-reinforcement system to amplify voices; research has shown that this is possible in any classroom, unless instructors have quiet voices.[17] Voice training for instructors may be an effective option to increase speech levels and ensure clear articulation. Finally, the quality of a classroom's lighting, seating, and air should be sufficiently high.

V. CONCLUSION

In this study, we have developed a questionnaire-based score (PLE) to measure subjective perception, by users, of the listening environment in a classroom, and we evaluated physical, personal, and other factors that may modify how respondents score a classroom. The study population was heterogeneous, suggesting good external generalizability within the age range of this study. PLE was associated with both objective and subjective factors, with variable environmental factors at least as important as fixed physical measures or personal factors in predicting PLE. Finally, the questionnaire results indicate that communication between students in the classroom is as important to the students as communication from the instructor in determining subjective perception of listening ease.

These results point to the conclusion that acoustical design criteria need to take into account the "in-use" (occupied) characteristics of classrooms, in addition to physical characteristics of the unoccupied classrooms. The PLE score may be useful to other researchers in the field of classroom acoustics, as an adjunct to speech-intelligibility tests, and to measured or predicted physical parameters, in these complex environments.

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APPENDIX: PERCEPTION OF LISTENING EASE QUESTIONNAIRE

Part 1: The listening environment in this classroom

These questions ask about your experience with the listening environment in *this classroom*. When answering, please think about this course in this classroom, since the term began in September. Please circle the most appropriate number response for each question. **If no response seems exactly correct, please indicate the one that seems closest**.

1. There are many possible sources of noise that may affect the listening environment in a classroom. Please indicate **how often each of the following *interferes with your ability to hear***, in this classroom, for this course:

	ALMOST ALWAYS				RARELY
Students talking within the classroom:	1	2	3	4	5
Students moving or shuffling in the classroom:	1	2	3	4	5

Noise from classroom equipment (projectors, lab equipment):	1	2	3	4	5
Ventilation/air conditioning/ heating or lighting equipment:	1	2	3	4	5
Noises (from people or equipment) outside the classroom, but inside the building:					
- Noises that are present most of the time:	1	2	3	4	5
- Noises occurring only once in a while:	1	2	3	4	5
Noises (from people or equipment) outside the building:					
- Noises that are present most of the time:	1	2	3	4	5
- Noises occurring only once in a while:	1	2	3	4	5

2. Here is a list of consequences that some students have told us they have experienced as a result of a poor listening environment in a classroom. These may or may not apply to you. Please indicate how often the items listed below relate to *your listening experience in this classroom*, for this course:

	ALMOST ALWAYS				RARELY
I find I miss major points made in class due to noise:	1	2	3	4	5
I find my concentration broken:	1	2	3	4	5
I *fail to hear* questions asked by other students:	1	2	3	4	5
I find I have to ask for repetition of points made by the instructor:	1	2	3	4	5
I experience increased fatigue:	1	2	3	4	5
I leave class feeling frustrated:	1	2	3	4	5
I have to increase my effort during class:	1	2	3	4	5
I ask questions for clarification rather than for understanding:	1	2	3	4	5

3. Certain course activities may be affected by the listening environment more than others.

Please tell us whether or not your ability to *generally perform well* during each of the following activities is affected by the listening environment in this classroom.

	NO, my ability to *generally perform well* during this activity ***IS NOT*** affected by the listening environment in this classroom.	YES, my ability to *generally perform well* during this activity ***IS*** affected by the listening environment in this classroom.	Not applicable. This activity does not occur in this classroom or this course.
Lectures:	---	---	---
In-class essays, exams, tests:	---	---	---
Question periods:	---	---	---
Guest speakers:	---	---	---
Class discussions:	---	---	---

4. Please provide an **overall rating** for the listening environment of this classroom:

a) with respect to the **IDEAL** listening environment:

(Place a mark on the following line to show your rating)

WORST POSSIBLE LISTENING ENVIRONMENT	BEST POSSIBLE LISTENING ENVIRONMENT

|--|

b) with respect to **OTHER CLASSROOMS** in a university setting:

(Circle the appropriate number)

WORST 15%				BEST 15%
1	2	3	4	5

Part 2 asks about the room, and about the course material and its presentation. THIS IS NOT A COURSE OR INSTRUCTOR EVALUATION. We simply need to know about presentation style in order to interpret your answers about the listening environment.

Part 3 asks some general questions about you, so that we can interpret the results appropriately.

A complete copy of the questionnaire, including parts 2 and 3, can be obtained from the authors.

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