PARTNER

Partnership for AiR Transportation
Noise and Emissions Reduction
An FAA/NASA/Transport Canada-
sponsored Center of Excellence

# Two Laboratory Studies of People's Responses to Sonic Booms and Other Transient Sounds as Heard Indoors

## The PARTNER Project 24 final report

prepared by
Daniel J. Carr

May 2016

REPORT NO. PARTNER-COE-2016-002

# Two Laboratory Studies of People's Responses to Sonic Booms and Other Transient Sounds as Heard Indoors

PARTNER Project 24 Final Report

Daniel J. Carr

PARTNER-COE-2016-002

May 2016

This work is funded by the US Federal Aviation Administration Office of Environment and Energy. The project was managed by Mehmet Marsan of the FAA.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the FAA, NASA, Transport Canada, the U.S. Department of Defense, or the U.S. Environmental Protection Agency

The Partnership for AiR Transportation Noise and Emissions Reduction — PARTNER — is a cooperative aviation research organization, and an FAA/NASA/Transport Canada-sponsored Center of Excellence. PARTNER fosters breakthrough technological, operational, policy, and workforce advances for the betterment of mobility, economy, national security, and the environment. The organization's operational headquarters is at the Massachusetts Institute of Technology.

**The Partnership for AiR Transportation Noise and Emissions Reduction**
**Massachusetts Institute of Technology, 77 Massachusetts Avenue, 33-240**
**Cambridge, MA 02139 USA**
**http://www.partner.aero**

PURDUE
UNIVERSITY

# Project 24 Human Response - Annoyance
# Final Report

Two Laboratory Studies of People's Responses to Sonic Booms and Other Transient Sounds as Heard Indoors

## Purdue University


**Project Lead Investigator**
Patricia Davies (PI)
Professor, School of Mechanical Engineering
Director, Ray W. Herrick Laboratories
Purdue University
585 Purdue Mall
West Lafayette, IN 47907
Phone:
Email: daviesp@ecn.purdue.edu

Daniel Carr (Co-PI)
Graduate Research Assistant
School of Mechanical Engineering
Purdue University
585 Purdue Mall
West Lafayette, IN 47907
Phone: 765-430-3653
Email: djcarr@purdue.edu


**University Participant(s)**

*Purdue University*

- PI: Patricia Davies, Co-PI: Daniel Carr
- FAA Award Number: 09-C-NE-PU Amendments 014 and 019
- Period of Performance: April 6th, 2012 – May 31st, 2014

# TWO LABORATORY STUDIES OF PEOPLE'S RESPONSES TO SONIC BOOMS AND OTHER TRANSIENT SOUNDS AS HEARD INDOORS

A Thesis

Submitted to the Faculty

of

Purdue University

by

Daniel J. Carr

In Partial Fulfillment of the

Requirements for the Degree

of

Master of Science in Mechanical Engineering

December 2015

Purdue University

West Lafayette, Indiana

*Super omnia vincit veritas rationis*

# ACKNOWLEDGMENTS

The research described in this thesis was funded by the FAA/NASA/Transport Canada/DOD/EPA PARTNER Center of Excellence. I would like to particularly thank Mehmet Marsan and Rebecca Cointin at the FAA for their support of this research. Part of the research was done in collaboration with NASA Langley Acoustics Research Laboratory researchers (Alexandra Loubeau, Jonathan Rathsam, and Jacob Klos) using their Interior Effects Room, and I also thank Regina Johns of Analytical Mechanics Associates for help in recruitment of subjects in that part of the research.

Special thanks goes to my advisory committee, Prof. Patricia Davies, Prof. J. Stuart Bolton, Prof. George Chiu, and Prof. K. M. Li for their support.

Many thanks also go to Andrew McMullen and Brandon Sobecki for their guidance in experimental setup and analysis, and for their collaboration in data collecting. Special mention goes to Mr. Sobecki for allowing me to slam the doors of his car to get sounds for my experiments.

**Disclaimer:** Opinions, findings, conclusions and recommendations expressed in this material are those of the author and do not necessarily reflect the views of PARTNER sponsoring organizations.

# TABLE OF CONTENTS

# LIST OF TABLES

## LIST OF FIGURES

# NOMENCLATURE

| | |
|---|---|
| ASEL | A-weighted Sound Exposure Level (in dB) |
| $dLN_{max}$ | Maximum Derivative of long-term Loudness for the first peak – based on Moore and Glasberg's Time-Varying Loudness (in sones/second) |
| $dSN_{max}$ | Maximum Derivative of short-term Loudness for the first peak – based on Moore and Glasberg's Time-Varying Loudness (in sones/second) |
| $dZN_{max}$ | Maximum Derivative of Loudness for the first peak – based on Zwicker's Loudness (in sones/second) |
| Dur | Duration of the whole boom – from the first time the time history leaves the noise floor to the last time it returns (in seconds) |
| H | Heaviness (in dB) |
| HRTF | Head related transfer function |
| IER | Interior Effects Room at NASA Langley Research Center |
| $LN_{Et}$ | Time-Divided Integrated Loudness, long-term – based on Moore & Glasberg's Time-Varying Loudness (in sones) |
| $LN_{max}$ | Maximum of long-term Loudness – calculated with Moore and Glasberg's Time-Varying Loudness (in sones) |
| PL | Steven's Mark VII Perceived Level (in dB) |
| $S_{max}$ | Maximum of Von Bismarck Sharpness, based on Zwicker's Loudness algorithm (in acum) |
| $SN_E$ | Integrated Loudness, short-term – based on Moore & Glasberg's Time-Varying Loudness (in sones $\cdot$ seconds) |
| $SN_{max}$ | Maximum of short-term Loudness – calculated with Moore and Glasberg's Time-Varying Loudness (in sones) |

| | |
|---|---|
| $SN_{10}$ | Short-term Moore & Glasberg Loudness exceeded 10% of the time (in sones) |
| $SN_{20}$ | Short-term Moore & Glasberg Loudness exceeded 20% of the time (in sones) |
| SPL | Sound Pressure Level (in dB) |
| $ZN_{max}$ | Maximum of Loudness – calculated with Zwicker's Loudness (in sones) |

# ABSTRACT

Carr, Daniel J. MSME, Purdue University, December 2015. Two Laboratory Studies of People's Responses to Sonic Booms and Other Transient Sounds as Heard Indoors. Major Professor: Patricia Davies, School of Mechanical Engineering.

Manufacturers of business jets have expressed interest in designing and building a new generation of supersonic jets that produce shaped sonic booms of lower peak amplitude than booms created by the previous generation of supersonic aircraft. To determine if these "low" booms are less intrusive and the noise exposure is more acceptable to communities, new laboratory testing to evaluate people's responses must occur. To guide aircraft design, objective measures that predict human response to modified sonic boom waveforms and other impulsive sounds are needed. The current research phase is focused on understanding how people will react to booms when heard inside, and must therefore include considerations of house type and the indoor acoustic environment. A test was conducted in NASA Langley's Interior Effects Room (IER), with the collaboration of NASA Langley engineers. This test was focused on the effects of low-frequency content and of vibration, and subjects sat in a small living room environment. A second test was conducted in a sound booth at Purdue University, using similar sounds played back over earphones. The sounds in this test contained less very-low-frequency energy due to limitations in the playback, and the laboratory setting is a less natural environment. For the purpose of comparison, and to improve the robustness of the human response prediction models, both sonic booms and other more familiar transient sounds were used in the tests. In the Purdue test, binaural simulations of the interior sounds were included to compare responses to those sounds with responses to playback of binaural recordings taken in the IER.

Major conclusions of this research were that subject responses were highly correlated between the two tests, and that annoyance models including Loudness, maximum Loudness Derivative, Duration, and Heaviness terms predicted annoyance accurately.

# 1. INTRODUCTION

Aircraft manufacturers are currently developing designs for a new generation of supersonic aircraft. This current wave of interest in supersonic flight has been fueled by recent advances in aircraft technology [1]. It is now believed that new supersonic jets can be built that will produce shaped sonic booms with lower peak amplitude than that of traditional N-wave sonic booms [2]. Designing aircraft to produce these "low booms" may reduce supersonic aircraft noise to a level acceptable for communities. To determine whether this is the case, a new phase of testing to evaluate human response to sonic booms is underway. The immediate goal of this testing is to develop objective measures that predict human response to transient sounds including (but not necessarily limited to) modified sonic boom waveforms. These would be used with predictions of sounds to assess the impact of supersonic flights over a community.

This testing is initially being performed in laboratory settings, for a number of reasons. First, noise exposure levels are more easy to control in laboratory tests, thus allowing for more detailed examination of the effects of specific parameters on human response [1]. In laboratory tests the desired sound is produced directly, so there is no concern that atmospheric or weather conditions may adversely affect the boom heard on the ground from a real aircraft, which is a concern in field tests [3]. Lastly, laboratory facilities have the capacity to produce boom signatures that currently existing aircraft cannot [4], but that future aircraft may produce.

## 1.1 Overview of Current Research

The present phase of research is focused on examining human response to sonic booms heard indoors. Booms heard indoors are different than booms heard outdoors. Physical differences in the sounds are due to house construction and room acoustics, i.e.

the transmission of the sound through the structure and the reverberation characteristics of the room, as well as the presence of rattling sounds from shaking objects inside the room). Subjects' evaluations of sounds heard indoors may also be affected by the context, and by expectations of what is acceptable in that context. [5].

### 1.1.1 Realism of Playback

When conducting laboratory tests, there is concern whether the equipment being used has the capacity to reproduce sonic booms or other transient sounds with a sufficient degree of realism. Sounds played back in the laboratory can be presented over either earphones or loudspeakers, and each method has its own advantages and disadvantages. Earphones and headphones are easy to acquire and relatively easy to use, but their performance at low frequencies (<25-50 Hz) is limited. For instance, the Etymotic ER2 research earphones used at the Sound Quality booth in Herrick Laboratories are only effective down to 25 Hz [5]. Loudspeaker playback is sometimes conducted in specialized simulator facilities containing many speakers. These facilities may have much better playback at low frequencies (for instance, the Interior Effects Room at NASA Langley Research center can reproduce frequencies down to 6 Hz [6, 7]), but they are also not as available to the general research community, and their high-frequency capacity may be inferior to that of earphones. Sullivan, Davies, Hodgdon, Salamone, and Pilon [4] conducted a set of tests in three sonic boom simulators, to determine whether those facilities could reproduce adequately realistic outdoor boom sounds. They concluded that adequate realism was achievable, provided that the sounds being played were at least 1.5 seconds long and did not omit post-boom noise. The most realistic simulator had better high-frequency reproduction than the other two.

At present, neither earphone/headphone nor simulator playback can be said to be decisively superior. Each method allows the researcher to examine some aspect or aspects of sonic boom psychoacoustics that cannot be examined as precisely with the other method. Thus, in the research described in this thesis, both a simulator test and an earphone test were conducted, utilizing similar sounds and test format.

### 1.1.2 Response Prediction

Much of current research is focused on predicting subjective response to sonic booms in terms of either loudness or annoyance. As a result of two 1993 laboratory studies, Sullivan and Leatherwood concluded 1) that Stevens' Perceived Level (PL) and Zwicker Loudness Level were the best predictors of subjective loudness for recorded turbulence-modified booms [8], and 2) that PL was the best predictor of subjective loudness for simulated booms with ground reflections [9]). In a 1994 laboratory study, Leatherwood and Sullivan [10] concluded that A-weighted sound exposure level (ASEL) and Zwicker Loudness Level were also good predictors of subjective loudness (Sullivan and Leatherwood use the term *subjective loudness* to distinguish it from the values produced by Loudness metrics such as PL). They also examined the effects of boom shaping on subjective loudness, concluding that subject's ratings are reduced when front-shock overpressure and front-shock rise time are reduced.

Niedzwiecki and Ribner published three articles on loudness responses to various kinds of boom signatures. In a paper discussing N-waves [11], they concluded that loudness decreases with increasing rise time, but that boom duration has a significant effect when in excess of 250 milliseconds. Their conclusions regarding rise time are in agreement with the theory of Johnson and Robinson [12]; however, they note that their conclusions regarding duration are in contrast with those of Johnson and Robinson. In a paper on "minimized" booms, which are similar to N-waves, but with flatter peaks [13], the authors concluded that loudness ratings are determined largely by front-shock overpressure and front/rear-shock rise times, rather than by maximum overpressure. Hence, a "minimized" boom with the same loudness as an N-wave can have a much higher overpressure than does an N-wave. In a paper on N-waves that had been high-pass filtered at 50 Hz or below [14], they concluded that removing these low frequencies reduced loudness ratings slightly but not significantly, although it recognizably changed the sounds that subjects heard. They also stated that removing low frequencies raised annoyance ratings slightly.

Another interesting effect is described in two publications by Leatherwood and Sullivan, who conducted a set of experiments using asymmetrical booms [15,16]. The first experiment [15] was a more general investigation of sonic boom shaping. One conclusion of this study was that loudness ratings may be reduced by modifying the front-shock parameters of the boom (e.g. overpressure ratio and rise time), even though the peak overpressure remains the same. However, some interesting trends relating to boom asymmetry were also noticed in this study, and were examined in greater depth in the later study [16]. The conclusion of this later study was that asymmetrical booms (i.e. for which the PL of the first and second peaks are not equal) are given lower loudness ratings than are symmetrical booms, with PL held constant. This loudness rating reduction increased as asymmetry increased, and was the greatest when the rear shock was louder than the front shock. Leatherwood and Sullivan noted in both papers that PL, ASEL, and Zwicker Loudness Level were the more highly correlated predictors of loudness ratings and did not differ significantly from each other, while CSEL or unweighted SEL were less highly correlated.

Naka [17] provides an interesting example of more recent research, in which human responses to indoor and outdoor booms were tested in a simulator at the Japan Aerospace Exploration Agency (JAXA), using "loudness" as the subjective criterion. The conclusion from this research was that Perceived Level (PL), Perceived Noise Level (PNL), and A-weighted Sound Exposure Level (ASEL) were the highest-correlated metrics to loudness ratings for both outdoor and indoor sounds. One interesting result was that B- and C-weighted Sound Exposure Levels (BSEL and CSEL) were significantly less highly correlated to the data than was ASEL (the Pearson correlation coefficients differ by upwards of 0.04 in the case of BSEL, and 0.193 in the case of CSEL). Maximum Zwicker Time-Varying Loudness (designated by TVLZ in Naka's article, but by $\mathrm{ZN}_{max}$ in the remainder of this thesis) was also observed to be less highly correlated to the data than was PL (the Pearson correlation coefficient for $ZN_{max}$ and PL differ by upwards of 0.093).

Most of the publications cited to this point are about research using loudness as the subjective criterion. However, in a 2002 article, Leatherwood, Sullivan, Shepherd, McCurdy, and Brown [18] concluded that annoyance evaluations are just as good as loudness evaluations when testing with simulated outdoor booms, and better than loudness evaluations when testing with indoor booms (as evidenced both by higher indoor annoyance scores and by increased prediction accuracy over that when subjective loudness was used).

Marshall [19, 20] stated that startle and annoyance responses for outdoor booms were highly correlated, and that predictive models that are functions of the metrics: maximum Time-Varying Loudness, Rise Time, and Sharpness, were significantly more accurate in predicting annoyance ratings than were models of Loudness metrics alone. Giacomoni [5] attempted to apply Marshall's outdoor boom annoyance models to indoor booms, and concluded that these models (which utilized statistics of Moore & Glasberg long-term Time-Varying Loudness, von Bismarck Sharpness, and Duration) could be applied to indoor booms after some small alteration. Giacomoni has also developed a simulation program (in MATLAB) which predicts the indoor sound that will be produced in a given room by an outdoor signal. Support also exists for Stevens' Perceived Level (PL) as a good predictor of annoyance. McCurdy, Brown, and Hilliard [21] conducted a test utilizing loudspeaker systems in subjects' homes, and concluded that Perceived Level surpasses Zwicker Loudness and A-, C-, and unweighted Sound Exposure Level as a predictor of annoyance. One noteworthy feature of McCurdy's test is that it included both outdoor sounds and simulated indoor sounds, even though all the sounds were played indoors. The purpose of using both types of signals was to expand the range of spectral content in the signals. However, all sounds used in the test were booms. This is in contrast to Marshall's tests where a variety of outdoor transient sounds (including booms) were used as test stimuli.

All of these researchers agree that some form of Loudness metric predicts subjective responses reasonably well. However, Marshall and Giacomoni present a further conclusion: that the accuracy of predictive models can be significantly enhanced by combining Loudness metrics with other measures such as Sharpness and Rise Time. Hence, the research in this thesis includes an examination of multiple-metric models. Various Loudness metrics will be examined, including PL, Zwicker Time-Varying Loudness, and Moore & Glasberg Time-Varying Loudness. The Rise Time characteristics of the booms will be examined by calculating the maximum derivative of Time-Varying Loudness before the front shock. Following the conclusions of Leatherwood, Sullivan, Shepherd, McCurdy, and Brown [18], annoyance rather than loudness is chosen as the subjective criterion in this research.

### 1.1.3 Low Frequency

Since much of the spectral content of sonic booms occurs at low frequencies, there is particular concern that annoyance-predicting measures for sonic booms adequately account for low-frequency effects of sounds. Kryter concluded from a field test using acceptability as the subjective criterion [22] that examining frequencies below around 20 Hz is "not necessary, even perhaps slightly misleading." Niedzwiecki and Ribner [14] stated that reducing the low-frequency content of filtered N-wave booms produces only slight variations in both loudness and annoyance ratings. Also relevant are the findings of Leatherwood and Sullivan [15, 16] and of Naka [17], that CSEL is not as highly correlated to loudness ratings as is ASEL.

However, a significant number of other researchers support including specific low-frequency measures in sonic boom analysis. Investigations of steady-state low-frequency noise were conducted in the 1980s, including field investigations by Vasudevan and Leventhall [23] and laboratory experiments by Broner and Leventhall [24, 25]. Vasudevan and Leventhall concluded that A-weighted sound pressure level was not a satisfactory annoyance predictor in the field situations examined.

Broner and Leventhall [24] were more reserved in their critique of A-weighted sound pressure level, but they suggested B-weighted sound pressure level or a modified form of Perceived Noise Level as a superior annoyance predictor. Schomer [26] stated that the chief adverse characteristic of high-energy impulsive sounds is secondary rattles excited by low-frequency content, and that A-weighting is a misleading criterion because it attenuates this low-frequency content.

Schomer, Sias, and Maglieri [27] conducted a field test utilizing both real booms and blasts, and concluded that sonic booms and blasts elicit similar responses from people, and can be included in the blast-noise framework. However, they also acknowledged that sonic booms have more low-frequency energy than blasts, and that a weighting with a cutoff frequency of 5 Hz rather than 20 Hz might be a better predictor of annoyance than the C-weighted Sound Exposure Level (CSEL) used in their test. They stated that CSEL was chosen partly because it included more of the vibration- and rattle-inducing energy in the test sounds, and that for this reason, *outdoor* CSEL was to be preferred over *indoor* CSEL, which "predict[s] neither building response nor human response." Schomer and Sias published further results from this same test in a later publication [28]. They stated that Vos's [29] annoyance model for outdoor and indoor firearm noise (which was based largely on outdoor ASEL and another term combining ASEL and CSEL) does offer some improvement in prediction, but still does not fully account for the differences in perception between booms and blasts. They also suggested that window acceleration might explain the differences between subject responses to booms and blasts; however, they stated that the data on this issue was incomplete. In a review and comparison of previous work (published around the same time as [27]), Hubbard and Shepherd [30] list day-night average C-weighted sound level as a proposed appropriate metric for predicting annoyance due to sonic booms and other high-energy vibration-inducing sounds.

The divide between researchers on low-frequency effects may be explained in multiple ways. One possible explanation is that subjects pay better attention to low-frequency content when rating sounds in terms of annoyance rather than loudness.

Many of the researchers supporting the examination of lower frequencies used annoyance as their subjective criterion, while most of those not in favor (with the exception of Niedzwiecki and Ribner) used loudness or acceptability. A second possible explanation is that low-frequency information usually does make a difference in subjective ratings of any kind, but that it should be characterized by a different metric than CSEL. Since the research described in this thesis includes annoyance as the subjective criterion, the first possible explanation is satisfied. Also in this research, low frequency is quantified not by using CSEL but by using the Heaviness metric, which is the difference between CSEL and ASEL. This satisfies the second possible explanation.

Another important aspect to consider is the relationship between low-frequency sound, noise from secondary rattles, and structural vibration. Low frequency sound can excite structures in ways such that rattle and vibration occur; but even in situations where rattle and vibration do not occur, people may associate the low-frequency content of the sounds with the potential for rattle and vibration, and may thus perceive the sounds as more threatening. The research described in this thesis does not include an examination of rattle noise. Therefore, the final section of this literature review will be dedicated to vibration effects.

### 1.1.4 Vibration

The research community is also divided over whether whole-body vibration (i.e. the vibration that a person feels, as opposed to creak or rattle noises caused by shaking of structures or bric-a-brac) affects human response to sonic booms. Results from a set of laboratory and field tests in the 1960s and 1970s seem to discount the effects of vibration. Kryter [22] conducted a series of field experiments in which subjects listened to indoor and outdoor sonic booms and subsonic aircraft noise from real military aircraft. In one experiment, subjects alternated between plain chairs and chairs placed on vibration-isolating pads. Kryter's conclusion was that vibration effects did not significantly change the subjects' ratings of sonic booms relative to subsonic aircraft noise. Schomer [31] cited Kryter's work along with a series of other tests investigating vibration from sonic booms, subways, impact machinery, etc., concluding that even when vibration is directly perceived, it does not normally influence human response to large-amplitude impulsive noise at all. Kryter does state (while discussing a set of laboratory tests) that vibration from sonic booms may contribute to waking up sleeping subjects [32], which may also, in turn, affect annoyance; however, the issue of sleep effects is beyond the scope of this thesis.

Other researchers state that vibration is a possible factor influencing annoyance, although their conclusions are not much more specific than that. Nixon and Borsky [33] suggested that vibration is one factor that renders indoor booms more annoying than outdoor booms. They also stated that some subjects in their field test reported interference with daily activities due to house shaking, although these interferences did not result in high annoyance. Powell and Shepherd [34] review the results of a test in which noise and vibration measurements were taken around John F. Kennedy Airport in New York City. This west was conducted to determine the impact of noise from the Concorde aircraft. Two general conclusions of this test were that structural vibration (walls, floors, and windows) is highly correlated to noise level, and that average indoor annoyance ratings increase when vibration of the structure is detected. In a 1991 NASA Reference Publication, Maglieri and Plotkin [35] stated that indoor vibration is believed to be significant in some cases, but that research into vibration effects was not enough to gauge its relative importance. Leatherwood, Sullivan, Shepherd, McCurdy, and Brown [18] cite Maglieri and Plotkin [35] and journal articles by Paulsen and Kastka [36] and Öhrström [37] in support of vibration affecting human response. (However, the two journal articles were not judged particularly relevant to this thesis, as the sounds studied therein were more steady-state. Paulsen and Kastka's research was on the effects of noise from a tram and a hammermill, while Öhrström's research was on railway noise. The hammermill sounds discussed in Paulsen and Kastka included impulses, but these impulses occurred repeatedly at regular, closely spaced intervals, rather than singly at occasional, random intervals as would be expected for sonic booms.) Fields [38] also considered vibration to be a possible factor influencing human response, as residents in the vicinity of regular supersonic aircraft activity reported feeling vibration in their homes. Rathsam, Loubeau, and Klos [39] agreed with Fields's conclusion following a recent test conducted in the Interior Effects Room (IER) at NASA Langley. However, they also mentioned "improper modeling of low-frequency loudness" as another possible explanation for the trends in their test results.

Therefore, given the broad range of statements by members of the research community, the safest conclusion may be that further examination of the effects of whole-body vibration (caused by sonic booms or other environmental transient noises) on people's responses is needed. The research described in this thesis will include an examination of the effects of whole-body vibration on annoyance, as measured at the seat of a sitting subject.

## 1.2 Research Approach and Thesis Organization

The first part of this research was dedicated to revising and expanding an indoor simulation program developed by former Herrick student Clothilde Giacomoni. This program and the revisions to it will be discussed in Chapter 2. The second part of this research was dedicated to subjective testing. Two tests were conducted: one in a simulator, the other in a sound chamber over earphones. These tests had both a similar format and included similar signals. The simulator test, including analysis of the results and estimation of regression models for predicting annoyance responses from metrics, will be described in Chapter 3. Similarly, the earphone test will be described in Chapter 4. A comparison of the results of the two tests is given in Chapter 5. A summary of the findings and possible directions for future research are given in Chapter 6.

# 2. DESCRIPTION OF PURDUE'S SIMULATION PROGRAM

In her 2012 Master's Thesis, previous Herrick student Clothilde Giacomoni described an indoor simulation program that she had developed [5]. This program predicts a sound that will be heard indoors, given a recording of an outdoor sound, the size and construction of the house and room in which the sound will be heard, and the position of a point source and receiver inside the room. Also, the simulated indoor sound may be predicted for two types of receivers: a simple microphone or a binaural head.

The expansions and revisions made to Giacomoni's program by the present author and by another previous student, Mr. Yingxiang Jiang, are described in this chapter. The revised code was used to generate five indoor simulated sounds from outdoor signals used in a test at NASA Langley Research Center; this test is described in Chapter 3. The simulated sounds were used in another test conducted at Purdue University; this test is described in Chapter 4. The listing of the program and instructions for using it are included in Appendix B.

## 2.1 Basic Layout of the Simulation Program

The simulation program may be divided into two main stages. The first stage models the acoustic impulse response of a rectangular room of given dimensions and construction, with the sound source and receiver at given locations. This stage is executed primarily by the function *ReverbProg*, which assembles the frequency response of the room by summing reflection paths, and inverse Fourier transforms to generate the impulse responses. *ReverbProg* in turn calls several subsidiary functions to calculate reverberation times, to model reflection characteristics of the surfaces in the room, and (if the receiver is a binaural head) to compute the azimuthal and elevation angles at which each path approaches the receiver, and to call the appropriate head-related transfer functions (or HRTFs) for each path.

The second stage models the transmission of an outdoor source sound into a house, and convolves the transmitted signal with the room impulse response to produce a simulated indoor sound. This stage is executed primarily by the function *ReverbSimulationProgram_rev3*, which calls the transmission filter from a MAT file, and sends the room specifications to *ReverbProg*. *ReverbSimulationProgram_rev3* calls one other subsidiary function, *mylongconv*, which convolves the indoor signal with the room impulse response. *mylongconv* utilizes a long convolution algorithm that is more time efficient than that of the *conv* function in MATLAB.

## 2.2 Revisions to the Program

Most of the present author's revisions and expansions were confined to Stage 1 (i.e. *ReverbProg* and its subsidiary functions). The only Stage 2 function to undergo serious revision was *mylongconv*. A truncated version of *ReverbSimulationProgram_rev3* was also generated, but only for the purpose of importing and summing preexisting impulse responses generated *ReverbProg* (as opposed to calling *ReverbProg* itself).

General revisions included 1) streamlining (or correcting where necessary) the calculations, 2) rearranging operations to reduce runtime and memory usage, and 3) adding error codes to facilitate ease of debugging. The more significant revisions included improving the reflection characteristics of the simulation and expanding the use of HRTFs.

### 2.2.1 Reflection Coefficients

To model the room's reflection characteristics, *ReverbProg* selects a set of octave-band absorption coefficient magnitudes from a data file. Each surface in the room (floor, ceiling, and walls) has its own set of absorption coefficients depending on the specified material. After calling the octave-band absorption coefficients, *ReverbProg* converts them to reflection coefficient values and extrapolates a reflection coefficient curve across the frequency domain from 0 to $f_s/2$.

The original *ReverbProg* utilized a simple extrapolation scheme in which each octave-band value was extended in a straight line from its own center frequency to just below the next center frequency. This method produced a zero-phase reflection curve with abrupt transitions between center frequencies, which may be considered a crude approximation but was still not satisfactory. In order to make the reflection behavior of the surfaces more realistic, it was desired to develop an extrapolation process that generated a smooth reflection frequency response curve containing both magnitude and phase information.

A smooth magnitude curve was produced using three MATLAB codes developed by Jiang. Jiang's codes took a linear interpolation algorithm and applied it between consecutive octave-band values to produce a linear spline curve across the half-frequency domain, with horizontal end-regions (i.e. beyond the highest and lowest defined center frequencies). This curve was smoothed with a moving average filter.

To generate phase information for the absorption curve, it was assumed that each surface in the room would behave as a minimum-phase system. Using this assumption, a phase curve could be reconstructed from the reflection frequency response magnitude curve by using a Hilbert transform. Jiang had demonstrated that MATLAB's *hilbert* function produced unsatisfactory results; this was judged to be due to a poor algorithm. Upon further examination, it was decided to generate a Hilbert transform digital filter by using the more robust *firpm* function, which designs finite impulse response filters using Parks and McClellan's Remez Exchange Algorithm.

Jiang's codes were utilized in the revised program to produce a double-sided spline curve of reflection coefficient magnitudes in the frequency domain. This curve was smoothed with a moving average filter 10 Hz wide on each side. The smoothed curve was scaled to bring the endpoints to 1, and the natural logarithm of the scaled curve was convolved with a Hilbert transform to produce the phase. A 2047-point Hilbert transform was chosen to minimize the length of the transition regions of the transform, thus keeping the phase well-behaved at lower frequencies. Sample reflection curves generated using the original and revised codes are plotted in Figure 2.1.

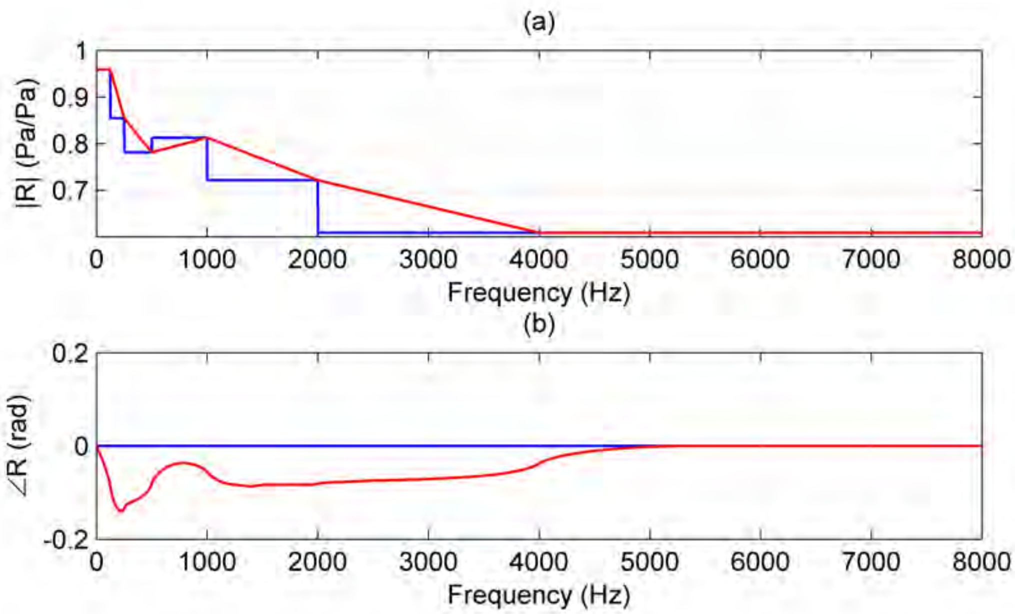


Figure 2.1. Original (blue) and revised (red) reflection curves generated by the simulation program: (a) magnitude, (b) phase.

### 2.2.2 Head Related Transfer Functions

As originally designed, *ReverbProg* was capable of simulating room impulse responses as measured both by a microphone and by a KEMAR dummy head. For the KEMAR impulse responses, *ReverbProg* modified each reflection path in the room with a head-related transfer function (HRTF). Giacomoni had acquired a public-domain set of HRTF impulse responses recorded at MIT Media Labs [40], and modified them to have a flat response at low frequencies [5]. A subsidiary program, *find_hrtf*, selects the proper left- and right-ear HRTFs for each reflection, computes their discrete Fourier transforms (DFT), and sends them to *ReverbProg*.

However, the original *find_hrtf* was only capable of outputting the HRTFs at their original sampling frequency of 44.1 kHz, which put a practical limit on the binaural impulse responses that *ReverbProg* could produce. The present author's desire was to make *ReverbProg* capable of producing binaural impulse responses at 48 kHz. This is the sampling frequency used by the Interior Effects Room (IER) at NASA Langley, where the test described in Chapter 3 was conducted. By making *ReverbProg* compatible with 48-kHz sounds, it would be possible to take outdoor source signals from the test at NASA Langley and generate indoor simulated sounds without having to re-sample the signals first.

In order to make *ReverbProg* compatible with 48-kHz sound recordings, *find_hrtf* was expanded to re-sample the HRTFs by zero-padding in the frequency domain. When performing this re-sampling method, it is important to set the frequency resolution so that the sampled frequency domain contains both the old and the new half-sampling frequencies exactly. Otherwise, the resampled HRTF will be distorted. However, there is a drawback to this method. For the purpose of computation efficiency, it is desirable to set the number of points in the frequency domain to a power of 2. Achieving both the necessary frequency resolution and a computationally optimal number of points may not be impossible, but it may be impractical if the sampled frequency domain that satisfies both conditions is very long. In their present form, *ReverbProg* and *find_hrtf* satisfy the frequency resolution condition necessary for performing this re-sampling, but they do not set the number of points to be a power of 2. Hence, the runtime of the discrete Fourier transform algorithm is no longer optimized. Sample HRTFs are plotted in Figure 2.2.

*ReverbProg* can run slowly even when simulating a reverberation impulse response for a medium-sized room, and Fourier transforming the HRTF impulse responses is one of the more computationally costly parts of the algorithm. Hence, there was some interest in whether the runtime of the simulation program could be reduced by generating files of HRTF frequency responses beforehand, so that the program could simply read the frequency responses from the files rather than executing a large number of Discrete Fourier Transforms. In order to investigate this possibility, the subroutine *find_hrtf* was expanded with an option to read pre-made Discrete Fourier Transforms of the HRTFs from a bank of files. This method was tested before the re-sampling procedure had been implemented, so it was tried only at the original sampling frequency of 44.1 kHz. Although this method reduced runtime in some cases, it increased memory usage by at least an order of magnitude. This was because the transforms needed to be calculated at multiple frequency resolutions to make the program robust, and because the banks of higher-resolution transform files were very large (i.e. on the order of tens or hundreds of megabytes, or larger).

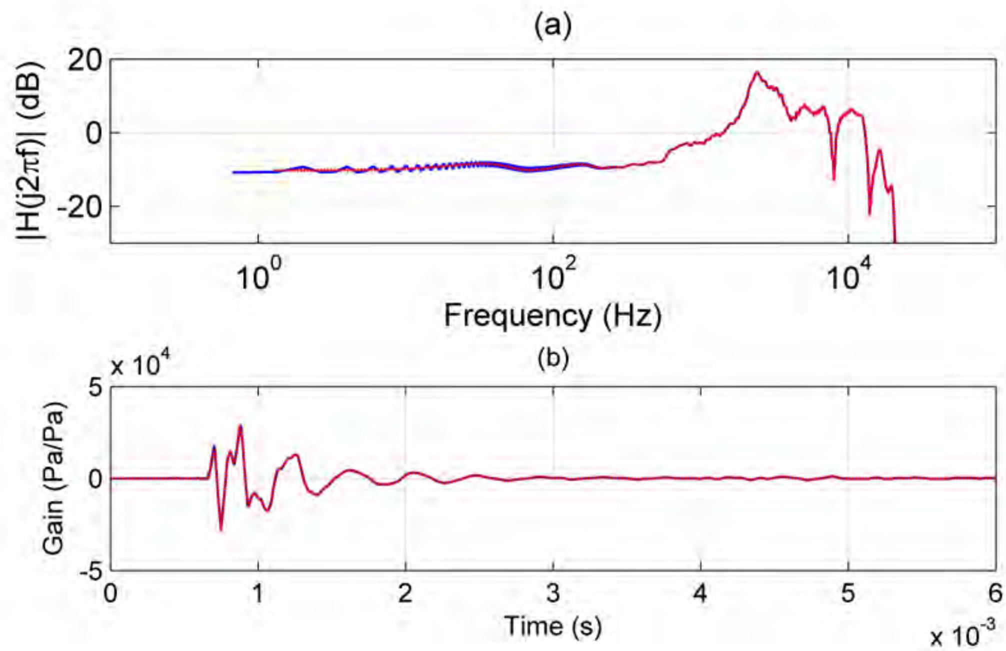


Figure 2.2. Original 44.1 kHz (blue) and 48 kHz re-sampled (red) head related transfer function: (a) frequency response magnitude, (b) impulse response.

## 2.3 Summary

Giacomoni's room reverberation simulation program was revised to improve the modeling of surface reflection characteristics, and to make the program compatible with sounds sampled at frequencies higher than 44.1 kHz. General revisions were also made to improve efficiency and robustness of operations. The revised program was used to generate five sounds for the test described in Chapter 4. As noted earlier, the MATLAB functions are included in Appendix B.

# 3. TEST CONDUCTED IN THE NASA SIMULATOR

The first test was performed in the Interior Effects Room (IER) at NASA Langley Research Center. This facility is described in detail in a conference paper by Klos [6], and in a NASA Technical Memorandum by Rathsam, Loubeau, and Klos [7]. The IER was built using construction materials and methods that are typically used in American houses. Two large arrays of subwoofer and midrange speakers are placed against two of the IER's walls on the outside. These arrays present outdoor booms (or similar sounds) to the structure, which naturally filters the sounds to produce indoor booms inside the room. A small number of satellite speakers are placed inside the room to provide optional rattle noise.

As a testing facility for sonic booms, the IER has three distinctive characteristics. First, it provides a relatively natural environment for conducting tests, as the interior design of the room is similar to that of a sitting room in a house. Second, the electronic hardware in the IER is capable of reproducing sounds to frequencies as low as 6 Hz [6, 7]. Third, the acoustic loading induces vibration of the room itself, which allows investigators to study the effects of tactile cues on subject responses.

This first test (henceforth called the NASA test) was designed and conducted with the collaboration of Rathsam, Loubeau, and Klos, of NASA Langley. Permission to conduct the test was granted by the NASA Langley Institutional Review Board. The overall design of the test was to examine annoyance to transient sounds of various types with a wide variety of characteristics. Additionally, due to the low-frequency playback capabilities of the IER and the presence of vibration, the NASA test was specifically designed to examine subjective response to the low-frequency content of stimuli, and to whole-body vibration. The focus of this chapter will be primarily on acoustic effects, since Rathsam, Loubeau, and Klos conducted the bulk of the investigation of vibration effects in this test. Their conclusions regarding vibration effects are presented in a conference paper [41].

### 3.1 NASA Test Experimental Methodology

The NASA test was conducted in two parts. Each part was a parametric test in which subjects listened to eighty sounds (consisting of recorded booms, synthetic booms, explosions, gunfire, and car door slams), and rated the sounds on an annoyance scale. Both the sounds and the order in which they were presented were exactly the same in Part 1 as in Part 2. The random playback order used each time the test was run was different; the purpose of this was to reduce the likelihood of subjects' ratings being biased due to ordering effects.

Subjects were tested two at a time. Preliminary hearing checks were administered by recruitment staff at NASA Langley, testing subjects' hearing in octave bands from 125 to 8000 Hz. Subjects passed the test if their hearing thresholds were $\leq$ 30 dB in each band. Following the hearing check, the subjects were escorted to their seats in the IER. Laptop computers had already been placed at each seat. Subjects were each given a copy of a consent form and a Privacy Act notice to sign, the test format outline, and the test instructions.

Before the test was begun, a ten-sound familiarization session and a six-sound practice rating session were administered with the test director in the room. The test director assisted subjects who were having difficulties and answered questions. The test director then exited the IER and Part 1 of the test was administered. After Part 1 was concluded, the test director re-entered the room and offered the subjects a short break. Following the break (or if the subjects desired to proceed immediately to Part 2), the subjects were instructed to change seats, the test director left the room, and Part 2 was administered.

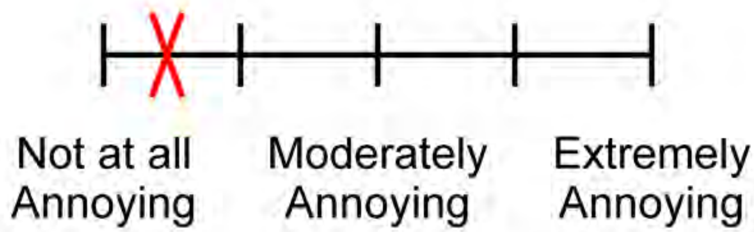


Figure 3.1. Scale used in the NASA test, with red cursor. The tick marks were assigned numerical values of 2.0, 3.5, 5.0, 6.5, and 8.0 (from left to right). The cursor was moved by using a rotary dial.

After completing Part 2, subjects were asked for feedback about the test, and then escorted to recruitment staff for a post-test hearing check. Subjects were compensated $50 for taking the test, plus mileage reimbursement.

Subjects entered their annoyance ratings on laptop computers, using a scale with a sliding cursor. Input was done using rotary dials rather than a mouse or mouse pad, as the action of turning a knob to adjust the volume of a system was judged more intuitive than the act of clicking and dragging with a mouse would be. The cursor appeared at the left end of the scale after each sound was played. A schematic of the rating scale is shown in Figure 3.1. When the subject was happy that the cursor position reflected their response of the sound, they depressed the button to record their rating.

### 3.1.1 NASA Test Sounds

Eighty sounds were used for the NASA test. These were generated from twenty source signals. Fourteen signals were supplied by Purdue, and included three sonic boom recordings, six synthetic booms, two explosion recordings, two car door slam recordings, and one gunfire recording. Six additional source signals (consisting entirely of booms) were supplied by NASA Langley. The source signals were expanded to eighty test sounds by varying the amplification levels and/or the high-pass filtering. Thirty-two sounds were filtered at 50 Hz to allow for examination of the effects of low frequency noise. The remaining sounds were high-pass filtered at 4 Hz, 6 Hz, 25 Hz (in the case of the gunfire sounds), or not at all. Sounds were stored in 24-bit WAV files.

The fourteen signals supplied by Purdue were amplified to up to three different levels each to produce twenty-four test sounds. Rathsam, Loubeau, and Klos supplied a set of transfer functions which could be used to predict sounds heard inside the IER at the two designated subject seats. The original outdoor signals were convolved with these transfer functions to generate predicted indoor sounds, which were then analyzed to determine the desired amplification. The initially adopted amplification scheme was to scale the signals so that the predicted indoor sound would have levels of 60, 70, and 78 dB, as predicted by Stevens' Perceived Level metric (PL). Once the desired scaling factors were found, an additional three metrics were computed for the predicted indoor signals, and the distribution of the metrics was examined. The three other metrics generated were maximum Zwicker Loudness, maximum Sharpness, and maximum Zwicker Loudness Derivative. The final 24 sounds were selected so that the four metrics were de-correlated. Also, the amplification on three of the louder sounds was reduced to 71, 74, and 75 dB PL, so that the distribution of metrics across the signal set would not contain any major outlier values. The six signals supplied by NASA were each amplified to four different levels, yielding twenty-four sounds. Scaling factors were determined by the engineers at NASA.

The filtering on the twenty-four Purdue signals with low-frequency content was applied as follows. The explosion, recorded boom, and car door slam signals were generated from raw recordings, and were filtered with a Butterworth 2nd-order 6-Hz cut-off frequency high-pass filter, applied in the forward direction only (by using the *filter* command in MATLAB). The filter specifications were chosen on the recommendation of Rathsam, Loubeau, and Klos [6, 7]. The six synthetic booms and single gunfire sound available for the test had already been passed through two filters: a 3rd-order Butterworth zero-phase 25-Hz cut-off frequency high-pass filter (applied by using the *filtfilt* command in MATLAB), and a filter designed to model outer-ear effects so that the signal could be presented directly to a subject's eardrum via earphones. Both of these filters were unnecessary and/or inappropriate for pre-processing signals to be used in the NASA test: the high-pass filter, because the playback equipment in the IER can reproduce frequency content as low as 6 Hz; the ear filter, because the IER reproduces sounds over loudspeakers rather than over earphones. The ear filter was removed first, by convolving the signals with an inverse filter's impulse response (supplied by Marshall). To restore low-frequency content in the 6-25 Hz range for the synthetic booms, a set of two filters was designed to replace or cancel out the auto-regressive terms of the original high-pass filter, so that the composite filter approximated 3rd-order Butterworth 6-Hz cut-off frequency high-pass filter applied in the forward direction only. An additional 3rd-order Butterworth 3-Hz cut-off frequency high-pass filter was applied in the forward direction to prevent over-compensation of low-frequency noise. The gunfire signal was left with the original 25-Hz filter, because the re-filtering method over-compensated much too severely.

To allow for greater examination of the effects of low-frequency content on annoyance, thirty-two sounds having frequency content down to 50 Hz were included in the NASA test. These sounds were generated by making copies of the signals described above, and by passing them through a 3rd-order Butterworth 50-Hz cut-off frequency high-pass filter, applied in the forward direction only (by using the *filter* command in MATLAB). Eight signals prepared by Purdue and all twenty-four signals prepared by NASA were copied and high-pass filtered in this way.

The thirty-two Purdue signals (the original twenty-four signals with low-frequency content and the eight signals high-pass filtered at 50 Hz) were also resampled to 12 kHz for the purpose of compatibility with NASA IER system software. Resampling was done in the time domain using zero interspersion or decimation in conjunction with a low-pass filter. A Butterworth 9th-order 4-kHz low-pass filter was generally used; the cutoff frequency corresponds to the upper limit of audible sound components in sonic booms [7], and the filter order corresponds to standard procedures used by Rathsam, Loubeau, and Klos. However, the filter order was reduced to 8 when resampling the blast signals. The original blast recordings were sampled at 51.2 kHz, and the resampling process included a stage in which the signals were upsampled by a factor of 5. In this stage, the filter order was reduced to prevent ringing.

All sounds to be input into the IER system were 2 seconds long, in order to keep the length of the test reasonable. Windowing was generally done with 1/2-cosine ramps of length 20 milliseconds (on the front of the signal) and 200 milliseconds (on the back of the signal). However, the blast signals decayed so slowly that cosine ramps produced unnatural-sounding attenuation. The blast signals were therefore windowed on the back with exponential ramps (decay rate $\approx 2.5$) that began just after the maximum pressure peak in the signal. 10 milliseconds of silence were placed at the lower end of each ramp (these intervals were included in the 2-second duration of the sound files). The signals supplied by NASA Langley attenuated naturally within 2 seconds, and thus did not need to have ramps applied.

Once the desired filtering and windowing had been applied, the 12-kHz signals and their corresponding scaling factors were input to a MATLAB function produced by NASA, which performed the specific filtering, equalization, and scaling necessary to play back the signals over the IER equipment. This process lengthened the signals considerably, and increased the sampling back to 48 kHz.

### 3.1.2 NASA Test Subjects

Thirty subjects from the general Hampton, Virginia area were recruited for the test. The subject pool consisted of eighteen females and twelve males, aged 18-61. The average age was 27 years and the median age was 22 years.

### 3.1.3 Vibration Examination

In order to accurately quantify and control the vibration that subjects would experience during the test, subjects were seated in two un-cushioned wooden chairs. The first chair rested directly on the floor, while the second chair was mounted on four Newport SLM-1A pneumatic vibration isolators. Also, an 83-lb lead weight was placed on the rig beneath the isolated seat. Since the behavior of the isolators changes with the magnitude of the loading, the subjects' experience of vibration in the isolated seat would change depending on their weight and posture. Adding a constant 83 lb to the loading of the chair put the isolators in a region where subject weight variation would have a smaller effect than in the case where no additional weights were applied, thus ensuring a more uniform vibration experience across the subject pond.

Since the vibration in the IER was entirely sympathetic with the acoustic loading, rather than being applied in a more controlled fashion by shakers, there was concern that a long test would expose subjects to an excessive amount of vibration. The isolators under the second chair had a nominal natural frequency of 3-5 Hz, and there was concern that the isolators might amplify some of the lower-frequency vibration components from the booms, thus raising overall subject vibration to unacceptable levels.

To ensure that subject vibration during the test would be within acceptable limits, the vibration at each chair was measured with accelerometers, and transfer functions relating input signal and the vibration of the chairs at the middle of the seat were generated. These transfer functions were used to predict the vibration response of the chairs to some of the louder sounds. By plotting the vibration spectra against exposure curves, it was observed that the vibration in either chair did not exceed the ISO 2631 fatigue/decreased proficiency boundary for 24-hour exposure, and was well below the reduced comfort boundary for 1-minute exposure. As an additional safety check, the vibration dose values were calculated for three sample signals played 200 times. The values ranged between 0.012 and 0.050 m/s$^{1.75}$, which is well below the British Standards 6841 exposure limit of 15 m/s$^{1.75}$ [42].

## 3.2 NASA Test Results and Discussion

Average annoyance values from all subjects' ratings are plotted in Figures 3.2 and 3.3. A few general formatting conventions regarding these figures should be noted, as they will be adopted for all subsequent figures containing plots of annoyance ratings or sound characteristics. Blue and red data points correspond to sounds prepared by Purdue, with red points representing sounds that were high-pass filtered at 50 Hz. Green and yellow data points correspond to sounds prepared by NASA Langley, with yellow points representing sounds that were high-pass filtered at 50 Hz. If error bars are included with the data points, they represent the standard deviation of the estimated mean, rather than the standard deviation of the data. Finally, the subdivision of the annoyance axis corresponds to the tick marks on the rating scale.

In Figures 3.2 and 3.3, annoyance ratings to groups of sounds are plotted, arranged either by source signal or by sound type, in order of increasing predicted indoor Perceived Level. From these figures it is observed that subjects' annoyance ratings of the signals generally increase with increasing playback amplitude. This trend is not as evident in Figure 1 as it is in Figure 2. The reason for the relative scatter of the annoyance ratings in Figure 1 is that multiple source signals were used for each sound type so, e.g., for synthetic booms, five different sound recordings were used. Also evident is that annoyance ratings for 50-Hz high-pass filtered sounds are either lower or not significantly different than are annoyance ratings for less aggressively filtered signals. In Figure 3.3, the ratings for the 50-Hz high-pass filtered versions of source signal 2 are significantly lower than for the non-50-Hz high-pass filtered versions. These results are understandable, since source signal 2 was produced using both a high-pass and a low-pass filter with a cutoff frequency of 27 Hz. Hence, applying an additional 50-Hz high-pass filter removes much of the remaining energy from the signal. By contrast, annoyance ratings for source signal 5 are not significantly different when the 50-Hz high-pass filter is applied. This is also understandable, since source signal 5 was produced using a high-pass filter with a cutoff frequency of 45 Hz. The additional 50-Hz filter accordingly does not modify the sound as severely.

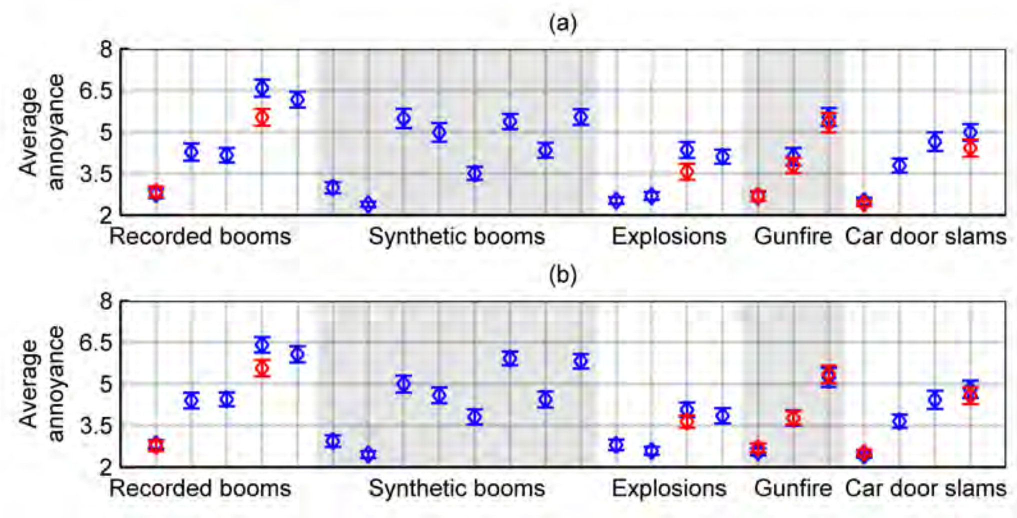


Figure 3.2. Average annoyance ratings for sounds prepared by Purdue, arranged by sound type: (a) plain seat, (b) isolated seat. For information on color-coding, error bars, and subdivision of the annoyance axis, see Page 25.

In Figure 3.4, average annoyance ratings across the entire test for each chair are plotted against each other. The correlation is high ($R^2 = 0.976$), and the best-fit line (shown in magenta) is close to the one-to-one line (shown in black). Also, only 15 ratings out of 80 are more than one standard deviation away from one-to-one correlation. Of these 15 outliers, only three ratings exceed two standard deviations from the best-fit line; and of those three, only two exceed two standard deviations from the one-to-one correlation. (These three outliers are all for synthetic booms.) However,

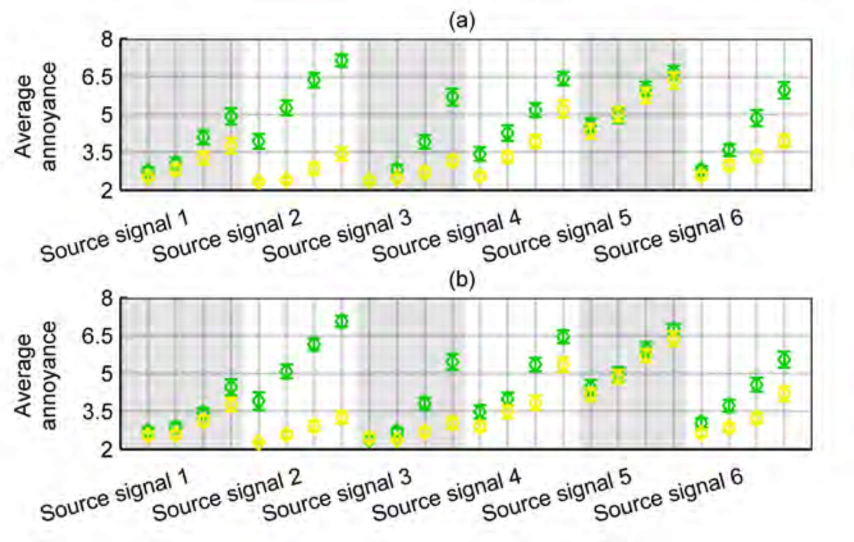


Figure 3.3. Average annoyance ratings for sounds prepared by NASA Langley, arranged by source signal: (a) plain seat, (b) isolated seat. For information on color-coding, error bars, and subdivision of the annoyance axis, see Page 25.

this does not indicate that the effects of location (either acoustical or vibratory) on annoyance ratings are negligible. Rather, it indicates that the location ordering effects are roughly balanced; that is, if a subject sits in the isolated chair first, her/his judgment is not more affected than if she/he had sat in the plain chair first. Hence, when ratings in each chair are averaged across the entire test, the ordering effects largely cancel out. In order to determine whether ordering effects are present, the results must be examined in groups of average ratings per test-half per chair.

Subjects in the NASA test may be divided into two groups: those who first sat in the plain chair, and those who first sat in the isolated chair. In Figure 3.5, average annoyance ratings for each of these groups are shown in separate plots. For each group of subjects, subsets of annoyance ratings made at each chair are plotted against each other. The magenta best-fit lines both appear to be close to one-to-one, and have $R^2$ values of (a) 0.958 and (c) 0.956. This indicates that subjects gave consistent ratings throughout the test, regardless of which chair they occupied first.

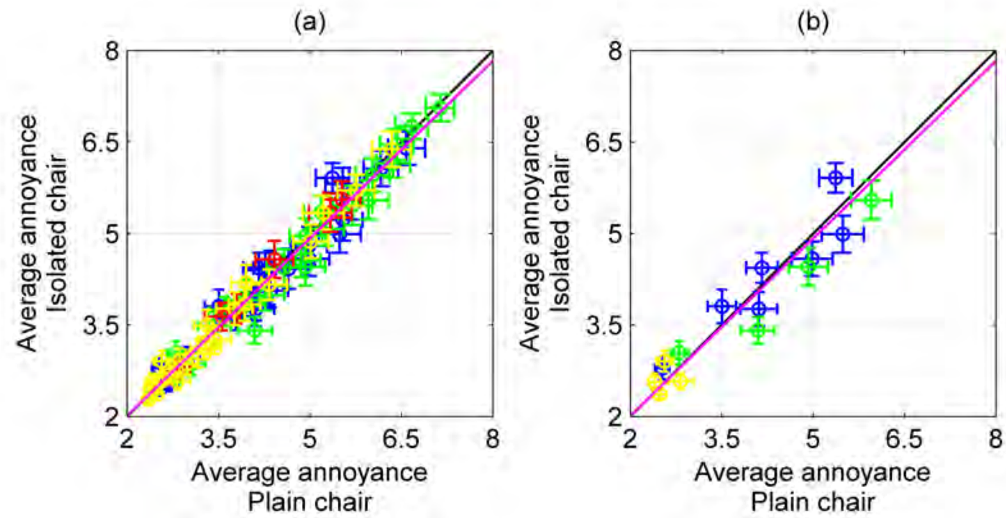


Figure 3.4. Whole-test average annoyance ratings at each chair plotted against each other: (a) all ratings, (b) outliers exceeding one standard deviation from one-to-one correlation. $R^2 = 0.976$. For information on color-coding, error bars, and subdivision of the axes, see Page 25.

Plots (b) and (d) ind Figure 3.5 contain only the ratings from plots (a) and (c) that are more than one standard deviation away from one-to-one correlation. However, only two ratings in (d) are more than two standard deviations away from one-to-one correlation. These ratings are both for sounds contributed by NASA Langley, generated from recorded booms. Also, only one rating in (b) and (d) is more than two standard deviations away from the best-fit line. This rating is for the same sound in both (b) and (d): a synthetic boom contributed by NASA Langley, band-pass filtered (center frequency 27 Hz) and high-pass filtered with a cut-off frequency at 50 Hz, and played back at low amplitude.

In Figure 3.6, annoyance ratings are divided by chair, and for each chair annoyance ratings made in the first or second half of the test are plotted against each other. Here the best-fit lines are markedly different from one-to-one, although the correlations are still high ($R^2 \geq 0.946$). In Figure 3.6(b) there are 44 outlier ratings, 11 of which exceed two standard deviations from one-to-one correlation, and in Figure 3.6(d)

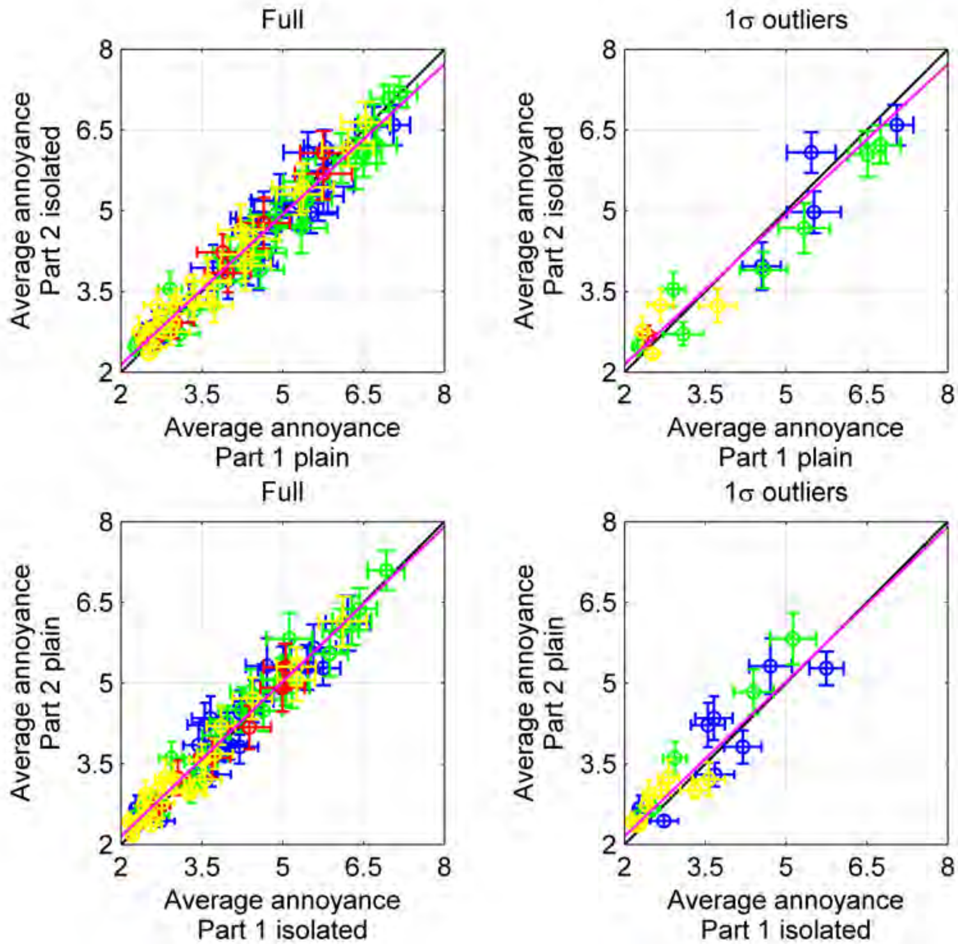


Figure 3.5. Average annoyance ratings given by subjects who first sat in the (a) plain chair, (c) isolated chair. (b) and (d) contain ratings from (a) and (c) that are more than one standard deviations away from one-to-one correlation. For information on color-coding, error bars, and subdivision of the axes, see Page 25.

there are 54 outlier ratings, 18 of which exceed two standard deviations from one-to-one correlation. From these plots it may be deduced that subjects who sat in the plain chair first were generally more annoyed throughout the test (i.e. not only while they sat in the plain chair), while subjects who sat in the isolated chair first were generally less annoyed throughout the test. Rathsam, Loubeau, and Klos examined these trends in greater detail, concluding (as a result of statistical analysis) that the differences in ratings are indeed significant [41].

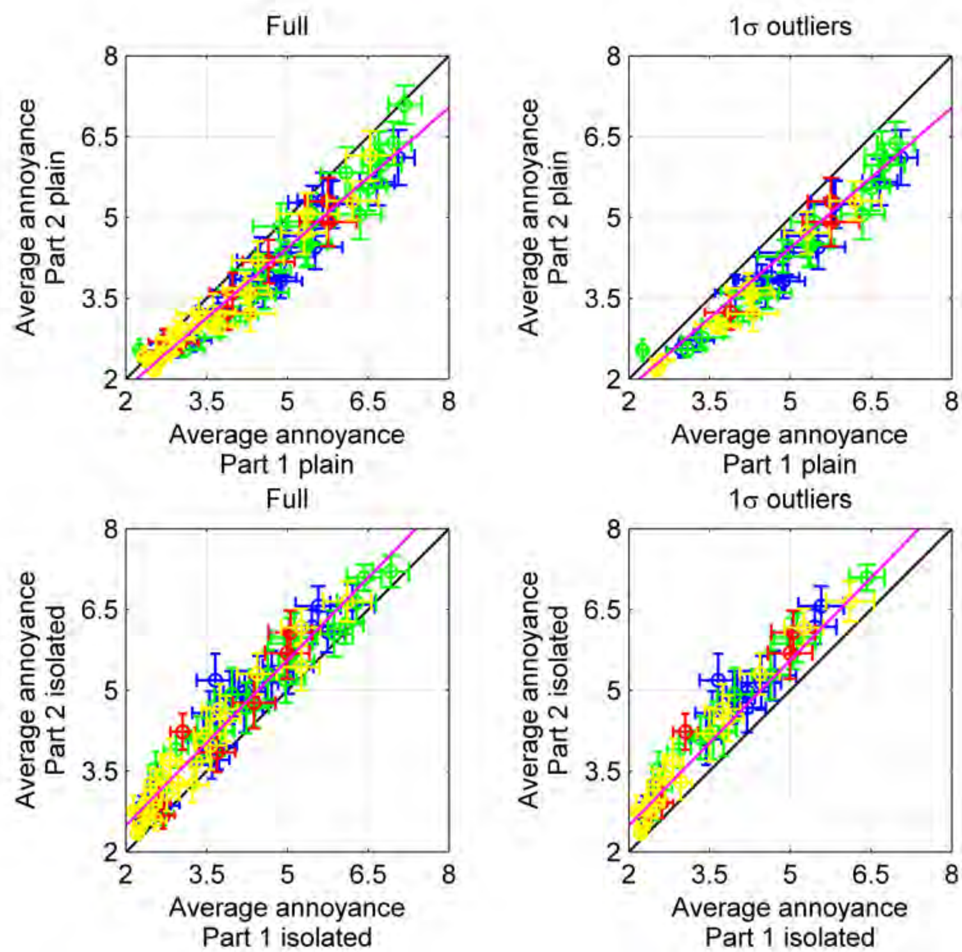


Figure 3.6. Half-test average annoyance ratings plotted against each other for (a) plain chair, $R^2 = 0.955$, (c) isolated chair, $R^2 = 0.946$. (b) and (d) contain ratings from (a) and (c) that are more than one standard deviation away from one-to-one correlation. For information on color-coding, error bars, and subdivision of the axes, see Page 25.

## 3.3 Models of Annoyance

Linear models relating sound metric values to average annoyance ratings were constructed. Various metrics were examined. The metrics used in the final analysis were not calculated for the indoor predicted signals, as had been done when preparing the signals for use in the test (see Section 3.1.1). Rather, the indoor sounds were recorded in the IER at the locations where the subjects sat, and metrics were generated for the actual recorded sounds. The indoor sounds were recorded both with single microphones and with binaural heads, but only the microphone-recorded signals were used when calculating metrics. The binaural head-recorded sounds were recorded during the day at NASA Langley, and thus contained some background noise from the HVAC system and from doors being opened at other places in the laboratory [43]. By contrast, the microphone-recorded signals were recorded at night, and each individual signal was recorded ten separate times and the pressure time histories were averaged. The resulting signals were treated with combination rectangular- and Hann-type windows [44]. Thus, the microphone-recorded signals were judged to be more robust for the purpose of calculating metrics. The metrics calculated and the effectiveness of the models are described below.

### 3.3.1 Description of Metrics

The metrics used in the analysis of the NASA test data that were included in the models described in the following section are listed in Table 3.1. For some of the metrics used in this analysis, multiple versions of the metrics were generated by using various algorithms, and the performance of these metrics in single and in multiple-metric models were compared. The most effective versions of these metrics were then selected for use in the primary analysis. Eight Duration metrics were generated, using four different algorithms applied to both Zwicker and Moore & Glasberg Loudness time histories. The Duration metric finally selected was defined as the time from when the Zwicker loudness first left the noise floor to when it last returned to the noise floor. The noise floor was arbitrarily set to be 0.23 sones. This metric appeared in the model with the highest observed $R^2$ value (a PL-based model). Slightly higher $R^2$ values could be achieved for some of the models using a similar Duration metric based on Moore & Glasberg short-term Loudness rather than Zwicker Loudness. However, these observed increases in $R^2$ value were only within 0.003, and substituting this other Duration metric also decreased the $R^2$ values of some five-metric models by up to 0.004.

Table 3.1. List of major metrics used in examining the NASA test data.

| **Metric** | **Symbol** | **Units** |
|---|---|---|
| Stevens' Perceived Level | PL | dB |
| Maximum Zwicker Loudness | $ZN_{max}$ | Sones |
| A-weighted Sound Exposure Level | ASEL | dB |
| Maximum Moore & Glasberg Time-Varying Loudness, short-term | $SN_{max}$ | Sones |
| Maximum Moore & Glasberg Time-Varying Loudness, long-term | $LN_{max}$ | Sones |
| Maximum Zwicker Loudness Derivative | $dZN_{max}$ | Sones/second |
| Maximum M&G short-term Loudness Derivative | $dSN_{max}$ | Sones/second |
| Maximum M&G long-term Loudness Derivative | $dLN_{max}$ | Sones/second |
| Maximum von Bismarck Sharpness | $S_{Zmax}$ | Acum |
| Duration | Dur | Seconds |
| Heaviness | H | dB |
| M & G short-term Loudness exceeded 20% of the time | $SN_{20}$ | Sones |
| M & G short-term Integrated Loudness | $SN_E$ | Sones $\cdot$ second |

Integrated Loudness and Percentile Loudness ($N_p$ Loudness exceeded $p$% of the time) metrics were generated based on both Zwicker and Moore & Glasberg Loudness, in the expectation that they might more fully reflect differences in the energy content of the signals than would maximum Loudness. Integrated Loudness metrics were generated by integrating the Loudness time histories of the sounds over the time interval where the loudness exceeded half of the maximum Loudness value. Because the sounds used in the NASA test were transient, Percentile Loudness metrics were calculated within the duration of each sound, which was specified using the Duration metrics. They were generated in 5% increments from 5% to 50%. The Percentile Loudness metric used most in this analysis was based on the Duration metric using the same algorithm as the accepted Duration metric, but applied to the Moore & Glasberg Loudness time histories (as opposed to the Zwicker Loudness time histories). Moore & Glasberg short-term Loudness exceeded 20% of the time ($SN_{20}$) was specifically selected because of the high correlation of five-metric models in which it was used (discussed in the following section), and because it was the lowest percentile for which this high correlation could be achieved (this criterion was used because in general practice, Percentile Loudness metrics are calculated for lower percentage values, around 5-10%). Moore & Glasberg short-term Integrated Loudness ($SN_E$) was also chosen for the higher correlations of the five-metric models in which it was used. Additional information about the metrics generated, including metrics that were considered but discarded, may be found in Appendix A.

Maximum Sharpness ($S_{max}$) was calculated prior to the Duration metric used in the analysis. Since the metrics were calculated from averaged and windowed pressure time histories, there was already a rough duration period “built into” the signals, and very little background noise. So the values generated by the $S_{max}$ metric do reflect the actual signal characteristics, even though the duration period of the signals was not defined by a Duration metric while $S_{max}$ was being calculated.

Correlations between metrics of the same source sounds recorded at different subject locations are generally high. Loudness metrics and the Heaviness metric have $R^2$ values of 0.960 or higher, and the correlations are close to one-to-one. Loudness Derivative metrics have $R^2$ values of 0.928 or higher, but the correlations of

$dZN_{max}$ and $dSN_{max}$ are not as close to one-to-one. $S_{max}$ is the least correlated, with an $R^2$ value of 0.750, and the best-fit line generally predicts higher $S_{max}$ values for isolated-chair sounds than for plain-chair sounds. Duration has an $R^2$ value of 0.915 total, and 0.832 with Sounds 22 and 56 excluded (Sounds 22 and 56 are unique in that they contain secondary as well as primary booms, and thus have noticeably longer durations than do all other signals).

### 3.3.2 Regression Models

$R^2$ values for models of single metrics are listed in Table 3.2. PL, $ZN_{max}$, and ASEL are the three most highly correlated metrics, followed by the four Moore & Glasberg Loudness metrics, and then by the three loudness derivative metrics. It is notable that the $R^2$ value of a $ZN_{max}$ model of annoyance exceeds the $R^2$ values of $LN_{max}$ and $SN_{max}$ models by 0.223 and 0.298, respectively. This behavior is contrary to Marshall's results for outdoor booms [19], that maximum Moore & Glasberg Time-Varying Loudness is more highly correlated to annoyance than are either $ZN_{max}$ or ASEL. However, this behavior is at least partially due to a small number of outliers in the $LN_{max}$ and $SN_{max}$ models. These outliers are for synthetic booms from NASA Langley, generated from two source signals. The sounds were treated with 27-Hz or 45-Hz-centered bandpass filters but have no additional high-pass filtering. They have relatively high spectral peaks in the 25-40 Hz range, and were played back at medium to high amplitude. Removing the outlier signals decreases the difference in $R^2$ values between maximum Moore & Glasberg Loudness models and the $ZN_{max}$ model to 0.104-0.183. The $SN_{20}$ and $SN_E$ models have outliers corresponding to some of the same sounds, and a few outliers corresponding to two other sounds: a recorded boom with both primary and secondary shocks (prepared by Purdue), and a synthetic boom with a wide spectral peak at 5-10 Hz (prepared by NASA Langley). Removing these outlier signals decreases the difference in $R^2$ values between $SN_{20}$ and $SN_E$ models and the $ZN_{max}$ model to 0.062-0.147.

Table 3.2. $R^2$ values for single-metric models in NASA test. Metric acronyms are given in Table 3.1.

| **Metric** | **$R^2$ (all 160 signals)** | **$R^2$ (# outliers removed)** |
|---|---|---|
| PL | 0.840 | |
| $ZN_{max}$ | 0.805 | |
| ASEL | 0.795 | 0.88 (12) |
| $LN_{max}$ | 0.582 | 0.701 (8) |
| $SN_{max}$ | 0.507 | 0.622 (8) |
| $SN_{20}$ | 0.521 | 0.721 (15) |
| $SN_E$ | 0.662 | 0.790 (11) |
| $dLN_{max}$ | 0.492 | |
| $dZN_{max}$ | 0.492 | |
| $dSN_{max}$ | 0.450 | |
| Dur | 0.505 | |
| $S_{max}$ | 0.011 | |
| H | 0.006 | |

The investigation of multiple-metric models was primarily focused on models combining a single Loudness metric with one or more other metrics, including no more than one Loudness Derivative metric. $R^2$ values for these models are significantly higher than those of single-metric models, as shown by comparing results in Tables 3.3 and 3.4. PL-based models still have the highest observed correlations, followed by ASEL- and $ZN_{max}$-based models, and then by Moore & Glasberg-based models. One interesting detail is that as the number of metrics in the model is increased, ASEL-based models eventually surpass $ZN_{max}$-based models and have nearly the same $R^2$ values as do PL-based models. Also noteworthy is that the $R^2$ value differences between models based on different loudness metrics are significantly smaller.

Table 3.3. $R^2$ values of multiple-metric models containing PL, $ZN_{max}$, and ASEL in NASA test. Metric acronyms are given in Table 3.1.

| **Metrics** | $\mathbf{R^2}$ |
|---|---|
| PL | 0.840 |
| PL, H | 0.879 |
| PL, H, $dZN_{max}$ | 0.901 |
| PL, H, $dZN_{max}$, $S_{max}$ | 0.911 |
| PL, H, $dZN_{max}$, $S_{max}$, Dur | 0.924 |
| $ZN_{max}$ | 0.805 |
| $ZN_{max}$, Dur | 0.866 |
| $ZN_{max}$, Dur, H | 0.891 |
| $ZN_{max}$, Dur, H, $S_{max}$ | 0.898 |
| $ZN_{max}$, Dur, H, $S_{max}$, $dZN_{max}$ | 0.902 |
| ASEL | 0.795 |
| ASEL, H | 0.861 |
| ASEL, H, $S_{max}$ | 0.891 |
| ASEL, H, $S_{max}$, Dur | 0.914 |
| ASEL, H, $S_{max}$, Dur, $dZN_{max}$ (or $dSN_{max}$) | 0.917 |

The annoyance models in Tables 3.3 and 3.4 were selected by using the following procedure:

1. All possible five-metric models based on a specific Loudness metric (within the criteria noted above) were generated, and the model with the highest correlation was selected.

Table 3.4. $R^2$ values of multiple-metric models containing $LN_{max}$, $SN_{max}$, $SN_{20}$, and $SN_E$, NASA test results. Metric acronyms are given in Table 3.1.

| **Metrics** | $\mathbf{R^2}$ | **Metrics** | $\mathbf{R^2}$ |
|---|---|---|---|
| $LN_{max}$ | 0.582 | $SN_{20}$ | 0.521 |
| $LN_{max}$, H | 0.833 | $SN_{20}$, Dur | 0.781 |
| $LN_{max}$, H, Dur | 0.860 | $SN_{20}$, Dur, H | 0.885 |
| $LN_{max}$, H, Dur, $dSN_{max}$ | 0.873 | $SN_{20}$, Dur, H, $S_{max}$ | 0.895 |
| $LN_{max}$, H, Dur, $dSN_{max}$, $S_{max}$ | 0.873 | $SN_{20}$, Dur, H, $S_{max}$, $dSN_{max}$ | 0.900 |
| $SN_{max}$ | 0.507 | $SN_E$ | 0.662 |
| $SN_{max}$, H | 0.753 | $SN_E$, H | 0.838 |
| $SN_{max}$, H, Dur | 0.821 | $SN_E$, H, $S_{max}$ (or Dur) | 0.851 |
| $SN_{max}$, H, Dur, $dLN_{max}$ | 0.825 | $SN_E$, H, $S_{max}$, Dur | 0.873 |
| $SN_{max}$, H, Dur, $dLN_{max}$, $S_{max}$ | 0.827 | $SN_E$, H, $S_{max}$, Dur, $dLN_{max}$ | 0.877 |

2. Of the five metrics in the model selected in step 1, all possible two-metric models containing one Loudness metric and one other metric were examined, and the two-metric model with the highest correlation was selected.

3. All possible three-metric models containing the metrics from the best two-metric model and one other metric were examined, and the three-metric model with the highest correlation was selected.

4. All possible four-metric models containing the metrics from the best three-metric model and one other metric were examined, and the four-metric model with the highest correlation was selected.

As can be seen from Tables 3.3 and 3.4, Heaviness (H) is generally the most effective second metric to add to the annoyance models, resulting in $R^2$ improvements of up to 0.260. This result is counterintuitive, since in Table 3.2 a single-metric model of H has an $R^2$ value of only 0.006. The relative effectiveness of H as a second metric may be caused by one or two things:

1. H is not highly correlated to many of the characteristics of the sounds, but it is highly correlated to those characteristics of the sounds that are not modeled by the Loudness metrics alone (e.g. low-frequency content).

2. Noise on metrics: the Loudness metrics mis-predict the responses to some characteristics of the sounds, and the addition of H to the model corrects the model's handling of those characteristics.

In either case, the effect of H on the annoyance model could be considered as an adjustment to Loudness.

In Tables 3.5-3.8, the estimated coefficients of the linear models are listed. From these tables, it is observed that the range of values for H is in the same order of magnitude as are the ranges of values for the Loudness metrics and ASEL. It is also observed the coefficients for the Heaviness terms in the annoyance models are all within an order of magnitude of the coefficients for the Loudness and ASEL terms. Hence, the term contributions for H are within an order of magnitude of the term contributions for the Loudness metrics and ASEL. This confirms that Heaviness is a significant contributor to annoyance models. $F_{1,154}$ ratios were calculated to determine whether the addition of a fifth metric in these models significantly improved the model fit. All calculated $F_{1,154}$ ratio values are greater than 0.00395, so the null hypothesis may be rejected in all cases with $P < 0.05$ (i.e. the addition of the fifth metric is probably significant) [45]. One detail of particular interest is the difference between the four- and five-metric models based on PL. Given the model-building procedure described beginning on Page 36, it is generally expected that the $R^2$ value of the model will increase by lesser amounts as the model order increases. This is true in every case for the NASA test data except for the transition between the last two PL-based models. The $R^2$ value of the PL-based model increases by 0.010 (1%) with the addition of the fourth metric ($S_{max}$), and by 0.013 (1.3%) with the addition of the fifth metric($Dur$). Hence it appears that adding $Dur$ to the model corrects noise on some or all of the other four metrics.

Figures 3.7 and 3.8 contain plots showing how the performance of the PL- and $SN_{20}$-based annoyance models improve as the number of metrics in the model is increased. Triangular data points represent ratings for sounds recorded at the plain chair, and circular data points represent ratings for sounds recorded at the isolated chair. In Figure 3.7(a), the blue and red data points (which correspond to Purdue-prepared sounds) generally fall into three vertical clusters. This behavior is understandable, given that the Purdue signals were originally generated at three values of PL. In part (b), with the addition of H to the model, the clusters begin to spread. In Figure 3.8(a), which shows the performance of the $SN_{20}$ model, the array of green data points on the extreme left of the graph correspond to versions of a 27-Hz centered band-pass filtered synthetic boom prepared by NASA Langley. As more metrics are added to the $SN_{20}$ model, these points noticeably shift towards the red one-to-one correlation line. The two blue outlier points (above the red one-to-one line) correspond to a recorded boom prepared by Purdue, containing both a primary and a secondary boom. Correlations between the metrics used in these models are shown in Tables 3.9 and 3.10.

Figures 3.9 and 3.10 contain plots showing how the predicted annoyance values change as the number of metrics in the PL- and $SN_{20}$-based models is increased. When $dZN_{max}$ is added to the PL-based model (Figure 3.9(b)), the greatest positive adjustments (on the right of the plot) are for signal recordings at the plain chair that are versions of Sounds 19, 21, 22, and 23. These are all louder sounds prepared by Purdue, with Sounds 19 and 21 being synthetic booms, and Sounds 22 and 23 being recorded booms. When $Dur$ is added to the model (Figure 3.9(d)), the four signals with the greatest positive adjustment are from the plain-chair and isolated-chair versions of Sounds 22 and 56. These sounds were prepared by Purdue and generated from a recorded boom. This boom is the only source signal in the NASA test which includes a

Table 3.5. Coefficients of multiple-metric models containing PL and $ZN_{max}$ in the NASA test. Metric acronyms are given in Table 3.1. Numbers in parentheses (#-#) denote ranges of metric values for the signals.

| **Coefficients of metrics:** | | | | | | $\mathbf{R^2}$ | $\mathbf{F_{1,154}}$ |
|---|---|---|---|---|---|---|---|
| **Intercept** | **PL (dB) (48.3 - 87.0)** | **H (dB) (13.3 - 37.6)** | **dZNmax (sone/s) (21 - 866)** | **$S_{max}$ (acum) (0.221 - 0.826)** | **Dur (s) (0.563 - 1.989)** | | |
| -6.28 | 0.149 | | | | | 0.840 | |
| -7.59 | 0.153 | 0.040 | | | | 0.879 | |
| -6.44 | 0.123 | 0.060 | 0.002 | | | 0.901 | |
| -7.35 | 0.129 | 0.062 | 0.002 | 0.968 | | 0.911 | |
| -7.45 | 0.121 | 0.049 | 0.001 | 1.32 | 0.970 | 0.924 | 25.4 |
| **Intercept** | **$ZN_{max}$ (sone) (2.57 - 33.63)** | **Dur (s) (0.563 - 1.989)** | **H (dB) (13.3 - 37.6)** | **$S_{max}$ (acum) (0.221 - 0.826)** | **$dZN_{max}$ (sone/s) (21 - 866)** | $\mathbf{R^2}$ | $\mathbf{F_{1,154}}$ |
| 1.89 | 0.164 | | | | | 0.805 | |
| 0.646 | 0.133 | 1.73 | | | | 0.866 | |
| -0.025 | 0.145 | 1.37 | 0.034 | | | 0.891 | |
| -0.640 | 0.143 | 1.58 | 0.045 | 0.846 | | 0.898 | |
| -0.704 | 0.130 | 1.38 | 0.045 | 0.765 | 0.001 | 0.902 | 5.60 |

Table 3.6. Coefficients of multiple-metric models containing ASEL in the NASA test. Metric acronyms are given in Table 3.1. Numbers in parentheses (#-#) denote ranges of metric values for the signals.

| **Coefficients of metrics:** | | | | | | $\mathbf{R}^2$ | $\mathbf{F}_{1,154}$ |
|---|---|---|---|---|---|---|---|
| **Intercept** | **ASEL (dB) (39.6-71.6)** | **H (dB) (13.3-37.6)** | $\mathbf{S}_{max}$ **(acum) (0.221-0.826)** | **Dur (s) (0.563-1.989)** | $\mathbf{dZN}_{max}$ **(21-866 sone/s)** ($\mathbf{dSN}_{max}$) **(23-926 sone/s)** | | |
| -4.82 | 0.161 | | | | | 0.795 | |
| -6.69 | 0.171 | 0.054 | | | | 0.861 | |
| -8.21 | 0.180 | 0.061 | 1.69 | | | 0.891 | |
| -7.89 | 0.156 | 0.050 | 1.99 | 1.23 | | 0.914 | |
| -7.38 | 0.143 | 0.058 | 1.82 | 1.06 | 0.001 | 0.917 | 5.95 |
| -7.46 | 0.143 | 0.058 | 1.85 | 1.11 | (0.001) | 0.917 | 4.81 |

Table 3.7. Coefficients of multiple-metric models containing $LN_{max}$ and $SN_{max}$ in the NASA test. Metric acronyms are given in Table 3.1. Numbers in parentheses (#-#) denote ranges of metric values for the signals.

| **Coefficients of metrics:** | | | | | | **$R^2$** | **$F_{1,154}$** |
|---|---|---|---|---|---|---|---|
| **Intercept** | **$LN_{max}$ (sone) (0.73 - 22.25)** | **H (dB) (13.3 - 37.6)** | **Dur (s) (0.563 - 1.989)** | **$dSN_{max}$ (sone/s) (23 - 926)** | **$S_{max}$ (acum) (0.221 - 0.826)** | | |
| 2.37 | 0.199 | | | | | 0.582 | |
| -1.17 | 0.269 | 0.116 | | | | 0.833 | |
| -1.46 | 0.229 | 0.094 | 1.25 | | | 0.860 | |
| -1.43 | 0.316 | 0.086 | 1.39 | -0.002 | | 0.873 | |
| -1.49 | 0.314 | 0.086 | 1.42 | -0.002 | 0.103 | 0.873 | 0.123 |
| **Intercept** | **$SN_{max}$ (sone) (1.00 - 27.71)** | **H (dB) (13.3 - 37.6)** | **Dur (s) (0.563 - 1.989)** | **$dLN_{max}$ (sone/s) (6 - 192)** | **$S_{max}$ (acum) (0.221 - 0.826)** | **$R^2$** | **$F_{1,154}$** |
| 2.43 | 0.166 | | | | | 0.510 | |
| -1.30 | 0.236 | 0.121 | | | | 0.769 | |
| -1.63 | 0.161 | 0.085 | 1.85 | | | 0.821 | |
| -1.70 | 0.265 | 0.088 | 1.96 | -0.015 | | 0.825 | |
| -1.46 | 0.286 | 0.083 | 1.84 | -0.017 | -0.406 | 0.827 | 1.25 |

Table 3.8. Coefficients of multiple-metric models containing $SN_{20}$ and $SN_E$ in the NASA test. Metric acronyms are given in Table 3.1. Numbers in parentheses (#-#) denote ranges of metric values for the signals.

| **Coefficients of metrics:** | | | | | | $\mathbf{R}^2$ | $\mathbf{F}_{1,154}$ |
|---|---|---|---|---|---|---|---|
| **Intercept** | **$\mathbf{SN}_{20}$ (sone) (0.81-20.64)** | **Dur (s) (0.563-1.989)** | **H (dB) (13.3-37.6)** | **$\mathbf{S}_{max}$ (acum) (0.221-0.826)** | **$\mathbf{dSN}_{max}$ (sone/s) (23-926)** | | |
| 2.394 | 0.219 | | | | | 0.521 | |
| -0.179 | 0.168 | 3.10 | | | | 0.781 | |
| -2.03 | 0.241 | 2.28 | 0.082 | | | 0.885 | |
| -2.74 | 0.238 | 2.52 | 0.083 | 1.01 | | 0.895 | |
| -2.85 | 0.278 | 2.83 | 0.075 | 1.11 | -0.001 | 0.900 | 7.06 |
| **Intercept** | **$\mathbf{SN}_E$ (sone $\cdot$ s) (0.22-8.71)** | **H (dB) (13.3-37.6)** | **$\mathbf{S}_{max}$ (acum) (0.221-0.826)** | **Dur (s) (0.563-1.989)** | **$\mathbf{dLN}_{max}$ (sone/s) (6-192)** | $\mathbf{R}^2$ | $\mathbf{F}_{1,154}$ |
| 2.47 | 0.581 | | | | | 0.662 | |
| -0.212 | 0.705 | 0.093 | | | | 0.838 | |
| -0.938 | 0.725 | 0.098 | 1.09 | | | 0.851 | |
| -0.498 | 0.622 | 0.078 | | 0.918 | | 0.851 | |
| -1.57 | 0.621 | 0.081 | 1.46 | 1.23 | | 0.873 | |
| -1.61 | 0.516 | 0.087 | 1.16 | 1.17 | 0.005 | 0.877 | 6.10 |

primary and secondary boom. Hence, it is understandable why the addition of *Dur* to the model would result in significant adjustment in the predicted annoyance values for these four signals. In Figure 3.10, the four signals with the greatest positive adjustments (to the right) in subplot (a) and with the greatest negative adjustments (to the left) in subplot (b) correspond to Sounds 22 and 56 at both chairs. As the other metrics are added, there is a reduction in the size of the adjustments for many of the signals.

Table 3.9. Correlations between metrics for best PL-based model, expressed in $R^2$ values. Numbers in (parentheses) refer to correlations where the correlation coefficient is negative. Metric acronyms are given in Table 3.1.

| | **PL** | **dZN**$_{max}$ | **S**$_{max}$ | **Dur** | **H** |
|---|---|---|---|---|---|
| **PL** | 1 | 0.560 | (0.039) | 0.391 | (0.017) |
| **dZN**$_{max}$ | | 1 | ($4.5\times10^{-4}$) | 0.264 | (0.199) |
| **S**$_{max}$ | | | 1 | (0.122) | (0.023) |
| **Dur** | | | | 1 | 0.027 |
| **H** | | | | | 1 |

Table 3.10. Correlations between metrics for best $SN_{20}$-based model, expressed in $R^2$ values. Numbers in (parentheses) refer to correlations where the correlation coefficient is negative. Metric acronyms are given in Table 3.1.

| | **SN**$_{20}$ | **Dur** | **H** | **S**$_{max}$ | **dSN**$_{max}$ |
|---|---|---|---|---|---|
| **SN**$_{20}$ | 1 | 0.098 | (0.242) | $2.8\times10^{-6}$ | 0.799 |
| **Dur** | | 1 | 0.027 | (0.122) | 0.213 |
| **H** | | | 1 | (0.023) | (0.256) |
| **S**$_{max}$ | | | | 1 | ($1.2\times10^{-4}$) |
| **dSN**$_{max}$ | | | | | 1 |

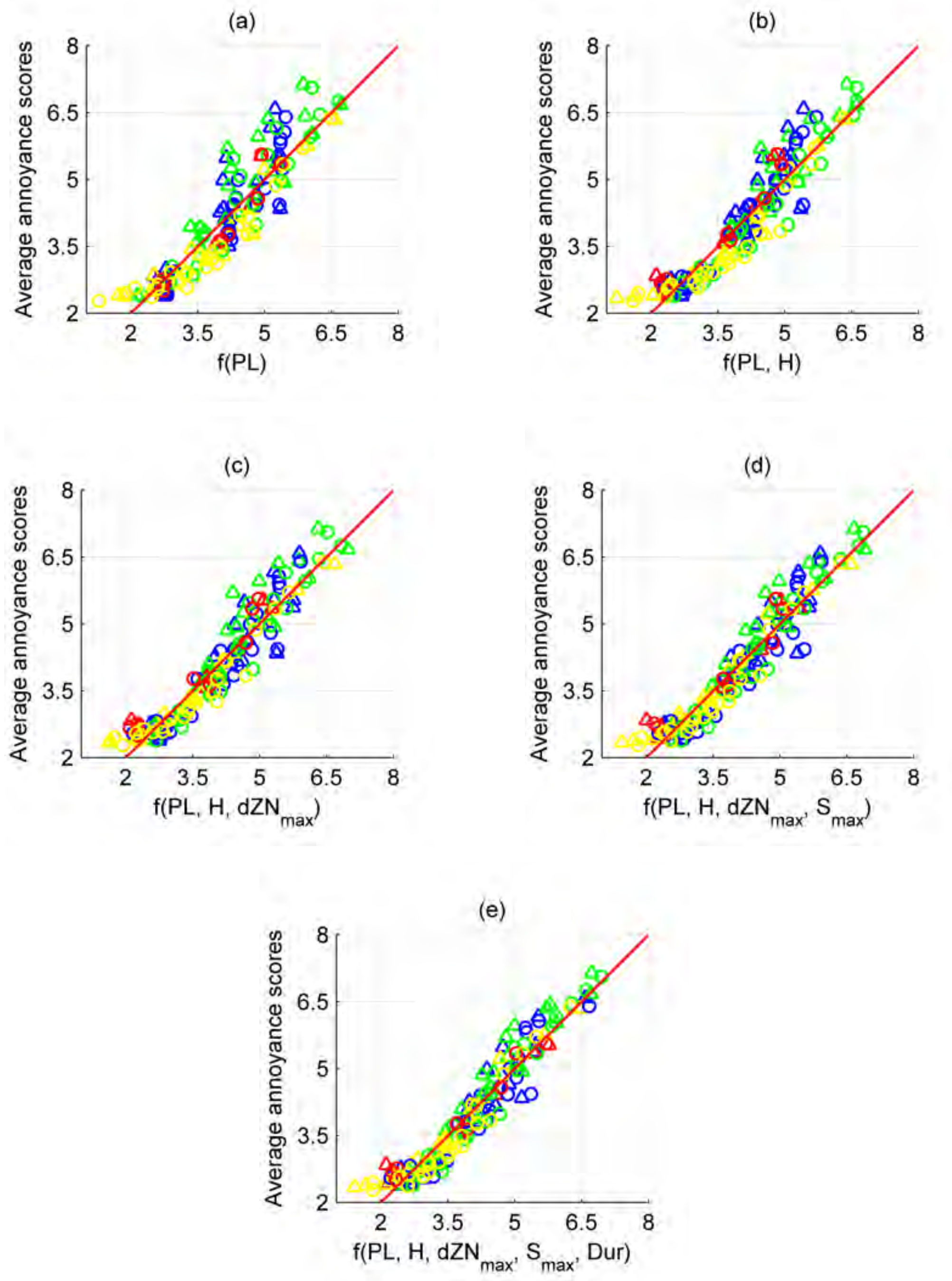


Figure 3.7. Average annoyance ratings from the NASA test plotted against PL-based annoyance models that are functions of (a) 1 to (e) 5 metrics. One-to-one correlation line shown in red. $R^2$ values are: (a) 0.840, (b) 0.879, (c) 0.901, (d) 0.911, (e) 0.924. Metric acronyms are given in Table 3.1. For information on color-coding, error bars, and subdivision of the axes, see Page 25.

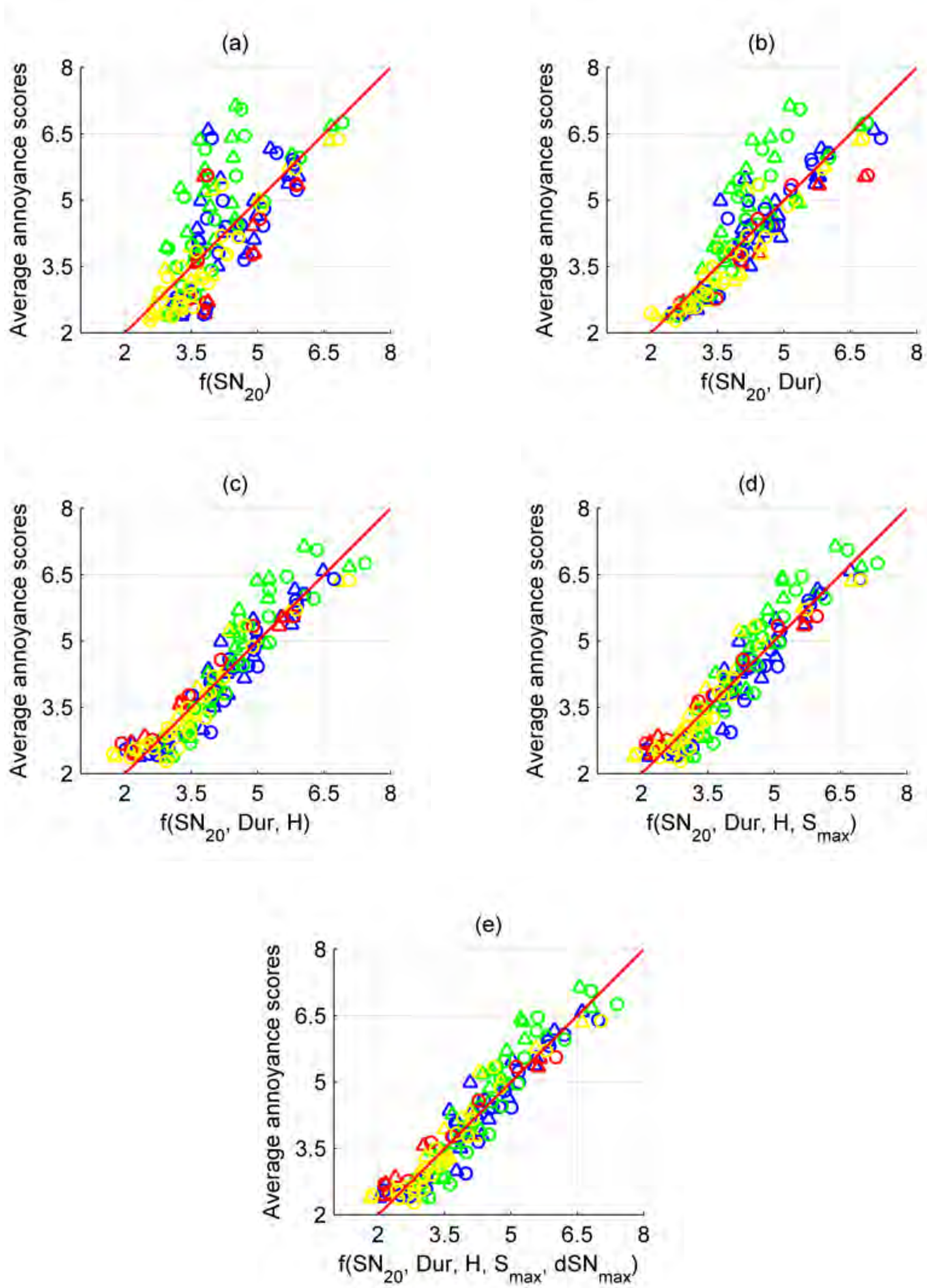


Figure 3.8. Average annoyance ratings from the NASA test plotted against $SN_{20}$-based annoyance models that are functions of (a) 1 to (e) 5 metrics. One-to-one correlation line shown in red. $R^2$ values are: (a) 0.521, (b) 0.781, (c) 0.885, (d) 0.895, (e) 0.900. Metric acronyms are given in Table 3.1. For information on color-coding, error bars, and subdivision of the axes, see Page 25.

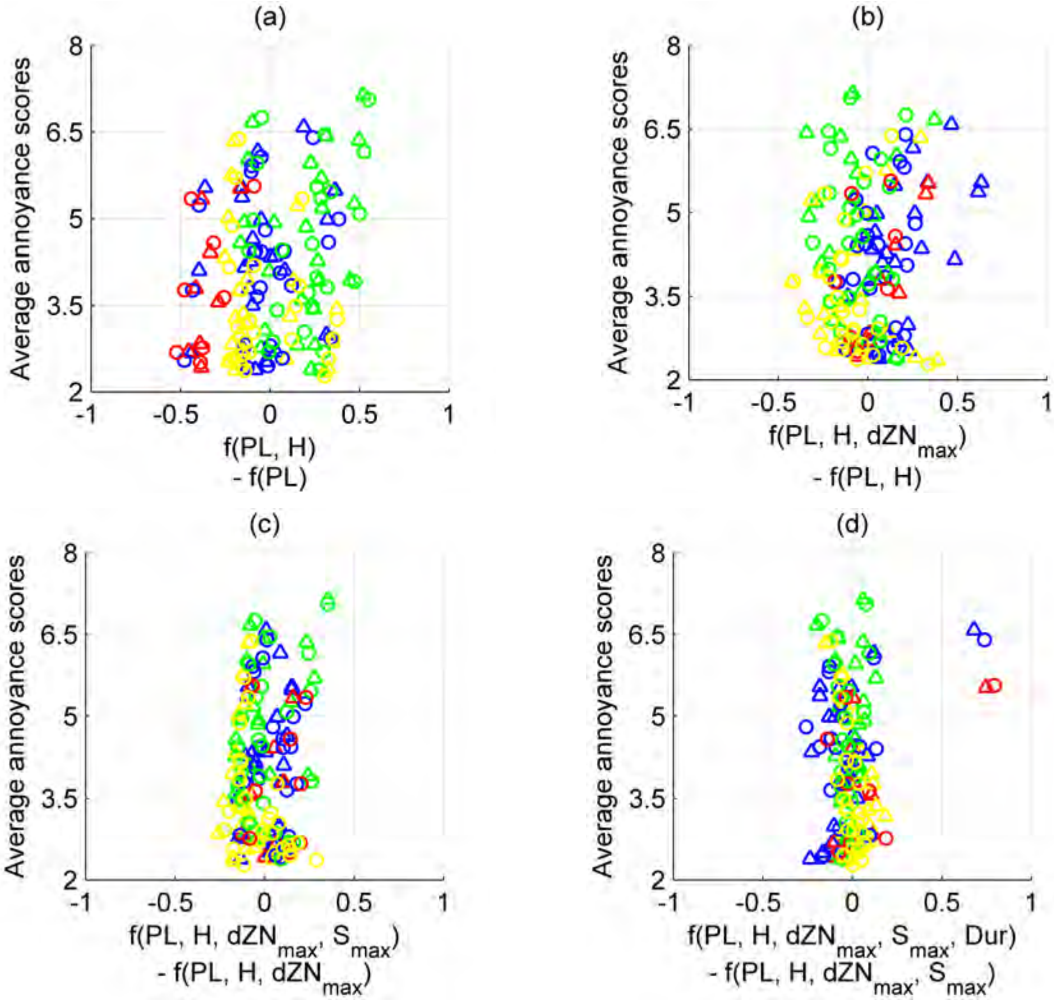


Figure 3.9. Average annoyance ratings from the NASA test plotted against adjustments in predicted values of PL-based annoyance models as additional terms are added to the model. Metric acronyms are given in Table 3.1. For information on color-coding, error bars, and subdivision of the annoyance axis, see Page 25.

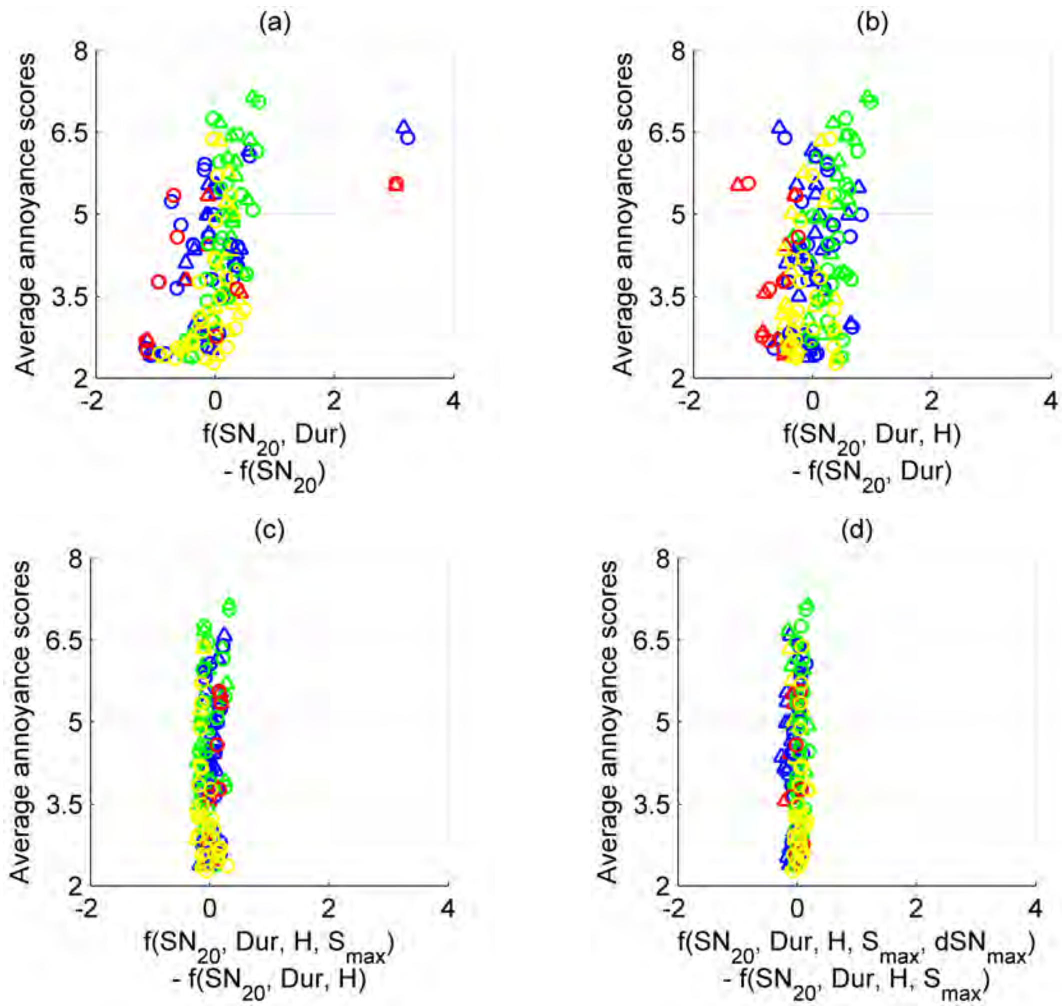


Figure 3.10. Average annoyance ratings from the NASA test plotted against adjustments in predicted values of $SN_{20}$-based annoyance models as additional terms are added to the model. Metric acronyms are given in Table 3.1. For information on color-coding, error bars, and subdivision of the annoyance axis, see Page 25.

### 3.3.3 Examination of Outliers in Regression Models

In the best-fit PL-based five-metric model shown in Figure 3.7(e), there are two signals (blue data points) for which the model clearly over-predicts the annoyance. These correspond to the plain- and isolated-seat versions of Sound 20, a loud synthetic boom contributed by Purdue, and scaled so that the original outdoor sound has a PL of 78 dB. The spectra and loudness time histories of these sounds are plotted in Figure 3.11, superimposed on the spectra and loudness time histories of Sound 16, a car door slam sound with similar Loudness signature shape and spectral characteristics. (The average annoyance ratings for Sound 16 are up to 0.64 units greater than the average annoyance ratings of Sound 20, although Sound 16 is not an outlier.) The Loudness time histories of Sound 16 have been scaled to match the magnitude of the Sound 20 Loudness time histories, to allow for easier comparison of the signature shapes. The spectra have not been scaled.

As may be seen in these figures, the Loudness time histories of Sound 20 are distinguishable by a small bump on the beginning. In his doctoral thesis, Marshall [20] discusses the phenomenon of *pre-pulse inhibition*, in which a small pulse before the main event of the signal causes the subject to anticipate the main event, thus reducing the subject's startle. Given Marshall's previously noted conclusion that startle and annoyance are highly correlated for outdoor booms (see Chapter 1.1.2), the presence of pre-pulse inhibition may result in a reduced annoyance rating as well. Hence, it may be that pre-pulse inhibition caused the discrepancy in annoyance ratings for Sound 20.

The Loudness Derivative metrics in the annoyance models were defined in a manner intended specifically to account for pre-pulse inhibition effects. Since the subject's response to a transient sound seems largely dependent on the initial pulse, the maximum Loudness derivative was taken within the interval between the signal first leaving the noise floor and the signal's first Loudness peak. However, since the Loudness pre-pulse on Sound 20 does not reach a peak before the main event, the

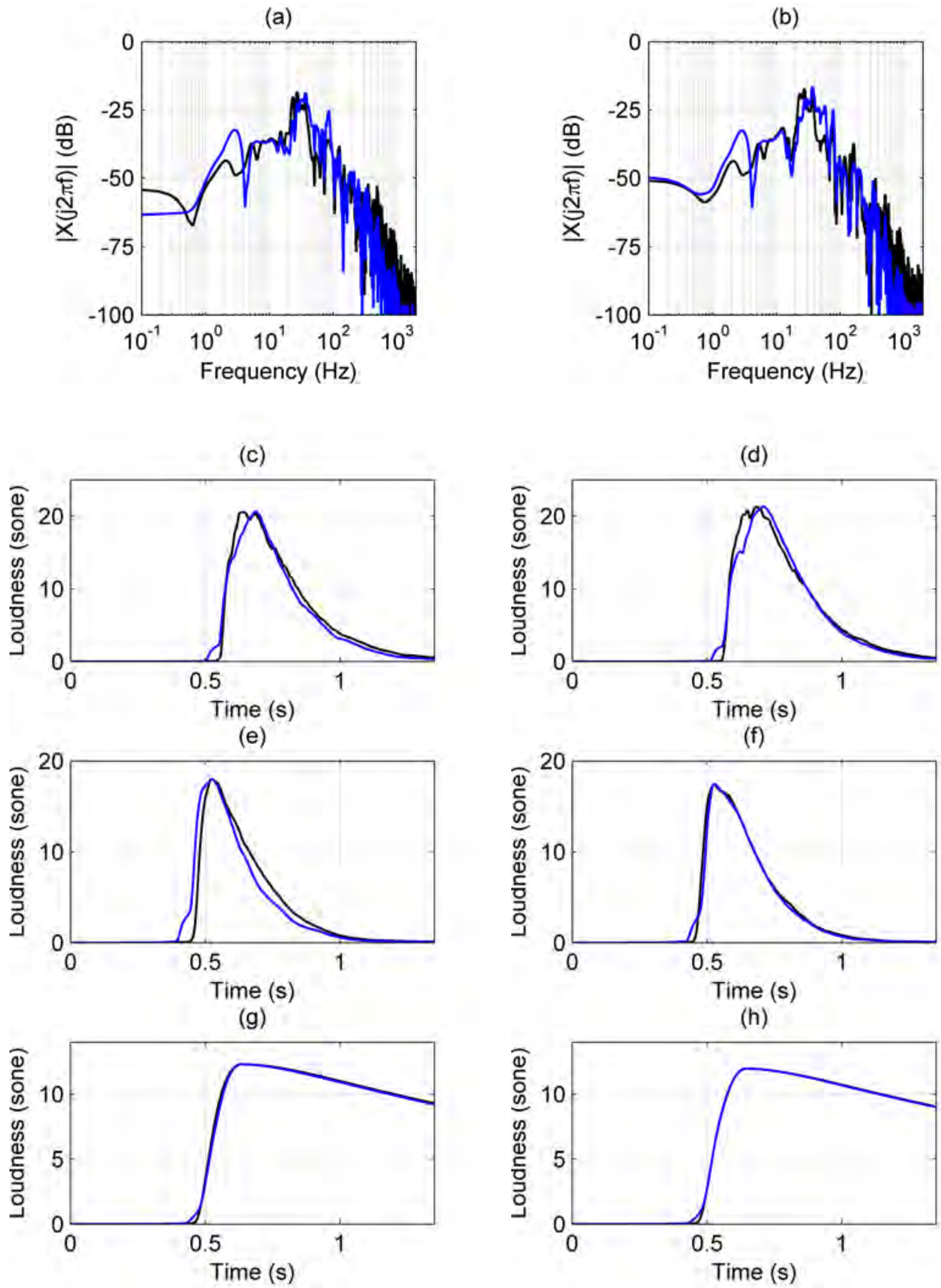


Figure 3.11. Characteristics of Sounds 20 (blue) and 16 (black): (a-b) spectra, (c-d) Zwicker Loudness, (e-f) short-term Moore & Glasberg Loudness, (g-h) long-term Moore & Glasberg Loudness. (a, c, e, g) plain-seat sounds; (b, d, f, h) isolated-seat sounds. Loudness time histories of Sound 16 are scaled; spectra are not.

maximum Loudness Derivative for Sound 20 was defined on the side of the main peak above the pre-pulse. This resulted in a higher maximum Loudness Derivative value than if only the pre-pulse had been considered, which in turn could have caused the annoyance model to over-predict. Since Sound 20 was in fact over-predicted by the five-metric PL-based model, this explanation appears to be plausible.

On the other hand, it should be noted that the annoyance predictions for two quieter synthetic booms with similar pre-pulses do not give rise to outliers. These two "non-outlier sounds" are Sounds 6 and 13. Sound 6 is generated from the same source signal as is Sound 20, and is scaled so that the original outdoor signal has a PL of 60 dB. Sound 13 is generated from a different source signal, has greater spectral content in the 7-20 Hz range, and was scaled to produce an outdoor PL of 70 dB.

In the best-fit $SN_{20}$-based five-metric model 3.8, the two greatest outlier predictions are for Sounds 31 and 40, heard at the plain chair (marked with green triangles in the figure). The predictions for these sounds are smaller than the average annoyance ratings. These sounds are both medium-loud to loud synthetic booms contributed by NASA Langley, with high frequency peaks at 27 and 45 Hz respectively. The spectra and loudness time histories of these two sounds are plotted in Figure 3.12, along with two sounds for which the model did not significantly over- or under-predict the average annoyance ratings. These "non-outlier sounds" are Sounds 29 and 37 at the plain chair, which are generated from lower-amplitude versions of the same outdoor source signals as Sounds 31 and 40, respectively. The Loudness time histories of the non-outlier sounds have been scaled, but the spectra have not been scaled.

In the Zwicker Loudness time histories of these sounds, the peaks are rounded and widely separated by a round trough. In the short-term Moore & Glasberg Loudness time histories, the peaks and troughs are much more dramatic but equally spread out. The peaks of Sounds 37 and 40 and the trough of Sound 31 are round similar to those in the Zwicker Loudness time histories, whereas the peaks of Sounds 31 and 29 and the troughs of Sounds 29, 37, and 40 are more sharp. The Moore & Glasberg Loudness time histories of all four sounds also have small pre-pulses before the first main peak;

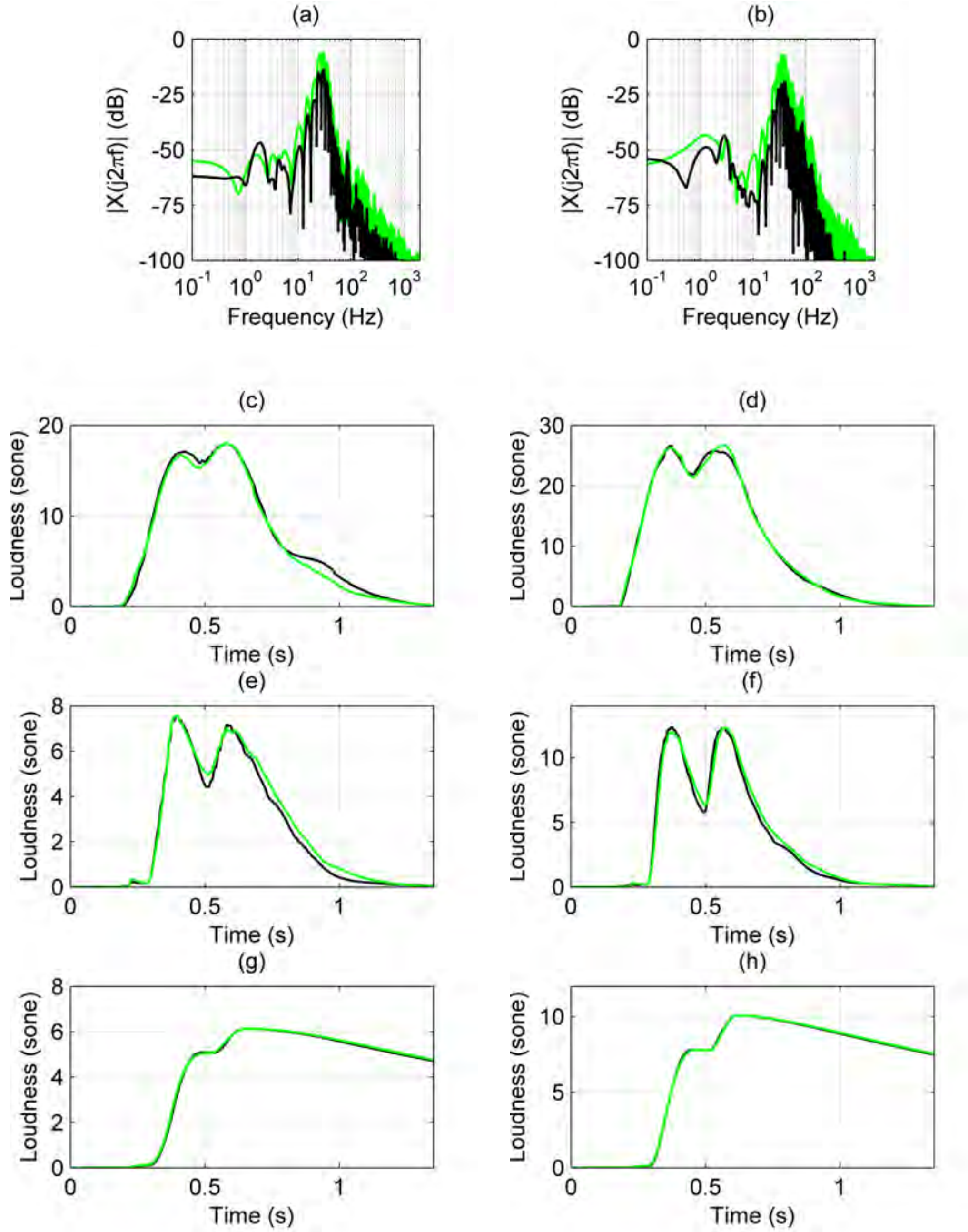


Figure 3.12. Characteristics of two outlier sounds (green) and two non-outlier sounds (black) from the five-metric $SN_{20}$-based model: (a-b) spectra, (c-d) Zwicker Loudness, (e-f) short-term Moore & Glasberg Loudness, (g-h) long-term Moore & Glasberg Loudness. (a, c, e, g) Sound 31 plain (outlier) and Sound 29 plain; (b, d, f, h) Sound 40 plain (outlier) and Sound 37 plain. Loudness time histories of Sounds 29 and 37 are scaled; spectra are not.

but since these pre-pulses are less than 0.5 Sones, they may be insignificant. It is possible that these pre-pulses are an artifact of the signal processing, since they are not present in the Zwicker Loudness time histories.

In comparing the outliers (green lines in the plots) with the non-outliers (black lines in the plots), a few differences are recognizable. In Figure 3.12(c), the Zwicker time history for Sound 29 (non-outlier) has a bump on the trailing end, whereas the trailing end of Sound 31 is smoother. In Figure 3.12(e) and 3.12(f), the short-term Moore & Glasberg Loudness time histories of Sounds 29 and 37 seem slightly rougher on the trailing ends than do those of Sounds 31 and 40. Also in Figure 3.12(e), the short-term Moore & Glasberg Loudness peaks are proportionally more different in height for Sound 29 than for Sound 37. It should additionally be noted that although Sound 40 is the loudest version of its particular source signal, Sound 31 is not. Sound 32 is a louder sound generated from the same source signal as is Sound 31, but Sound 32 is significantly less under-predicted than is Sound 31. Hence, it is unclear what causes Sound 31 to be an outlier. However, the greatest differences between the outlier and non-outlier sounds are seen in the Moore & Glasberg short-term Loudness time histories.

## 3.4 NASA Test Summary

In this chapter, a test conducted in NASA Langley's Interior Effects Room (IER) was described. First, the format of the test, the signals, and the test facility and equipment were described. Second, the results of the test were presented, and the conclusion was made that some strong ordering effects are present in the annoyance ratings. Third, annoyance models that are linear combinations of metrics were examined.

Subjects' annoyance ratings are significantly different depending on which chair they occupied first. This may be due to differences in vibration exposure. However, as Rathsam, Loubeau, and Klos state, the effects of vibration on annoyance in this test are uncertain, due to transfer bias resulting from the switching of chairs during the test. Hence, further experimentation is needed to quantify vibration effects. [41].

Of the annoyance models examined, models containing Perceived Level (PL) are the most highly correlated with average annoyance ratings, with the highest $R^2$ value (0.924) for a five-metric model. A five-metric ASEL-based model has the second highest $R^2$ value. This is interesting given that A-weighted filtering omits much of the low-frequency energy in the test signals. However, since the five-metric model includes Heaviness (which is the difference between C-weighted and A-weighted Sound Exposure Level), this increase in $R^2$ value may not be so unexpected.

In order to more thoroughly distinguish between the effects of different parameters on annoyance, it may be helpful to design a test in which the same or similar indoor sounds from the NASA test are played back in a vibration-less environment.

# 4. TEST CONDUCTED WITH EARPHONES

The second test was performed in the Sound Quality booth at Herrick Laboratories, Purdue University. It was designed for a more general examination of subjects' annoyance reactions to sounds, without extremely low frequency content or vibration. The Sound Quality booth is an IAC double-walled sound chamber [19] equipped with a small desk holding a computer screen, keyboard, and mouse. Sounds are played using a desktop computer (located outside the booth) with a LynxONE sound card. Amplification is controlled by a Furman SP-20AB stereo amplifier; and playback is done over Etymotic ER-2 research earphones, which can accurately reproduce sounds (played at the levels in this test) down to around 25 Hz [5].

## 4.1 Purdue Test Experimental Methodology

The format of this test was very similar to the format of the first test in NASA Langley's IER. The test was conducted in two parts, each consisting of a parametric test with eighty sounds. However, the sounds in Parts 1 and 2 were slightly different. The test was administered by using Kyoung Hoon Lee's *SubjTest* software, which automatically randomized the playback order of the sounds. However, unlike in the NASA test, a different random playback order was used in each part, and playback orders were different for each subject (rather than for each pair of subjects).

Subjects were tested one at a time. Upon first arriving at the test facility, subjects read and signed the IRB-approved consent form for the test (Protocol # 1405014868), and filled out a questionnaire detailing their basic background information, awareness of sound quality and noise control, and experiences of noisy environments. A hearing check was then administered in the sound booth. Subjects exhibiting hearing thresholds $\leq$ 20 dB in all octave bands from 125 to 8000 Hz were admitted to the test. Subjects who did not pass the hearing check were compensated \$5 and given contact information for Purdue's Audiology Clinic, and the test run was terminated.

Accepted subjects were given earphones and a sheet of test instructions. The test instructions described annoyance with the synonyms "unpleasant, irritating, disturbing, unwanted, worrisome, or objectionable". SUbjects were asked to "imagine [themselves] in [their] house or in [their] office hearing these sounds several times during the day." After receiving the test instructions, subjects completed a familiarization session listening to ten sounds and a practice rating session with six sounds. The test operator was in the booth for the familiarization and practice sessions. The test operator then left the booth, and Part 1 was administered, following which a short break was given, and then Part 2 was administered. After completing Part 2, subjects were asked to write down their comments about the test, given a second hearing test, and compensated \$10.

Subjects entered their annoyance ratings on the desktop computer, using a scale (shown in Figure 4.1) that went from "not at all annoying" to "extremely annoying". Input was done using a keyboard and a mouse. The slider (represented by a red cross in Figure 4.1) appeared in the middle of the scale for the first rating. For each subsequent rating, the slider appeared in the place where the subject had put it for the previous rating. This was a precautionary measure to guard against biasing of subjects' ratings. Also, the ends of the scale extended slightly beyond the outer tick marks to prevent saturation.

### 4.1.1 Purdue Test Sounds

One hundred sixty sounds were used for the test. These sounds were derived from the indoor sounds heard by subjects in the previous test in the IER at NASA Langley. Part 1 of the test contained eighty sounds made from recordings at the non-isolated seat in the IER. Five sounds were made from recordings using binaural heads, and the rest were made from recordings using single microphones. Part 2 contained eighty

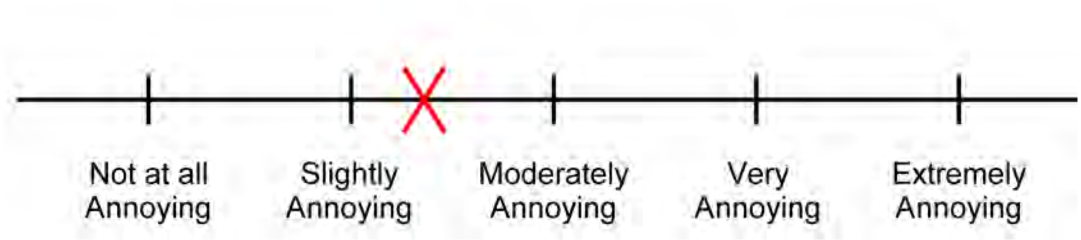


Figure 4.1. Rating scale used in the Purdue test. The tick marks were assigned numerical values of 2.0, 3.5, 5.0, 6.5, and 8.0 (from left to right). The endpoints of the scale were assigned numerical values of 1 and 9.

sounds corresponding to the isolated seat in the IER. Five sounds were made from binaural-head recordings; five were generated directly from the outdoor source signals using the revised version of Giacomoni's simulation code; and the remaining seventy were made from single-microphone recordings (ten recordings were made of the playback of each sound in the IER, and these were averaged to produce the sound used in the Purdue test). All sounds were filtered with a 3rd-order Butterworth 25-Hz high-pass filter to prevent overloading of the playback system. Also, since the sounds were to be reproduced directly inside the subject's ear canals with earphones, a filter was applied to approximate the spatial effects of the ear on the sounds [46]. The order of the parts was not varied. (A detailed description of the procedure used to generate the simulated sounds may be found in Appendix B).

The binaural recordings and simulations were included expressly for the purpose of comparison with the corresponding single-microphone recordings for the same source sound at the same IER location. Because of this, five of the original eighty non-isolated-seat recordings and ten of the original eighty isolated-seat recordings were removed from the test to keep the number of sounds at eighty per part.

One particular challenge in windowing the sounds for the Purdue test was that some of the initial attempts at windowing produced signals that did not sound natural at the ends. There would be squeaking or crackling noises, mostly on the trailing ends, but occasionally on the leading ends of the sounds. One possible source of this behavior is quantization noise, since the apparatus in the Herrick Sound Quality booth could only play back 16-bit files. To prevent these unnatural noises, small adjustments were made to the length and placement of the ramps on the ends of each sound. Additionally, the end regions of some sounds were modeled using a linear prediction algorithm, and the predicted models were spliced onto the ends of the sounds. (A detailed description of the windowing and linear prediction procedure may be found in Appendix E).

### 4.1.2 Purdue Test Subjects

Thirty-five subjects from Purdue and the greater Lafayette, Indiana area were recruited for the test. The subject pool consisted of twenty-one females and fourteen males, aged 18-58. The average age was 25 and the median age was 22.

## 4.2 Results and Discussion of the Purdue Test

Much of the material in this and the following section is taken from a conference paper written by the present author [47].

Average annoyance ratings are plotted in Figures 4.2 and 4.3, with the letters H and S marking the ratings for binaural-head and simulated sounds, respectively. Here, as in the NASA test, annoyance generally increases with increasing playback amplitude. It is also observed that annoyance ratings for 50-Hz high-pass filtered sounds are generally either not significantly different or else significantly lower than are ratings for sounds with lower cutoff frequencies. The only exceptions to this rule are the 50-Hz binaural head-recorded signals, in which case the difference between the signals is not only one of filtering but also of the recording method. The differences between responses to microphone-recorded, head-recorded, and simulated signals will be discussed later.

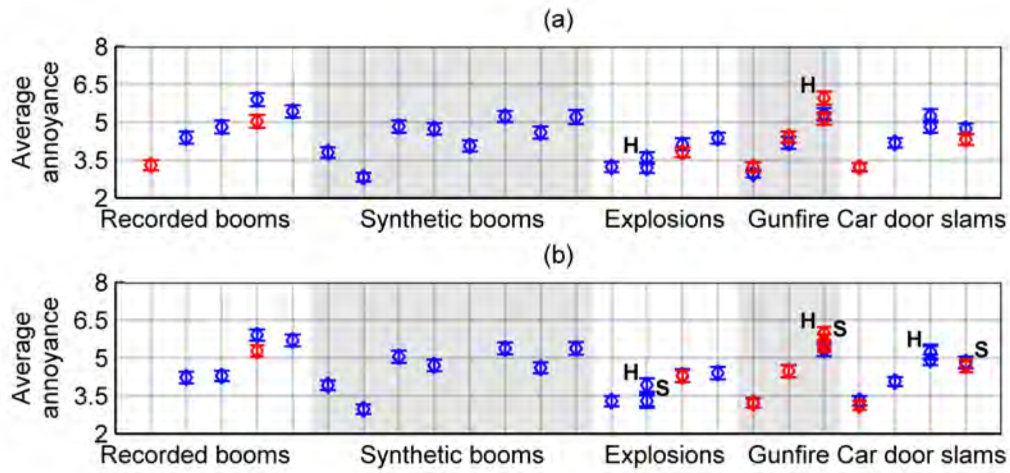


Figure 4.2. Average annoyance ratings for sounds prepared by Purdue, arranged by sound type: (a) Part 1, (b) Part 2. For information on color-coding, error bars, and subdivision of the annoyance axis, see Page 25.

Of the eighty sounds used in each part of the test, seventy-five have a corresponding sound in the other part of the test. For these seventy-five "common "sounds, the average annoyance ratings between Part 1 and Part 2 of the test are highly correlated ($R^2 = 0.967$), and the best-fit line (the magenta line in Figure 4.4 below) is very close to one-to-one correlation. Fifteen ratings are more than one standard deviation away from one-to-one correlation, and only two ratings are more than two standard deviations away. The latter ratings are for single-microphone sounds generated from one recorded boom and one synthetic boom, originally high-pass filtered at 4 or 6 Hz, and played back at medium to high amplitude. These results may indicate that the effects of position in the room on the test results are low. However, since the parts of the test were always presented in the same order, these results do not necessarily discount the presence of ordering effects.

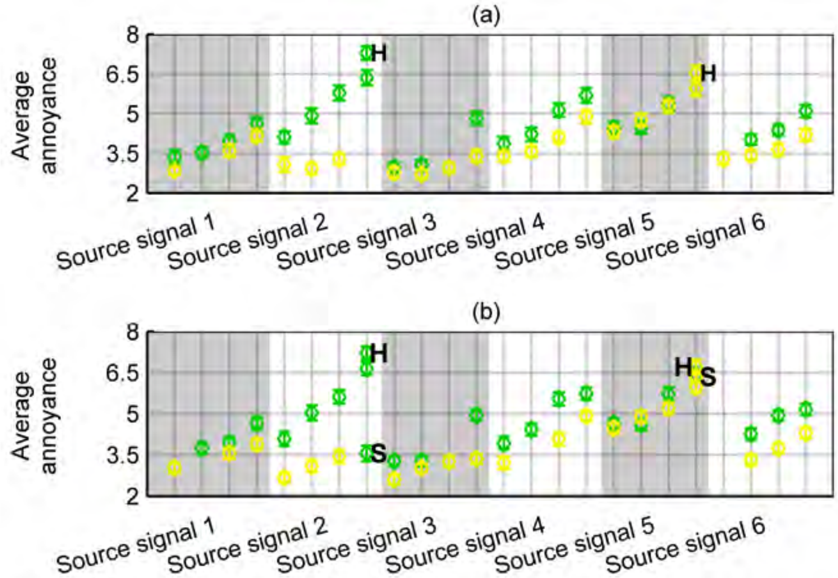


Figure 4.3. Average annoyance ratings for sounds prepared by NASA Langley, arranged by source signal: (a) Part 1, (b) Part 2. For information on color-coding, error bars, and subdivision of the annoyance axis, see Page 25.

The average annoyance ratings for sets of corresponding single-microphone, binaural-head, and simulated sounds are shown in Figure 4.5. The letters M, H, and S in the x-axis labels denote the respective recording methods, while the numbers refer to the master number of the sound (as assigned in the NASA test). The average annoyance ratings for binaural-head sounds are significantly higher than the average annoyance ratings for single-microphone sounds in 7 out of 10 cases. The average annoyance ratings for binaural simulated sounds are not significantly different from the average annoyance ratings for single-microphone sounds except in the case of Sound S32, and are not significantly different from the average annoyance ratings for binaural-head sounds except in the case of sounds S32 and S05. Sound 32 was one of the louder sounds supplied by NASA Langley, and was generated from a synthetic boom treated with a band-pass filter (with a center frequency of 27 Hz). The binaural simulated version has noticeably less high-frequency content than do either the single-microphone or binaural-head versions in Part 2. Sound 5 was one of the quieter

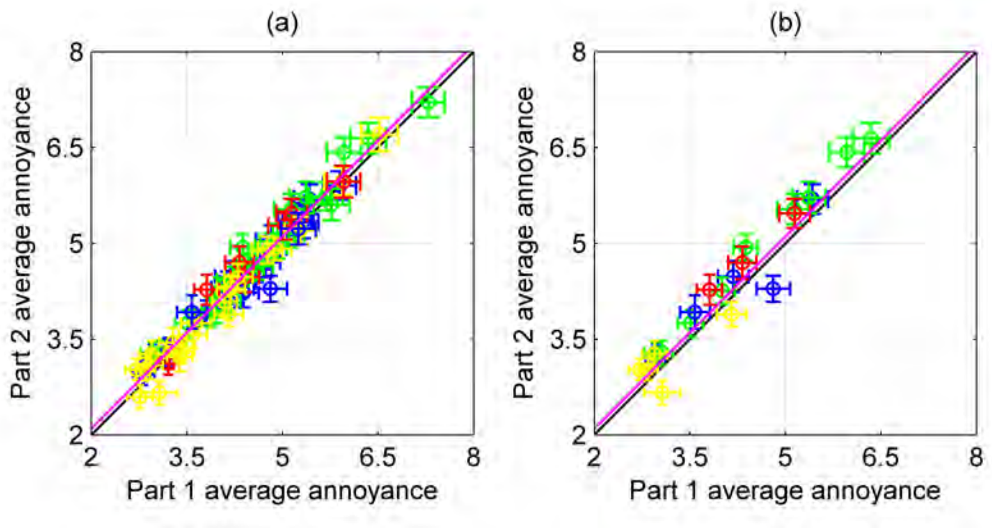


Figure 4.4. Average annoyance ratings for Part 2, plotted against average annoyance ratings for Part 1: (a) full plot, (b) outliers. For information on color-coding, error bars, and subdivision of the axes, see Page 25.

booms prepared by Purdue, and was generated from a recorded blast. Again, the binaural simulated sound has less high-frequency content than do the binaural-head or microphone recorded signals, but the difference (apart from what seems to be some high-frequency background noise in the binaural-head recorded signal) is not as great. Also, the binaural-head recorded sound has a wide spectral peak at around 25-60 Hz, whereas the simulated sound has a thinner spectral peak at around 40-50 Hz.

## 4.3 Models of Annoyance

In order to generate metrics for the Purdue test, the one hundred sixty signals were played in the Sound Quality booth and recorded, and the metrics were calculated from the recordings. Recordings were made using a HEAD Acoustics SQuadriga mobile recording system and a Brüel & Kjær Type 4942 1/2-inch microphone, attached to a single earphone using a Brüel & Kjær Type 4946 coupler and an ER1-07 adapter. Recordings were made for both earphones, and were treated with an inverse ear filter

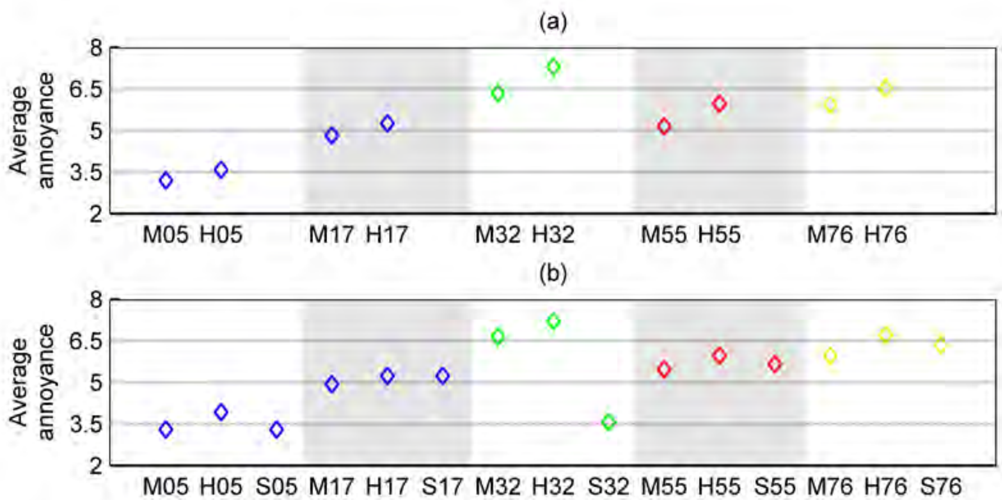


Figure 4.5. Average annoyance ratings for groups of microphone, binaural head, and simulated signals: (a) Part 1, (b) Part 2. Standard deviations of the estimated means are in the range (a) 0.211 to 0.287, (b) 0.205 to 0.294. For information on color-coding and subdivision of the annoyance axis, see Page 25.

to remove the effects of the ear filter used during preprocessing (see Section 4.1.1). Metrics were calculated for the signals at each ear, and the resulting values were averaged over both ears to produce the metrics used in the final analysis.

### 4.3.1 Description of Metrics

Metric analysis of the Purdue test data included most of the same metrics used in the NASA test. However, the Duration metric was defined differently. The background noise in the Loudness time histories was more easily visible in the Purdue sounds than in the NASA sounds; and thus the noise floor was calculated from the actual background noise rather than arbitrarily set to the 0.23 sone level used in the NASA test. Most of the best four-metric models in the Purdue test had the same or slightly higher $R^2$ values when Moore & Glasberg-based Duration was used rather than a Zwicker-based Duration similar to the Duration metric used in the NASA test. However, this improvement was generally within 0.002, and in one case resulted in an increase of 0.008. The Zwicker-based Duration metric was retained as the primary Duration metric for the Purdue test analysis, but the more significant $R^2$ value increase due to the Moore & Glasberg-based metric is noted in the text. (For information on alternative definitions of Duration, see Appendix A.) Also, different Integrated Loudness and Percentile Loudness metrics were used. The Integrated Loudness metric used for the Purdue test data was based on Moore & Glasberg long-term Loudness, and divided by the time interval over which the integration was performed (symbol $LN_{Et}$). Moore & Glasberg short-term Loudness exceeded 15% of the time was chosen because of the high $R^2$ value for 4-metric models that included it (see below). Finally, maximum Sharpness was excluded from the analysis. Sharpness time histories were observed to be higher in the background noise than in the actual sounds, with a dip in the general region of the actual sound. The maximum Sharpness point within the duration period of the sound (defined by the Duration metric) was often at or very close to one of the endpoints of the duration period. Hence, it was uncertain whether the numbers returned by the maximum Sharpness metric represented characteristics of the actual sounds, or were simply artifacts of the background noise. This problem had not been encountered when calculating maximum Sharpness for the NASA test signals, because the pressure time histories for those signals had been recorded in a potentially quieter environment, averaged from ten separate recordings (which may additionally have reduced the background noise levels), and windowed. Thus, the Sharpness time histories for the NASA test sounds were zero except during (or very close to) the actual sound. Metrics used in the final analysis of the Purdue test data are listed in Table 4.1.

Metrics calculated for the sounds that have the same origins and were used in the first and second halves of the test are highly correlated. Loudness metric correlations between the first and second parts of the main test have $R^2$ values of 0.965 or greater, and are near one-to-one. Loudness Derivative metrics have $R^2$ values of 0.916 or greater; $dLN_{max}$ is close to one-to-one, while values of $dSN_{max}$ and $dZN_{max}$ are often

Table 4.1. List of major metrics used in examining the Purdue test data.

| **Metric** | **Symbol** | **Units** |
|---|---|---|
| Stevens' Perceived Level | PL | dB |
| Maximum Zwicker Loudness | $ZN_{max}$ | Sones |
| A-weighted Sound Exposure Level | ASEL | dB |
| Maximum Moore & Glasberg Time-Varying Loudness, short-term | $SN_{max}$ | Sones |
| Maximum Moore & Glasberg Time-Varying Loudness, long-term | $LN_{max}$ | Sones |
| Maximum Zwicker Loudness Derivative | $dZN_{max}$ | Sones/second |
| Maximum M&G short-term Loudness Derivative | $dSN_{max}$ | Sones/second |
| Maximum M&G long-term Loudness Derivative | $dLN_{max}$ | Sones/second |
| Duration | Dur | Seconds |
| Heaviness | H | dB |
| M & G short-term Loudness exceeded 10% of the time | $SN_{10}$ | Sones |
| M & G long-term Time-Divided Integrated Loudness | $LN_{Et}$ | Sones·second |

higher in Part 1 than in Part 2. Duration and Heaviness have $R^2$ values of 0.946 and 0.985 respectively. Loudness metrics for the microphone and binaural recordings are within 0.01-5.2 sones of each other in Part 1, and within 0.02-2.7 sones of each other in Part 2. Loudness metric values for these sounds are in the range 3.6-35.3 sones in Part 1, and 2.2-35.8 sones in Part 2. ASEL values for these sounds are within 0.8 dB of each other in Part 1 and 0.3 dB in Part 2. Loudness metrics are lower for the binaural simulated sounds than for the binaural recorded sounds. The differences are generally no more than 6.2 sones, except in the case of Sound S32 (all Loudness metrics are 7.5-13.2 sones lower for this sound than for the binaural recorded sound) and Sound S55 ($SN_{max}$ is 9.2 sones lower). ASEL values for simulated sounds are generally no more than 2.3 dB below ASEL values for recorded sounds (either single-microphone or binaural-head), excluding sound S32 (9.0 dB below). Sound S32 is generated from a loud 27-Hz bandpass-filtered boom contributed by NASA Langley, and Sound S55 is generated from a gunfire recording high-pass filtered at 50 Hz.

### 4.3.2 Regression Models

$R^2$ values for models using single metrics are listed in Table 4.2. The most accurate single-metric predictors of annoyance are PL, $ZN_{max}$ and ASEL, followed by the four Moore & Glasberg Loudness metrics, then by the Loudness Derivative metrics.

Table 4.2. $R^2$ values for single-metric models in Purdue test. Metric acronyms are given in Table 4.1.

| **Metric** | $\mathbf{R^2}$ | **Metric** | $\mathbf{R^2}$ |
|---|---|---|---|
| PL | 0.781 | $SN_{15}$ | 0.549 |
| $ZN_{max}$ | 0.759 | $dLN_{max}$ | 0.470 |
| ASEL | 0.727 | $dZN_{max}$ | 0.476 |
| $LN_{max}$ | 0.612 | $dSN_{max}$ | 0.470 |
| $LN_{Et}$ | 0.616 | Dur | 0.328 |
| $SN_{max}$ | 0.548 | H | 0.001 |

$R^2$ values for multiple-metric models are given in Tables 4.3-4.6, along with the estimated coefficients. Since maximum Sharpness was excluded from the analysis of the Purdue test, the maximum number of metrics considered in any model was four. The models in these tables were selected using the procedure described on Page 36 for the NASA test. Here Heaviness is observed to be the most effective second metric in all cases, resulting in $R^2$ gains of up to 0.280. As in the NASA test, the term contributions for Heaviness are within an order of magnitude of the contributions for the Loudness terms and ASEL (the ranges of values are on the same order of magnitude, and the coefficients are within an order of magnitude of each other), which seems to confirm that the contribution of Heaviness in these models is statistically significant. Also in these models, the $R^2$ values usually converge as the number of terms in the model increases. The only exception is in the $LN_{Et}$-based model, in which the $R^2$ value increases by 0.009 when the third metric ($dSN_{max}$) is added, and by 0.010 when the fourth metric (Dur) is added. Hence it appears that there is some noise on metrics in this step of the $LN_{Et}$-based model, but noise is not apparent anywhere else. In the four-metric models, the $R^2$ values of PL-, $LN_{max}$-, $LN_{Et}$-, and $SN_{15}$-based models are all within 0.013 of each other, while the $R^2$ values of the $ZN_{max}$-, ASEL- and $SN_{max}$-based models are lower and within 0.009 of each other. The highest $R^2$ value for a 4-metric model in the Purdue test is based on $SN_{15}$ (Moore & Glasberg short-term Loudness exceeded 15% of the time). The $R^2$ value for this model is listed as 0.893 in Table 4.6, although it should be noted that the $R^2$ value increased to 0.901 when a Moore & Glasberg-based Duration was used (instead of Zwicker-based Duration). The addition of the fourth metric appears to significantly improve the model fit in all cases, as the $F_{1,155}$ values are all greater than 0.00395 (the value of the $F$ distribution for P = 0.05) [45].

Plots of average annoyance ratings versus predicted annoyance for the PL- and $SN_{15}$-based models are presented in Figures 4.6 and 4.7. Triangular points represent ratings for Part 1 sounds, and circular points represent ratings for Part 2 sounds. Here, as in the NASA test, outlier points noticeably shift towards the one-to-one correlation line as the number of metrics in the model increases. Also, the PL-based models in the Purdue test have similar features to the PL-based models in the NASA test: the PL-only model (shown in Figure 4.6(a)) gives rise to a few outliers; and the blue and red data points (corresponding to sounds prepared by Purdue) appear in relatively distinct blocks in the PL-only model, but are spread out with the addition of H (Figure 4.6(b)). Correlations between the metrics used in these models are listed in Tables 4.7 and 4.8.

Figures 4.8 and 4.9 contain plots showing how much the predicted annoyance values change as the number of metrics in the PL- and $SN_{15}$-based models, respectively, is increased. In Part (a) of both figures, the groups of yellow and green points standing out on the right side of the plot correspond to Sounds 29-32 and 61-63. These sounds were generated from a synthetic boom with a 27-Hz centered band-pass filter, prepared by NASA Langley. Also, when *Dur* is added to the models (in Figures 4.8(c) and 4.9(b)), the largest adjustments to predicted annoyance are for Sounds 22 and 56 (generated from a recorded boom containing both primary and secondary booms). This is similar to what happened in the models of the NASA responses.

### 4.3.3 Examination of Outliers in Regression Models

The two most obvious outlier points in the PL-based four-metric model (see Figure 4.6(d)) correspond to Part 1 and Part 2 versions of Sound H32, a synthetic boom treated with a 27-Hz centered band-pass filter, contributed by NASA Langley, and recorded for the Purdue test with a binaural head. This is one of the loudest sounds in the test, and the model under-predicts the average annoyance rating.

The spectra and Loudness time histories of Sound H32 Part 1 are plotted below in Figure 4.10, with the spectra and loudness time histories of Sound 29, a less loud microphone-recorded version of the same source signal. (Sound 29 was chosen for comparison because it is very similar to Sound H32 in terms of spectral and Loudness time history characteristics, and because it is not an outlier in any annoyance model for the Purdue test. Note that Sound 29 has two different spectra and time histories. This is because the sound was recorded at both earphones in the Sound Quality booth when the metrics were generated, even though it was originally recorded in the IER with a single microphone.) As in the discussion of outliers in Chapter 3, the Loudness time histories of Sound 29 have been scaled to match the maximum magnitude of the

Table 4.3. $R^2$ values and coefficients of multiple-metric models containing PL and $ZN_{max}$ in Purdue test. Metric acronyms are given in Table 4.1. Numbers in parentheses (#-#) denote ranges of metric values for the signals.

| **Coefficients of metrics:** | | | | | $\mathbf{R^2}$ | $\mathbf{F_{1,155}}$ |
|---|---|---|---|---|---|---|
| **Intercept** | **PL (dB) (49.6 - 88.1)** | **H (dB) (12.8 - 36.2)** | **$\mathbf{dLN_{max}}$ (sone/s) (6 - 203)** | **Dur (s) (0.557 - 2.029)** | | |
| -3.48 | 0.111 | | | | 0.781 | |
| -4.88 | 0.118 | 0.040 | | | 0.837 | |
| -3.21 | 0.074 | 0.069 | 0.010 | | 0.876 | |
| -3.04 | 0.069 | 0.063 | 0.009 | 0.354 | 0.880 | 5.03 |
| **Intercept** | **$\mathbf{ZN_{max}}$ (sone) (2.25 - 36.63)** | **H (dB) (12.8 - 36.2)** | **$\mathbf{dLN_{max}}$ (sone/s) (6 - 203)** | **Dur (s) (0.557 - 2.029)** | $\mathbf{R^2}$ | $\mathbf{F_{1,155}}$ |
| 2.71 | 0.114 | | | | 0.759 | |
| 1.50 | 0.124 | 0.046 | | | 0.833 | |
| 0.920 | 0.081 | 0.069 | 0.008 | | 0.852 | |
| 0.753 | 0.075 | 0.058 | 0.008 | 0.579 | 0.863 | 12.5 |

Table 4.4. $R^2$ values and coefficients of multiple-metric models containing ASEL in Purdue test. Metric acronyms are given in Table 4.1. Numbers in parentheses (#-#) denote ranges of metric values for the signals.

| **Coefficients of metrics:** | | | | | **$R^2$** | **$F_{1,155}$** |
|---|---|---|---|---|---|---|
| **Intercept** | **ASEL (dB) (37.6 - 73.3)** | **H (dB) (12.8 - 36.2)** | **$dLN_{max}$ (sone/s) (6 - 203)** | **Dur (s) (0.557 - 2.029)** | | |
| -1.92 | 0.111 | | | | 0.727 | |
| -3.92 | 0.125 | 0.054 | | | 0.823 | |
| -2.49 | 0.075 | 0.079 | 0.010 | | 0.864 | |
| -2.33 | 0.068 | 0.073 | 0.010 | 0.356 | 0.868 | 4.54 |

Table 4.5. $R^2$ values and coefficients of multiple-metric models containing $LN_{max}$ and $SN_{max}$ in Purdue test. Metric acronyms are given in Table 4.1. Numbers in parentheses (#-#) denote ranges of metric values for the signals.

| **Coefficients of metrics:** | | | | | $\mathbf{R^2}$ | $\mathbf{F_{1,155}}$ |
|---|---|---|---|---|---|---|
| **Intercept** | **$LN_{max}$ (sone) (0.91 - 24.59)** | **H (dB) (12.8 - 36.2)** | **$dSN_{max}$ (sone/s) (23 - 1011)** | **Dur (s) (0.557 - 2.029)** | | |
| 3.00 | 0.143 | | | | 0.612 | |
| 0.240 | 0.198 | 0.097 | | | 0.868 | |
| 0.299 | 0.253 | 0.093 | -0.001 | | 0.877 | |
| 0.209 | 0.248 | 0.079 | -0.002 | 0.560 | 0.886 | 13.5 |
| **Intercept** | **$SN_{max}$ (sone) (1.18 - 29.52)** | **H (dB) (12.8 - 36.2)** | **Dur (s) (0.557 - 2.029)** | **$dLN_{max}$ (sone/s) (6 - 203)** | $\mathbf{R^2}$ | $\mathbf{F_{1,155}}$ |
| 3.05 | 0.106 | | | | 0.548 | |
| 0.013 | 0.157 | 0.105 | | | 0.828 | |
| -0.150 | 0.142 | 0.086 | 0.826 | | 0.852 | |
| -0.259 | 0.239 | 0.084 | 0.925 | -0.014 | 0.859 | 8.04 |

Table 4.6. $R^2$ values and coefficients of multiple-metric models containing $LN_{Et}$ and $SN_{15}$ in Purdue test. Metric acronyms are given in Table 4.1. Numbers in parentheses (#-#) denote ranges of metric values for the signals.

| **Coefficients of metrics:** | | | | | $\mathbf{R^2}$ | $\mathbf{F_{1,155}}$ |
|---|---|---|---|---|---|---|
| **Intercept** | **$LN_{Et}$ (sone) (0.67-18.56)** | **H (dB) (12.8-36.2)** | **$dSN_{max}$ (sone/s) (23-1011)** | **Dur (s) (0.557-2.029)** | | |
| 3.00 | 0.189 | | | | 0.616 | |
| 0.250 | 0.262 | 0.097 | | | 0.871 | |
| 0.326 | 0.339 | 0.092 | -0.002 | | 0.880 | |
| 0.238 | 0.331 | 0.079 | -0.002 | 0.547 | 0.890 | 13.3 |
| **Intercept** | **$SN_{15}$ (sone) (0.95-26.18)** | **H (dB) (12.8-36.2)** | **Dur (s) (0.557-2.029)** | **$dZN_{max}$ (sone/s) (20-956)** | $\mathbf{R^2}$ | $\mathbf{F_{1,155}}$ |
| 3.12 | 0.133 | | | | 0.549 | |
| 0.172 | 0.195 | 0.103 | | | 0.822 | |
| -0.229 | 0.171 | 0.078 | 1.26 | | 0.886 | |
| -0.328 | 0.206 | 0.070 | 1.58 | -0.001 | 0.893 | 11.2 |

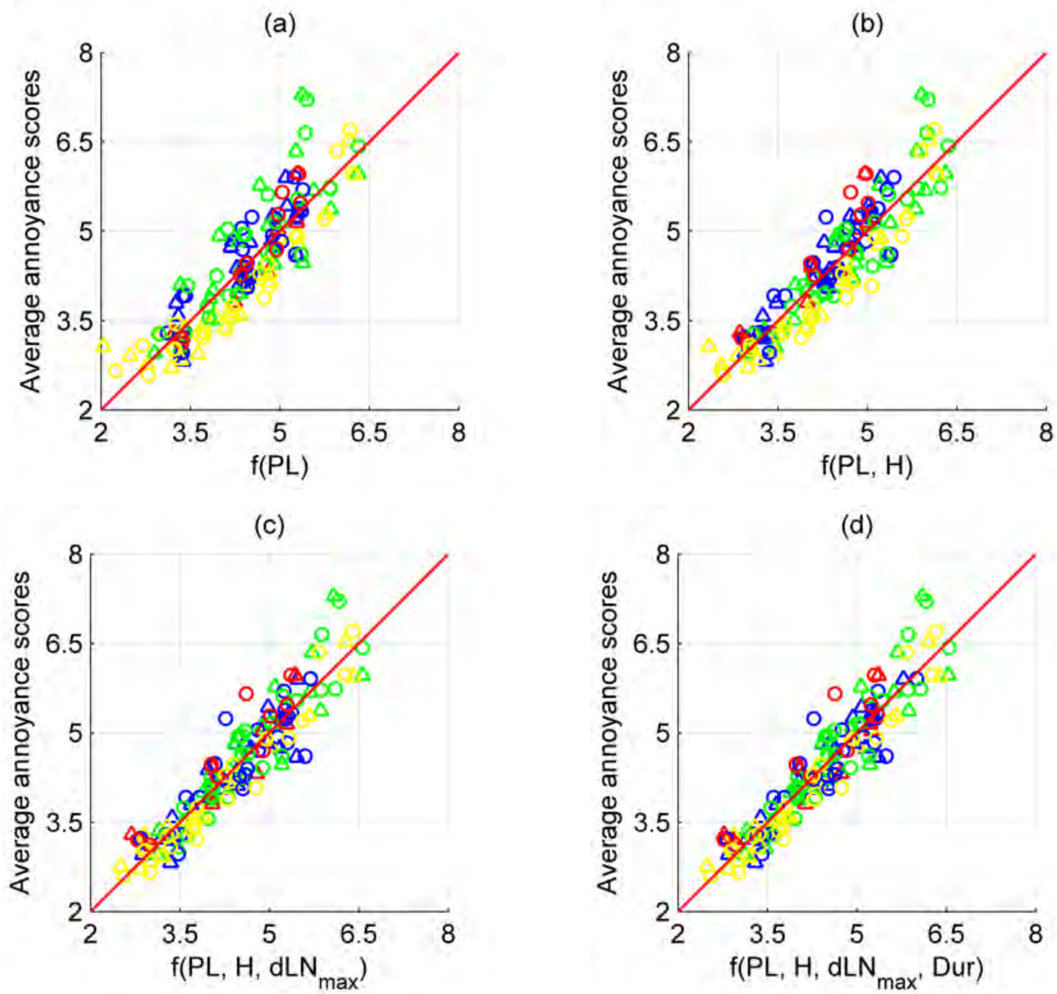


Figure 4.6. Average annoyance ratings from the Purdue test plotted against PL-based annoyance models that are functions of (a) 1 to (d) 4 metrics. One-to-one correlation line shown in red. $R^2$ values are: (a) 0.781, (b) 0.837, (c) 0.876, (d) 0.880. Metric acronyms are given in Table 4.1. For information on color-coding, error bars, and subdivision of the axes, see Page 25.

Sound H32 Loudness time histories. Sound H32 has a narrow spectral peak centered at 27 Hz that is generally higher than in other signals, and a lower peak around 90 Hz. In the Zwicker Loudness time history, the two main loudness peaks in the boom are wide, rounded in shape, and easily distinguished from each other by a similarly wide rounded trough. In Parts (c) - (f) of Figure 4.10, the latter parts of the Zwicker and short-term Moore & Glasberg time histories appear rougher than those for Sound

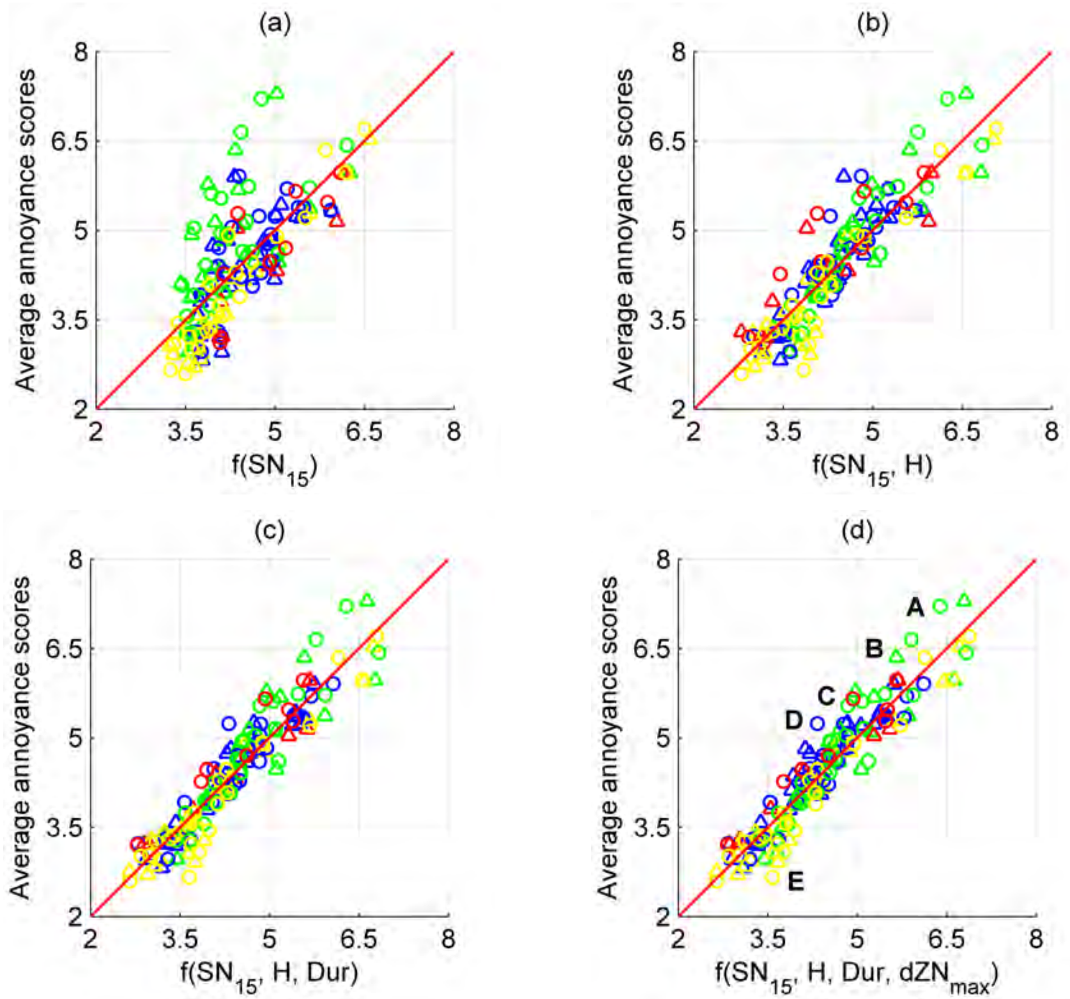


Figure 4.7. Average annoyance ratings from the Purdue test plotted against $SN_{15}$-based annoyance models that are functions of (a) 1 to (d) 4 metrics. One-to-one correlation line shown in red. Letters in (d) mark general location of outliers. $R^2$ values are: (a) 0.549, (b) 0.822, (c) 0.886 (d) 0.893. Metric acronyms are given in Table 4.1. For information on color-coding, error bars, and subdivision of the axes, see Page 25.

H32. Also in Parts (c) and (d), the latter parts of the Zwicker Loudness time histories of Sound 29 begin to flatten out before those for Sound H32. In Parts (e) and (f), the short-term Moore & Glasberg time histories of Sound 29 have a small bump at around 1.1-1.2 seconds that is not present in Sound H32. Two aspects unique to Sound H32 Part 1 may also be observed. First, in Figure 4.10 parts (e)-(h), the gap between the

Table 4.7. Correlations between metrics for best PL-based model, expressed in $R^2$ values. Numbers in (parentheses) refer to correlations where the correlation coefficient is negative. Metric acronyms are given in Table 4.1.

| | **PL** | **$dLN_{max}$** | **Dur** | **H** |
|---|---|---|---|---|
| **PL** | 1 | 0.690 | 0.227 | (0.052) |
| **$dLN_{max}$** | | 1 | 0.069 | (0.301) |
| **Dur** | | | 1 | 0.082 |
| **H** | | | | 1 |

Table 4.8. Correlations between metrics for best $SN_{10}$-based model, expressed in $R^2$ values. Numbers in (parentheses) refer to correlations where the correlation coefficient is negative. Metric acronyms are given in Table 4.1.

| | **$SN_{15}$** | **$dZN_{max}$** | **Dur** | **H** |
|---|---|---|---|---|
| **$SN_{15}$** | 1 | 0.820 | 0.025 | (0.304) |
| **$dZN_{max}$** | | 1 | 0.122 | (0.269) |
| **Dur** | | | 1 | 0.082 |
| **H** | | | | 1 |

two main peaks in the Moore & Glasberg time histories is not as pronounced as it is for Sound 29. Second, in parts (e) and (f), the short-term Moore & Glasberg time history has a small third peak just after the second peak.

In the $SN_{15}$-based four-metric model, Sound S17 from Part 2 (a loud simulated car door slam) is the most under-predicted. The annoyance for this sound is represented by the blue circular point near the letter D marked in Figure 4.7(d). The spectra and Loudness time histories of this sound are plotted along with those of Sound M17 Part 2 (a microphone-recorded sound generated from the same source signal) in Figure 4.11. In parts (a) and (b), Sound S17 has a spectral peak from around 40-50 Hz and a dip from around 50-100 Hz, while Sound M17 has a peak from around 25-40 Hz and

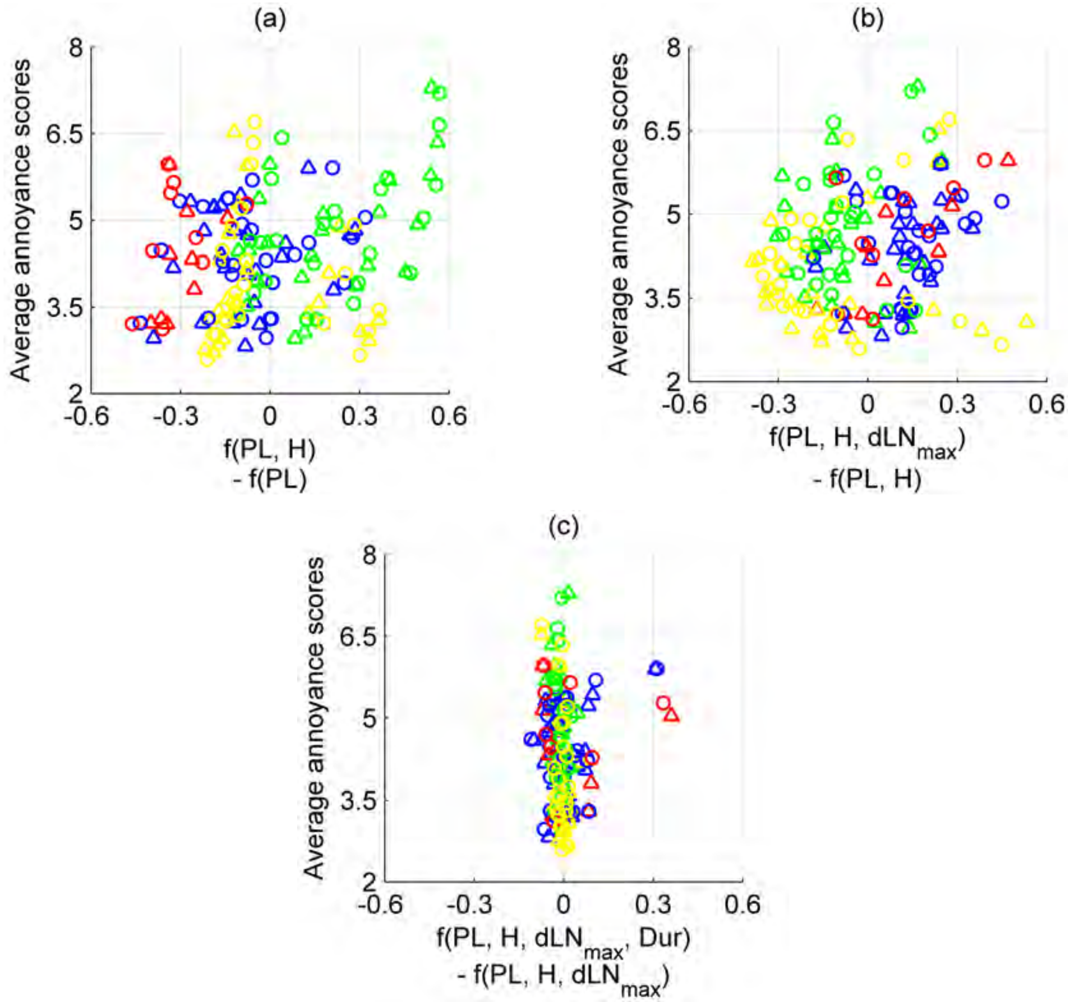


Figure 4.8. Average annoyance ratings from the Purdue test plotted against adjustments in predicted values of PL-based annoyance models as additional terms are added to the model. Metric acronyms are given in Table 4.1. For information on color-coding, error bars, and subdivision of the annoyance axis, see Page 25.

a more steady high-frequency roll-off. In parts (c)-(f), the Zwicker and short-term Moore & Glasberg Loudness time histories of Sound S17 appear to be rougher on the trailing ends and attenuate less quickly than do those of Sound M17.

Also in the $SN_{15}$-based four-metric model, a group of seven sounds is under-predicted by a smaller amount than Sound S17. The three most under-predicted sounds in this group are Sound H32 Part 2 (the green circular point near A), Sound

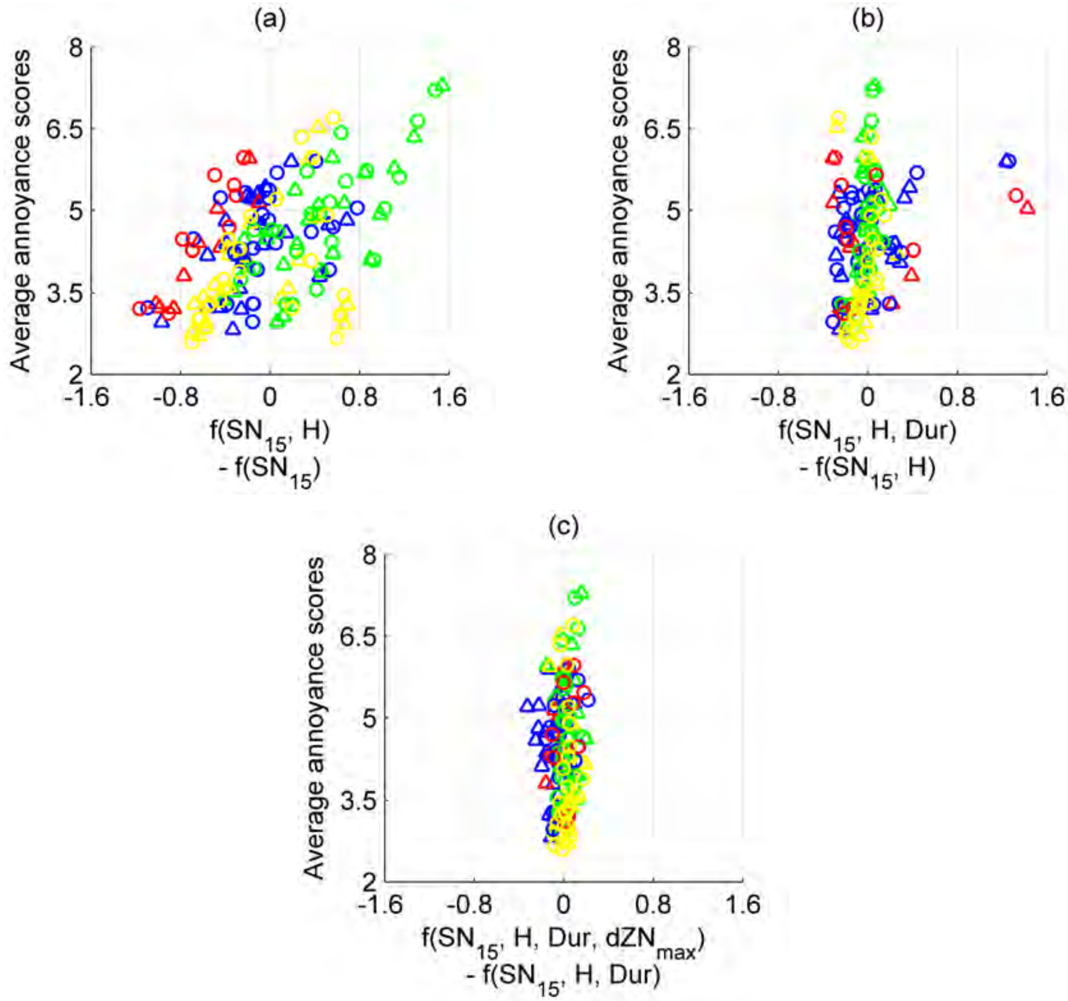


Figure 4.9. Average annoyance ratings from the Purdue test plotted against adjustments in predicted values of $SN_{15}$-based annoyance models as additional terms are added to the model. Metric acronyms are given in Table 4.1. For information on color-coding, error bars, and subdivision of the annoyance axis, see Page 25.

M31 Part 1 (the green triangle near C), and Sound M32 Part 2 (the green triangle near B). Also in this group are Sounds S55 Part 2 (the red circle near C), M39 Part 2 (the green circle near C), and M23 Part 1 (the blue triangle below D). It should be noted that while Sound H32 Part 2 is the second most over-predicted sound in the model, Sound H32 Part 1 (the green triangle to the right of A) is much more accurately predicted than the eight signals listed above. The most notably over-predicted sound

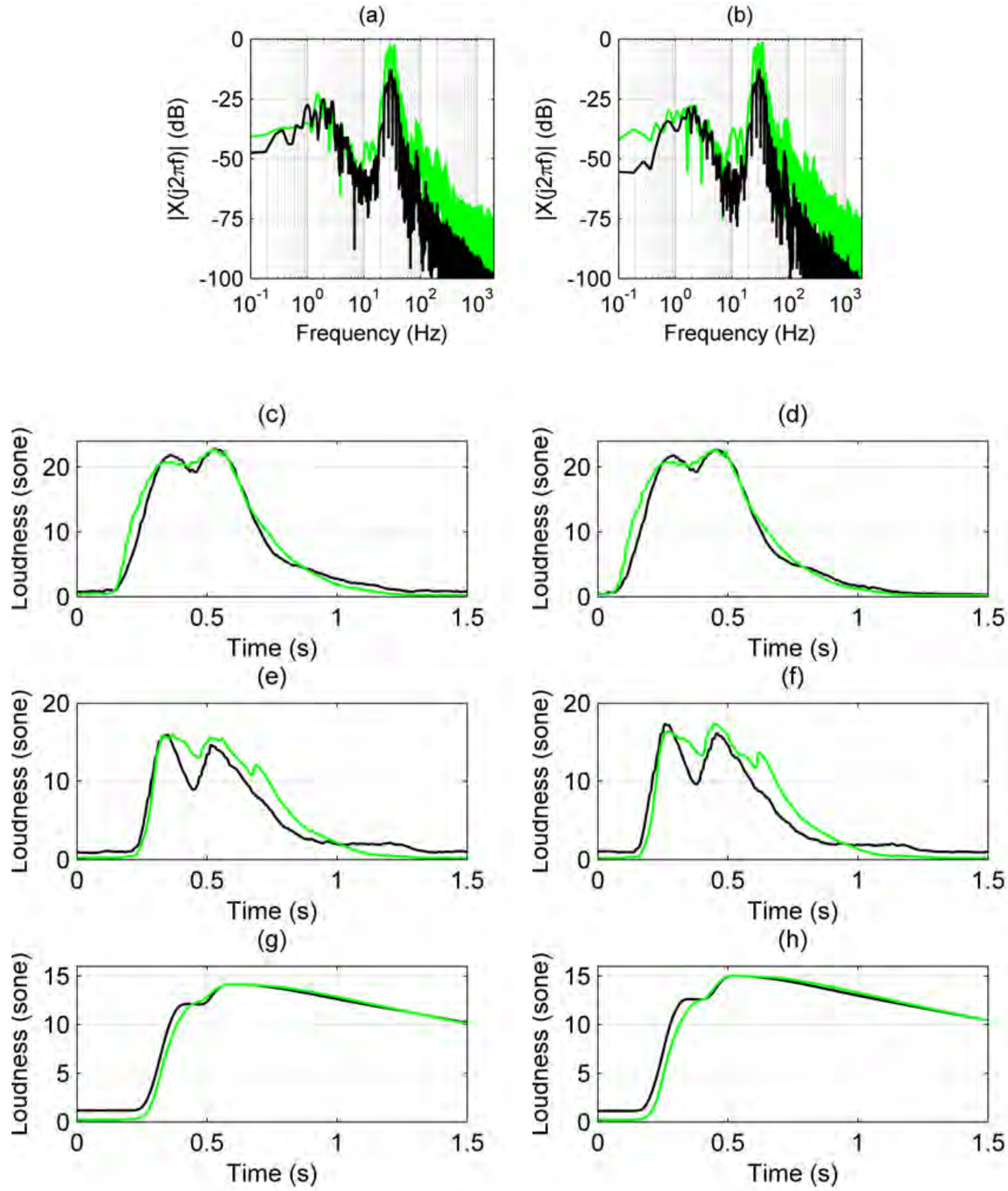


Figure 4.10. Characteristics of an outlier sound in the PL-based four-metric model, Sound H32, Part 1 (green), and a similar non-outlier sound M29, Part 1 (black): (a-b) spectra, (c-d) Zwicker Loudness, (e-f) short-term Moore & Glasberg Loudness, (g-h) long-term M & G Loudness. (a, c, e, g) left ear; (b, d, f, h) right ear. Loudness time histories of Sound M29 are scaled so that the shapes may be more easily compared; spectra are not.

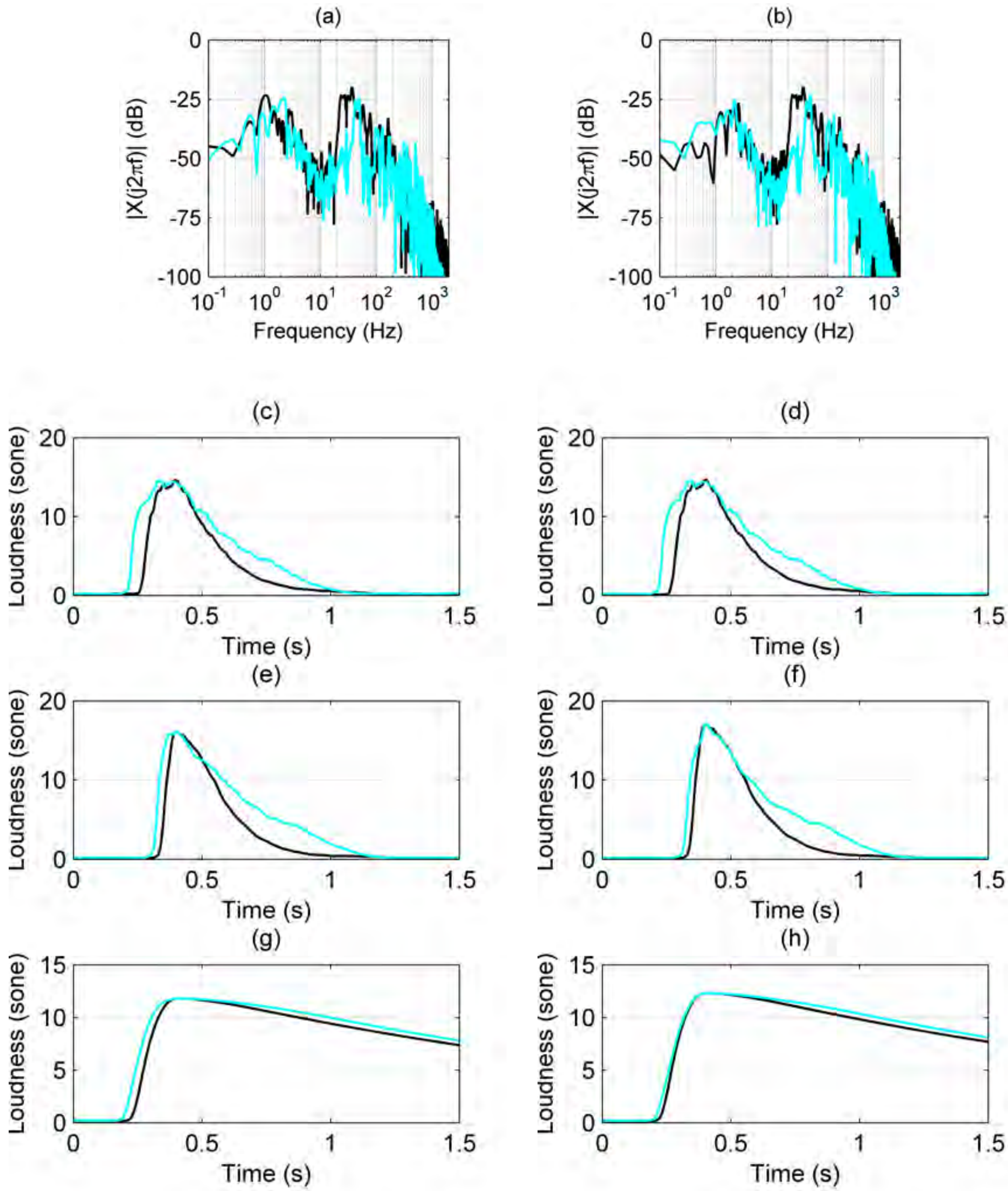


Figure 4.11. Characteristics of an outlier sound in the $SN_{15}$-based four-metric model, Sound S17, Part 2 (blue), and a similar non-outlier sound M17, Part 2 (black): (a-b) spectra, (c-d) Zwicker Loudness, (e-f) short-term Moore & Glasberg Loudness, (g-h) long-term M & G Loudness. (a, c, e, g) left ear; (b, d, f, h) right ear. Loudness time histories of Sound M17 are scaled so that the shapes may be more easily compared; spectra are not.

is Sound M61 Part 2 (the yellow circular point near the letter E in Figure 4.7(d)). The next most over-predicted sounds are Sounds M62 Parts 1 and 2 (also denoted by yellow markers near E).

- Sounds 31-32 and 61-62 are generated from a single synthetic boom, which was treated with a 27-Hz centered band-pass filter. Sounds 31 and 32 are among the louder sounds played in the test. Sounds M61-62 was treated with an additional 50-Hz high-pass filter, which attenuates much of the energy from the original boom. Hence, Sound M61 is one of the quieter sounds played in the test.

- Sound M23 was generated from a recorded boom. It is the only sound for which the average annoyance rating in Part 1 exceeds the average annoyance rating in Part 2 by 2 standard deviations of the estimated mean or more.

- Sound S55 is a loud simulated gunfire.

The Moore & Glasberg short-term Loudness time histories of the four most under-predicted sounds in the $SN_{15}$-based four-metric model are plotted in Figure 4.12. The Loudness time histories of the later three have been scaled to match the maximum Loudness of Sound S17.

In addition to examining the spectra and Loudness time histories of outlier sounds, there was also concern that these sounds were given outlier ratings due to the effects of the playback equipment. To determine whether this was the case, the original indoor sound recordings from the NASA test were high-pass filtered at 25 Hz, and metrics were generated for these sounds. The effect of this was to produce metric values that were not affected by the application of forward and inverse ear filters, the quantization of the 16-bit digital sound files, the sound card, or the amplifier and earphone system. Ten metrics were generated for the filtered NASA sounds: PL, ASEL, $ZN_{max}$, $LN_{max}$, $SN_{max}$, $LN_{Et}$, the three maximum Loudness Derivatives, and H. These metrics were plotted against the metrics for the actual Purdue test sounds, and the correlations and trends were observed. All ten metrics were highly correlated

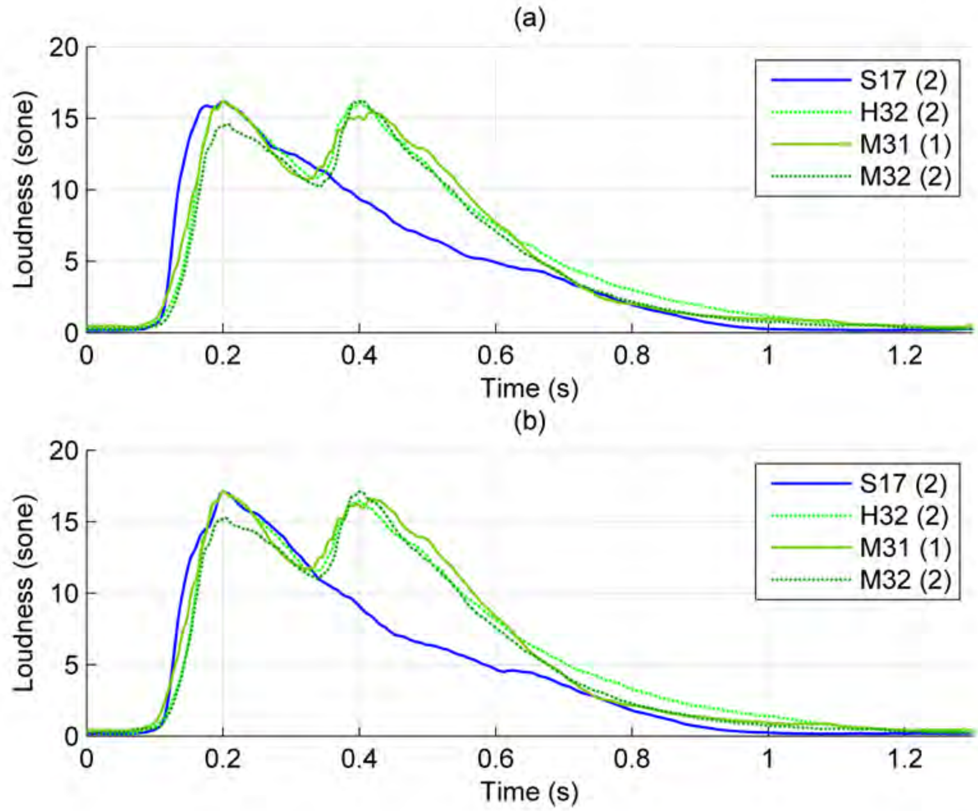


Figure 4.12. Moore & Glasberg short-term Loudness time histories of four sounds for which the average annoyance ratings are most under-predicted by the Purdue four-metric $SN_{15}$-based model. The Loudness time histories of the last three sounds are been scaled so that the shapes may be more easily compared.

($R^2 \geq 0.927$), which seems to indicate that the outlier signals were not particularly affected by the equipment. However, the correlations were noticeably different than one-to-one; the sounds from the Purdue test seemed proportionally louder than their corresponding sounds from the NASA test. This mismatch will be of some importance when comparing the Purdue and NASA tests with each other in Chapter 5.

### 4.4 Purdue Test Summary

In this chapter, an earphone test including signals and format similar to those of the NASA test was described, and the results of the test were presented. Subject ratings of common signals between Part 1 and Part 2 of the test are highly correlated. (Part 1 and Part 2 of the Purdue test mostly contained sounds that were measured at the plain and isolated chair, respectively, in NASA's IER simulator, and thus differed because of room acoustics. However, the seat locations in the IER were chosen so that the sounds heard were similar in the two locations.)

$R^2$ values for the four-metric annoyance models examined are all within 0.042 of each other. The two highest-correlated annoyance models examined were based on Moore & Glasberg short-term Loudness exceeded 15% of the time ($SN_{15}$) and time-divided Moore & Glasberg Integrated Loudness ($LN_{Et}$). The best single-metric model is Perceived Level (PL). One sound is often an outlier in the annoyance model predictions; this is generated from a binaural-head measurement (taken at the isolated chair in the IER) of a loud synthetic boom with a high spectral peak at 27 Hz. Alternate sounds generated from binaural-head or microphone measurements of the same source signal at either chair are also outliers in some models.

Both the average annoyance ratings and the predictive models from the Purdue test and the NASA test will be compared with each other in Chapter 5.

# 5. COMPARISON OF RESULTS OF TWO TESTS

In addition to analyzing the results of the NASA test and the Purdue test individually, there is also interest in comparing the results of the two tests against each other. The NASA test was conducted in a more natural environment, using signals with greater levels of very-low-frequency energy, and collecting annoyance ratings over potentially more intuitive and easier-to-use rating devices. On the other hand, the Purdue test was conducted in a less natural, vibration-less environment, in a facility with potentially better high-frequency playback capacity, using signals with lower levels of low-frequency energy, and collecting annoyance ratings over potentially less intuitive and more effort-consuming rating devices. Also, the rating scales in the NASA and Purdue tests were defined slightly differently. By comparing the results of the two tests against each other, a better understanding of the effects that playback environment have on annoyance ratings may be achieved. Much of the information in this chapter is also contained in a conference paper written by the present author [48].

## 5.1 Comparison of Annoyance Ratings

In this section, only the annoyance ratings for the seventy sounds common to all parts of all tests will be discussed. In regard to the Purdue test, all ratings in this group are for sounds recorded with single microphones.

Average annoyance ratings in the NASA and Purdue tests are plotted in Fig. 5.1. Responses are ordered from lowest to highest annoyance ratings. In this figure, the range of responses is larger in the NASA test than in the Purdue test. This is suspected not to be due to vibration, since both the plain-chair and isolated-chair subject responses have a similar range. (For a discussion of vibration effects in the NASA test, see [41].) Other possible explanations are:

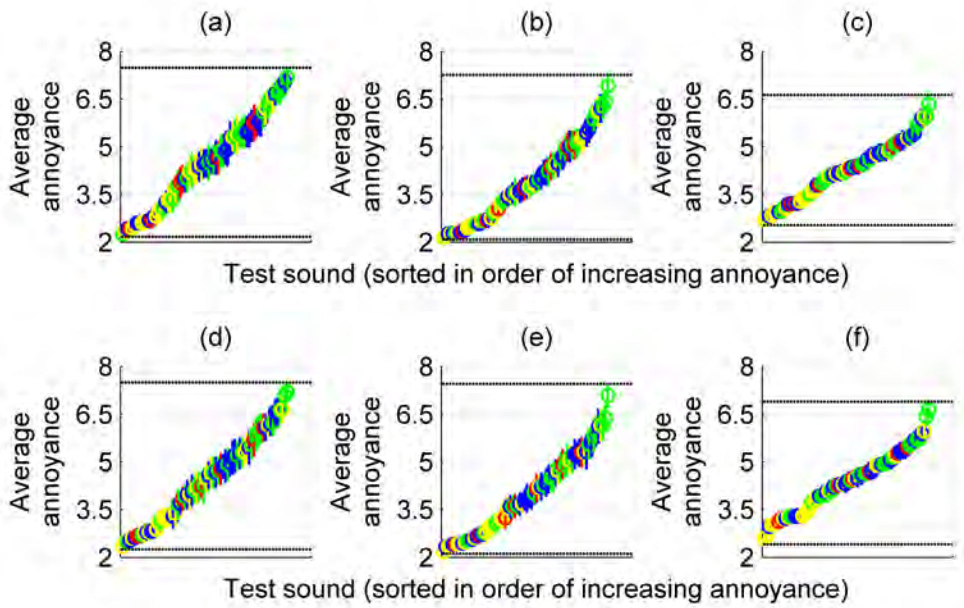


Figure 5.1. Average annoyance ratings in each test, sorted in order of increasing annoyance: (a) NASA test, plain seat, Part 1, (b) NASA test, isolated seat, Part 1, (c) Purdue test, Part 1, (d) NASA test, plain seat, Part 2, (e) NASA test, isolated seat, Part 2, (f) Purdue test, Part 2. Dashed lines are included to aid the viewer in visualizing the differences in range between the two tests. For information on color-coding, error bars, and subdivision of the annoyance axis, see Page 25.

1. Subjects in the Purdue test used less of the scale due to differences in the input devices. Clicking and dragging with a mouse requires greater effort than does turning a rotary dial.
2. Subjects in the Purdue test treated the scale differently due to the extra space on the ends of the scale (though one might expect a greater range from the Purdue test rather than a smaller one).
3. Subjects in the Purdue test treated the scale differently due to the extra labels on the scale. Whereas the NASA test scale had labels on the first, middle, and last tick marks only, the Purdue test scale had labels on every mark. Hence, it

is uncertain whether the NASA test subjects assigned the same meaning to the second and fourth tick marks as did the NASA test subjects.

4. The demographics and exposure to aircraft noise experiences of the groups were different.
5. The more natural environment of the IER played a role.

Groups of average annoyance ratings are plotted against each other in Figures 5.2 and 5.3. Boxes in parts (a), (c), and (e) are given to aid in visualizing the range differences between the groups. $R^2$ values between the ratings from different groups range from 0.942 to 0.960. A significant number of NASA signal ratings are more than two standard deviations away from exact one-to-one correlation trend line with the Purdue part 1 data, as shown in parts (b), (d), and (f) below. However, if the deviation of the average ratings from the linear prediction line (rather than to the one-to-one line) is examined, only 1-3 signal ratings in each subplot are more than two standard deviations away from the line. These outliers are listed in Table 5.1.

## 5.2 Comparison of Purdue Test Metric Models with NASA Test Metric Models

$R^2$ values for single-metric models common to both tests are given in Table 5.2. In both tests, PL, $ZN_{max}$, and ASEL were the most highly correlated single-metric models, followed by $LN_{max}$ and $SN_{max}$. $R^2$ values for PL, $ZN_{max}$, and ASEL models were up to 0.068 higher in the NASA test than in the Purdue test, while $R^2$ values for $LN_{max}$ and $SN_{max}$ models were up to 0.049 higher in the Purdue test than in the NASA test. Each of the loudness metrics treat low frequency content differently, and some of the differences observed in metric performance may be attributable to the contributions of the low frequency components to annoyance. This requires further examination.

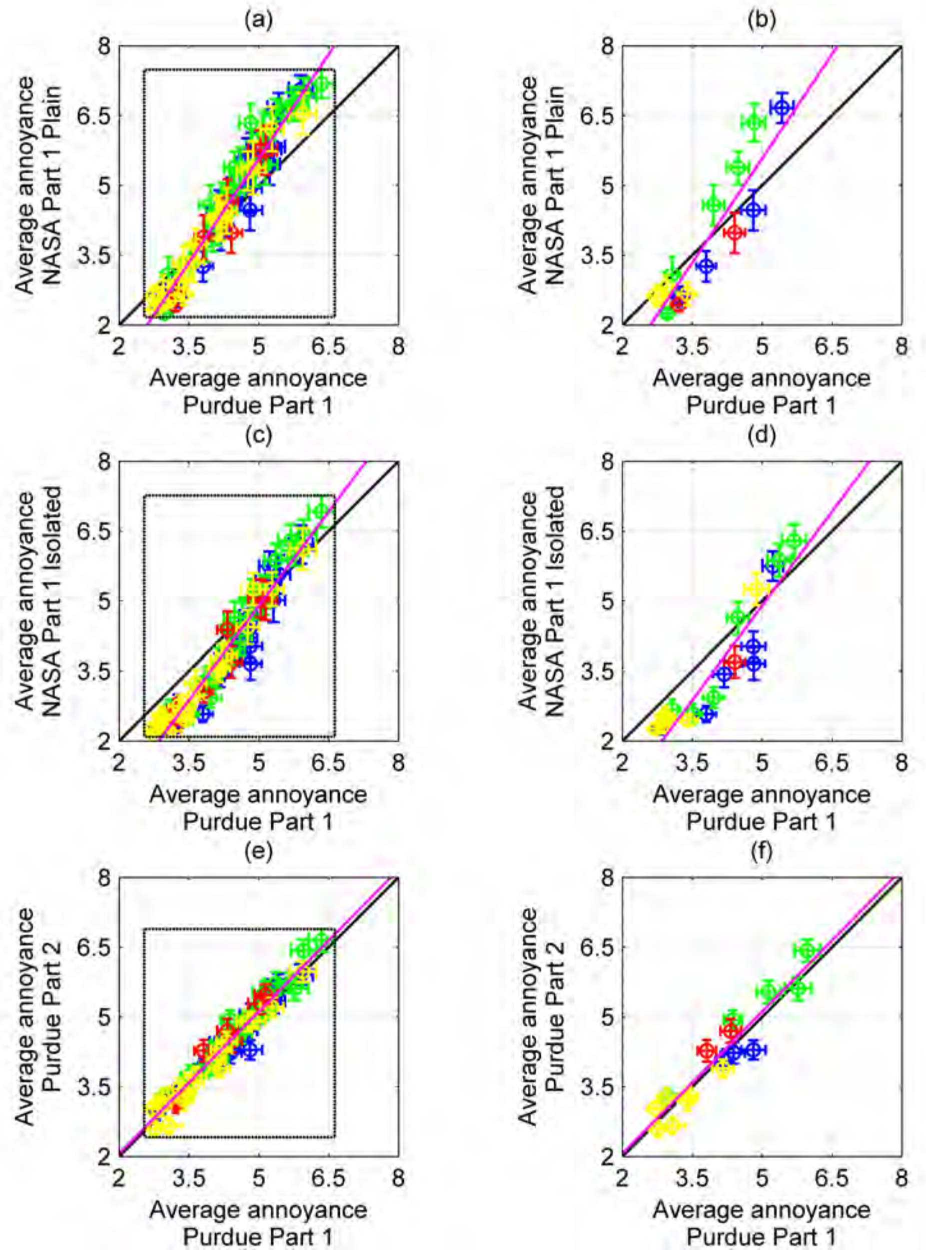


Figure 5.2. Average annoyance ratings for parts of Purdue and NASA tests plotted against Purdue test Part 1 ratings: (a), (c), (e) full, (b), (d), (f) outliers. Dashed-line boxes are included to aid the viewer in visualizing the differences in range between the two tests. For information on color-coding, error bars, and subdivision of the axes, see Page 25.

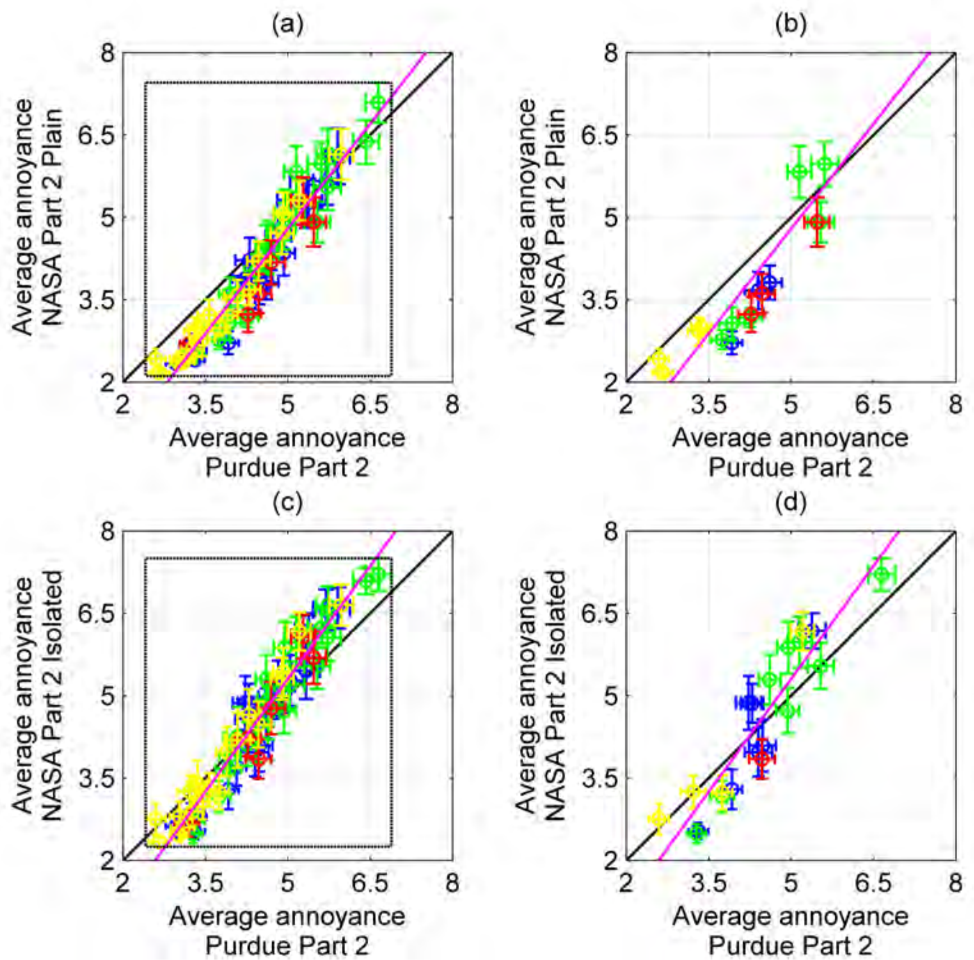


Figure 5.3. Average annoyance ratings for parts of Purdue and NASA tests plotted against Purdue test Part 2 ratings: (a), (c) full, (b), (d) outliers exceeding one standard deviation from one-to-one correlation. Dashed-line boxes are included to aid the viewer in visualizing the differences in range between the two tests. For information on color-coding, error bars, and subdivision of the axes, see Page 25.

Table 5.1. Annoyance ratings that are more than two standard deviations away from the best-fit line in Figures 5.2 and 5.3.

| **Figure** | **Sound number (from NASA test)** | **Signal description** | **Purdue rating $>$ or $<$ trend line** |
|---|---|---|---|
| 5.2(b) | 36 | Loud synthetic boom with wide spectral peak at 5-10 Hz | $<$ |
| 5.2(d) | 2 | Quiet synthetic boom | $>$ |
| | 17 | Loud car door slam | $>$ |
| 5.2(f) | 23 | Loud recorded boom | $>$ |
| | 47 | Medium-loud synthetic boom | $<$ |
| 5.3(b) | 2 | Quiet synthetic boom | $>$ |
| | 46 | Medium-quiet synthetic boom | $>$ |
| | 65 | Quiet synthetic boom, 50-Hz high-pass | $<$ |
| 5.3(d) | 52 | Medium gunfire, 50-Hz high-pass | $>$ |
| | 65 | Quiet synthetic boom, 50-Hz high-pass | $<$ |

Table 5.2. Common single-metric annoyance models for NASA and Purdue tests. Metric acronyms are given in Table 4.1.

| **Metric** | **$R^2$ (NASA)** | **$R^2$ (Purdue)** | **$R^2_{NASA}$−$R^2_{PU}$** |
|---|---|---|---|
| PL | 0.840 | 0.781 | 0.059 |
| $ZN_{max}$ | 0.805 | 0.759 | 0.046 |
| ASEL | 0.795 | 0.727 | 0.068 |
| $LN_{max}$ | 0.582 | 0.612 | -0.030 |
| $SN_{max}$ | 0.507 | 0.548 | -0.041 |
| $dLN_{max}$ | 0.492 | 0.533 | -0.041 |
| $dZN_{max}$ | 0.492 | 0.476 | 0.016 |
| $dSN_{max}$ | 0.450 | 0.470 | -0.020 |
| Dur | 0.505 | 0.321 | 0.184 |
| H | 0.006 | 0.001 | 0.005 |

Linear models that are functions of multiple metrics were also examined. Table 5.3 contains $R^2$ values for the best Purdue four-metric models, along with $R^2$ values of NASA test models including the same metrics. (Note that although Duration is specified differently in each test, the noise floor in each method is approximately the same.) PL-, $ZN_{max}$-, and ASEL-based models still have the highest $R^2$ values, and are more highly correlated to average annoyance in the NASA test, while $LN_{max}$- and $SN_{max}$-based models are more highly correlated to average annoyance in the Purdue test. However, the difference between the $R^2$ values from the Purdue-test and the NASA-test annoyance models has decreased from 0.068 (for single-metric Loudness models) to within 0.049.

Table 5.4 contains $R^2$ value for the best-fit 4- and 5-metric models from each test. When comparing the best-correlated four-metric models of each test against each other, the difference in $R^2$ values is as great as 0.046. However, $LN_{max}$- and $SN_{max}$-based models are still more highly correlated in the Purdue test, even when the best-performing four-metric Purdue test models are compared against the best-

Table 5.3. Common multiple-metric annoyance models for NASA and Purdue tests. Metric acronyms are given in Table 4.1.

| **Metrics** | **$R^2$ (NASA)** | **$R^2$ (Purdue)** | **$R^2_{NASA}-R^2_{PU}$** |
|---|---|---|---|
| PL, $dLN_{max}$, Dur, H | 0.906 | 0.880 | 0.026 |
| $ZN_{max}$, $dLN_{max}$, Dur, H | 0.896 | 0.863 | 0.033 |
| ASEL, $dLN_{max}$, Dur, H | 0.890 | 0.868 | 0.022 |
| $LN_{max}$, $dZN_{max}$ (or $dSN_{max}$), Dur, H | 0.837 (0.873) | 0.886 (0.886) | -0.049 (-0.013) |
| $SN_{max}$, $dLN_{max}$, Dur, H | 0.825 | 0.859 | -0.034 |

performing five-metric NASA test models (for instance, the $R^2$ values for the best $SN_{max}$-based four-metric model from the Purdue test is 0.032 higher than the $R^2$ value for the best $SN_{max}$-based five-metric model from the NASA test).

Figure 5.4 contains two plots of average annoyance versus predicted annoyance. In these plots, one of the more highly-correlated models from the NASA test is used to predict annoyance for the data from the Purdue test, and the best-correlated model from the Purdue test is used to predict annoyance for the data from the NASA test. The best-correlated model from the NASA test is not used in this figure, because it includes a metric that was excluded from the analysis of the Purdue data (i.e. $S_{max}$). Hence, the best-correlated four-metric model not containing $S_{max}$ is used. The best-correlated model from the Purdue test is used in this figure, because $SN_{15}$ was calculated for the NASA test sounds, even though it was not used in most of the analysis. The average annoyance values in this figure were averaged over both halves of each test, rather than separately over each half. Thus, the points in Figure 5.4(a) correspond to the 75 sounds common to both halves of the Purdue test and to the NASA test (i.e. seventy microphone-recorded sounds and five binaural-recorded sounds), while the points in Figure 5.4(b) correspond to all eighty sounds from the NASA test.

Table 5.4. Best-fit multiple-metric annoyance models for NASA and Purdue tests. Metric acronyms are given in Tables 3.1 and 4.1.

| **NASA** | | **Purdue** | |
|---|---|---|---|
| **Metrics** | **$R^2$** | **Metrics** | **$R^2$** |
| PL, $S_{max}$, Dur, H | 0.916 | PL, $dLN_{max}$, Dur, H | 0.880 |
| PL, $dZN_{max}$, $S_{max}$, Dur, H | 0.924 | | |
| $ZN_{max}$, $S_{max}$, Dur, H | 0.898 | $ZN_{max}$, $dLN_{max}$, Dur, H | 0.863 |
| $ZN_{max}$, $dZN_{max}$, $S_{max}$, Dur, H | 0.902 | | |
| ASEL, $S_{max}$, Dur, H | 0.914 | ASEL, $dLN_{max}$, Dur, H | 0.868 |
| ASEL, $dZN_{max}$ (or $dSN_{max}$), H, $S_{max}$, Dur | 0.917 | | |
| $LN_{max}$, $dSN_{max}$, Dur, H | 0.873 | $LN_{max}$, $dSN_{max}$ (or $dZN_{max}$), Dur, H | 0.886 |
| $LN_{max}$, $dSN_{max}$ (or $dLN_{max}$), $S_{max}$, Dur, H | 0.873 | | |
| $SN_{max}$, $dLN_{max}$, Dur, H | 0.825 | $SN_{max}$, $dLN_{max}$, Dur, H | 0.859 |
| $SN_{max}$, $dLN_{max}$, $S_{max}$, Dur, H | 0.827 | | |
| $SN_{20}$, $S_{max}$, Dur, H | 0.895 | $SN_{15}$, $dZN_{max}$, Dur, H | 0.893 |
| $SN_{20}$, $dSN_{max}$, $S_{max}$, Dur, H | 0.900 | | |

The correlations between the average annoyance and the predicted annoyance in these plots are not close to one-to-one; the Purdue test average annoyance ratings have a smaller range than the annoyance predicted by the NASA model, and the NASA test average annoyance ratings have a greater range than the annoyance predicted by the Purdue test model. This makes sense in light of the previous observation illustrated in Figure 5.1, that the ranges of responses in each test are different. However, the $R^2$ values are in the same range as the $R^2$ values of models that were generated from the data. The four-metric NASA model shown has an $R^2$ value of 0.870 in relation to the Purdue test data , while the Purdue test models have $R^2$ values of 0.859-

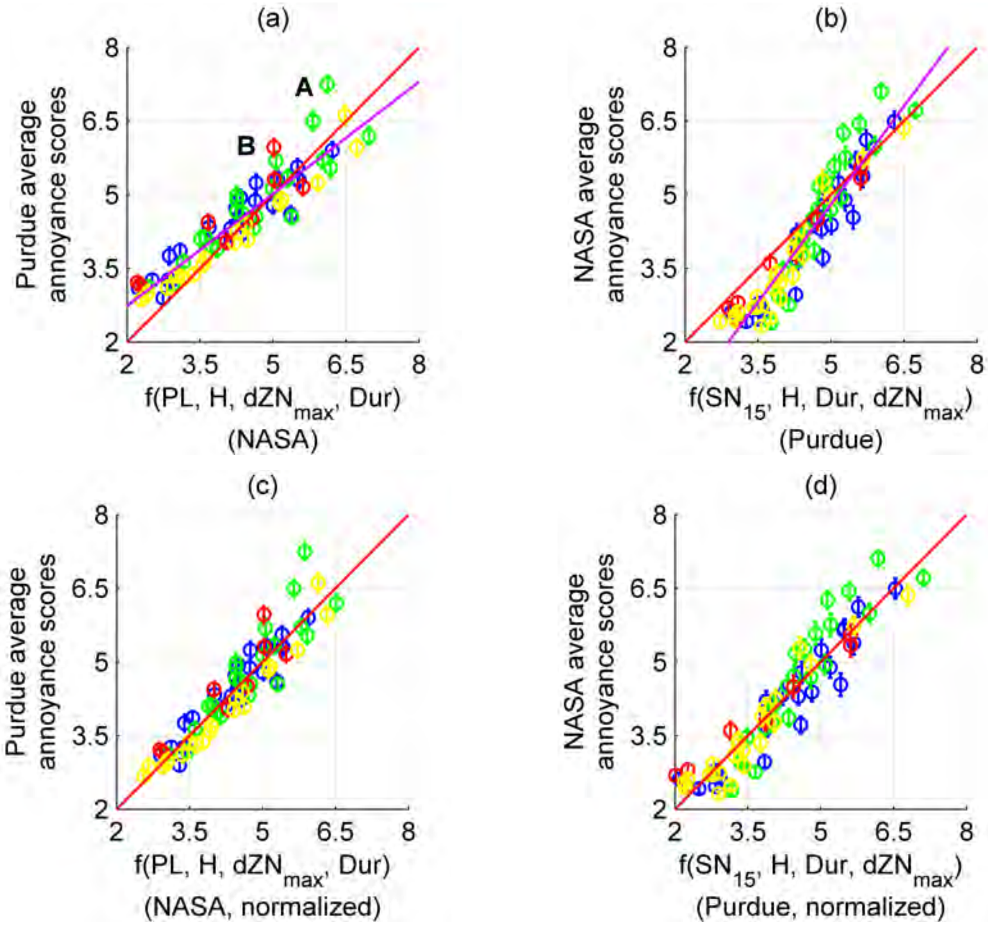


Figure 5.4. (a) Average annoyance from the Purdue test plotted against predicted annoyance values for the Purdue test sounds generated by a NASA test model; (b) average annoyance from the NASA test plotted against predicted annoyance values for the NASA test sounds generated by a Purdue test model. (c-d) Normalized models from (a) and (b). One-to-one correlation lines shown in red; best-fit lines in (a) and (b) shown in magenta. $R^2$ values are: (a) 0.870, (b) 0.889. Metric acronyms are given in Table 3.1. For information on color-coding, error bars, and subdivision of the axes, see Page 25.

0.853. Similarly, the four-metric Purdue test model shown has an $R^2$ value of 0.889 in relation to the NASA test data, while the NASA test models have $R^2$ values of 0.827-0.924. The two green points near the letter A in Figure 5.4(a) correspond to Sounds M32 and H32, which were generated from a loud synthetic boom. H32 was one of the sounds most under-predicted by the Purdue test models, and was recorded in the IER with a binaural head. The green point corresponding to the NASA test version of Sound 32 is clearly visible at the top of Figure 5.4(b). The red point near the letter B in Figure 5.4(a) corresponds to sound H55, which was generated from a 50-Hz high-pass filtered gunfire recording, and recorded in the IER with a binaural head. In the bottom corner of Figure 5.4(b), the points fall off steeply into a clump. This may be due to saturation effects.

As a final note, attention should be given to the Loudness mismatch between the Purdue test sounds and the NASA test sounds (as stated beginning at Page 79). In terms of analysis, the main concern regarding this mismatch is that it reduces the similarity between the two tests, thus limiting the kinds of conclusions that a researcher can draw from comparing the results from the two tests. The cause of the mismatch is not entirely certain; however, subsequent testing of the playback equipment revealed some amplitude distortion in the earphones and/or coupler, which may have contributed to the mismatch. The maximum A-weighted fast-averaged Sound Pressure Levels ($LAF_{max}$) of the Purdue test sounds are plotted in Figure 5.5, against the $LAF_{max}$ of the 25-Hz high-pass filtered recordings of the NASA test sounds (described on Page 79). The differences are all within 2.5 dBA, although the mean difference is only around 1.2 dB.

To examine the potential impact of this mismatch, the analysis recordings of the Purdue test sounds were multiplied by a factor of approximately 0.84. This adjustment reduced the mean difference in $LAF_{max}$ to around 0.6 dB. A new set of metrics was generated from these scaled sounds, and annoyance values were predicted from these metrics using the $SN_{15}$-based four-metric model from the Purdue test. These "adjusted" predicted values were more highly correlated to average annoyance values from the NASA test than were the predicted values from the actual Purdue test sounds, but only by a small margin (the $R^2$ value was increased from 0.886 to 0.890). Also noteworthy is that the adjustment of the Purdue sounds brought the higher $LAF_{max}$ values for the two tests closer, while causing the lower $LAF_{max}$ values to be too low. Thus, a simple scaling does not fully address the issue. One possible

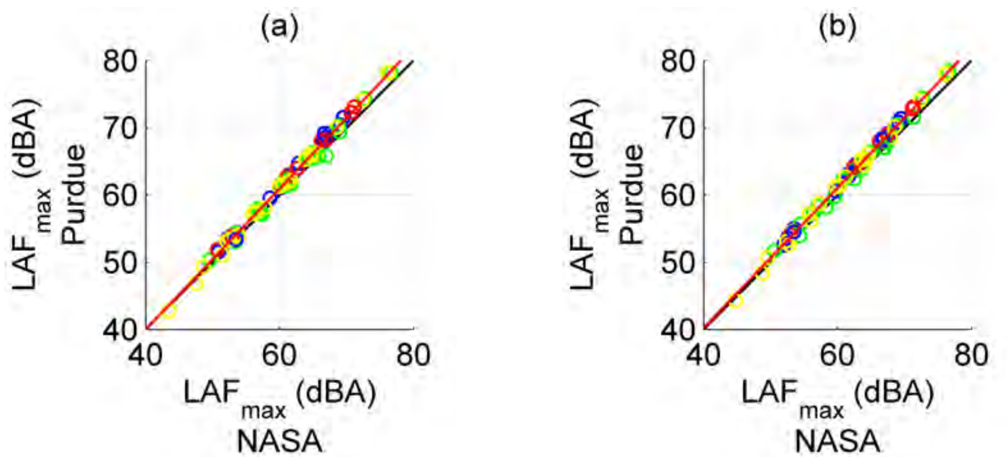


Figure 5.5. Maximum A-weighted Sound Pressure Level of Purdue test signals plotted against maximum A-weighted Sound Pressure Levels of 25-Hz high-pass filtered NASA test signals. (a) Plain chair; (b) isolated chair. $R^2$ values are 0.994 for both (a) and (b). For information on color-coding, error bars, and subdivision of the axes, see Page 25.

avenue of future research would be to more thoroughly measure the response of the earphones in Purdue's sound booth and generate a level-dependent scaling scheme.

## 5.3 Summary

The correlation between the results of the two tests is high in all cases ($R^2 > 0.942$), though the Purdue subjects, on average, used a smaller part of the range than the NASA subjects used. There are many possible explanations for this range difference. The highest $R^2$ values were for models of annoyance estimated from the NASA test data. However, models containing Moore & Glasberg maximum Loudness are more highly correlated to average responses in the Purdue test; this is true for both single- and multiple-metric models.

# 6. SUMMARY AND RECOMMENDATIONS FOR FUTURE WORK

In this thesis, two laboratory tests of annoyance to sonic booms and transient sounds heard indoors were described. The first test was performed in the Interior Effects Room (IER) at NASA Langley Research Center, which has superior low-frequency playback capabilities, provides a relatively natural subject environment, and also produces whole-body vibration cues. The average of annoyance ratings from the subjects in each of the two chairs were highly correlated, but also exhibited some effects possibly attributable to vibration. The best-performing annoyance model for the NASA test was a five-metric model containing Perceived Level (PL), maximum Zwicker Loudness Derivative ($dZN_{max}$), maximum von Bismarck Sharpness ($S_{max}$), Duration (Dur), and heaviness (H), with an $R^2$ value of 0.924.

The second test was performed in the Sound Quality Booth at Herrick Laboratories, Purdue University. This facility has less low-frequency playback capability but potentially superior high-frequency playback capability compared to the IER, and does not produce whole-body vibration. Average annoyance ratings between the parts of the test were highly correlated. The best-performing annoyance model for the Purdue test was a four-metric model containing Moore & Glasberg short-term Loudness exceeded 15% of the time ($SN_{15}$), maximum Zwicker Loudness Derivative ($dZN_{max}$), Duration (Dur), and Heaviness (H), with an $R^2$ value of 0.893 (or 0.901, using a similar Duration metric based on short-term Moore & Glasberg Loudness rather than on Zwicker Loudness).

The results of the NASA and Purdue tests were also compared with each other. Average annoyance values spanned a smaller range in the Purdue test than in the NASA test. This may be due to a number of factors: differences in subject group backgrounds and experiences, the presence of more low frequency content in the IER, the presence of vibration in the IER, the response input mechanism (which was easier to use in the NASA test), and/or the more realistic environment in the IER. The best-performing annoyance model from the NASA test produced an $R^2$ value 0.044 higher than did the best-performing annoyance model from the Purdue test. Annoyance models containing PL, maximum Zwicker Loudness ($ZN_{max}$), and A-weighted Sound Exposure Level (ASEL) are more highly correlated to responses in the NASA test than in the Purdue test, while models containing maximum Moore & Glasberg Loudness are more highly correlated to responses in the Purdue test than in the NASA test.

## 6.1 Recommendations for Future Work

1. In both tests, annoyance models containing Moore & Glasberg Loudness alone had significantly more outliers than did models containing PL, $ZN_{max}$, or ASEL alone. This may be due to the way that these metrics treat low-frequency content. It is recommended that the behavior of these loudness metrics at low frequencies be examined.

2. The effects of vibration on the results in the NASA test are still largely unclear. Rathsam, Loubeau, and Klos recommend that future tests be designed specifically to minimize transfer bias [41].

3. The factors influencing subjects' different use of the annoyance scale in the two tests may be examined. One possible approach for researchers at Purdue is to acquire a rotary dial for use in the Sound Quality Booth. This approach may confirm or discount the possibility that the input device used has a significant influence on subjects' use of the scale.

4. In both tests, annoyance models were generated using metrics of the indoor sounds that subjects heard. However, when conducting field tests, these metrics will be largely dependent on the house or building, and thus may not be the most robust in developing a widely applicable annoyance model that can be used to assess community annoyance and plan flight operations. It is recommended

that additional annoyance models be developed for the data from the two tests, using metrics of the original outdoor sounds rather than of the indoor sounds.

5. Further improvements may be made to Giacomoni's indoor simulation program. While the room reverberation portion of the program has been expanded and improved, the outdoor-to-indoor-transmission portion has not. Additionally, in listening to the simulated indoor sounds produced by the program, it was discovered that at least one simulated sound had significantly less high-frequency content than did the indoor sound recorded in the IER. It is not certain at what point in the program the simulated sound diverged the most from the recorded sound. Notwithstanding, it is recommended that Giacomoni's transmission filters be improved, and that a more accurate filter be designed if possible.

# LIST OF REFERENCES

# LIST OF REFERENCES

[1] A. Loubeau, J. Rathsam and J. Klos. Evaluation of an indoor sonic boom subjective test facility at NASA Langley Research Center. In *Proceedings of Meetings on Acoustics*, Volume 12, 040007, Seattle, Washington, USA, June 2011. Acoustical Society of America. Abstract published in *Journal of the Acoustical Society of America* 129: 2379, 2011.

[2] B. M. Sullivan, J. Klos and E. A. Haering. Human response to low-intensity sonic booms heard indoors and outdoors. NASA Technical Memorandum NASA/TM–2010-216685, NASA Langley Research Center, Hampton, Virginia 23681-2199, April 2010.

[3] L. J. Cliatt, E. A. Haering, T. P. Jones, M. D. Holtz, A. K. Parham, S. L. Wiley and E. R. Waggoner. A flight research overview of the Waveforms and Sonic-boom Perception and Response Project, the National Aeronautics and Space Administration's pilot program for sonic boom community response research. In *Proceedings of Meetings on Acoustics*, volume 19, 040044, Montreal, Quebec, Canada, 2013. Acoustical Society of America. Montreal, Quebec, Canada. Abstract published in *Journal of the Acoustical Society of America* 133: 3368, 2013.

[4] B. M. Sullivan, P. Davies, K. K. Hodgdon, J. A. Salamone and A. Pilon. Realism assessment of sonic boom simulators. *Noise Control Engineering Journal*, 56(2):141–157, 2008.

[5] C. Giacomoni. *Sound quality of supersonic aircraft noise as heard indoors and its impact on annoyance*. MS thesis, Purdue University, 2012.

[6] J. Klos. Overview of an indoor sonic boom simulator at NASA Langley Research Center. In *Proceedings of InterNoise 2012*, Paper Number 1335, pp. 8973–8983, New York City, USA, August 2012.

[7] A. Loubeau, J. Rathsam and J. Klos. Draft of a NASA Technical Memorandum describing the Interior Effects Room at NASA Langley. Technical report, NASA/TM–####-######, NASA Langley Research Center, 2014. Publication pending.

[8] B. M. Sullivan and J. D. Leatherwood. A laboratory study of subjective response to sonic booms measured at White Sands Missile Range. NASA Technical Memorandum NASA/TM–107746, NASA Langley Research Center, Hampton, Virginia 23681-0001, May 1993.

[9] B. M. Sullivan and J. D. Leatherwood. Subjective response to simulated sonic booms with ground reflections. NASA Technical Memorandum NASA/TM–107764, NASA Langley Research Center, Hampton, Virginia 23681-0001, June 1993.

[10] J. D. Leatherwood and B. M. Sullivan. Laboratory study of effects of sonic boom shaping on judged loudness and acceptability. *Noise Control Engineering Journal*, 42(2):59–69, 1994.

[11] A. Niedzwiecki and H. S. Ribner. Subjective loudness of *N*-wave sonic booms. *Journal of the Acoustical Society of America*, 64(6):1617–1621, 1978.

[12] D. R. Johnson and D. W. Robinson. Procedure for calculating the loudness of sonic bangs. *Acta Acustica united with Acustica*, 21(6):307–318, 1969.

[13] A. Niedzwiecki and H. S. Ribner. Subjective loudness of "minimized" sonic boom waveforms. *Journal of the Acoustical Society of America*, 64(6):1622–1626, 1978.

[14] A. Niedzwiecki and H. S. Ribner. Subjective loudness and annoyance of filtered *N*-wave sonic booms. *Journal of the Acoustical Society of America*, 65(3):705–707, 1979.

[15] J. D. Leatherwood and B. M. Sullivan. Laboratory study of effects of sonic boom shaping on subjective loudness and acceptability. NASA Technical Paper NASA-TP-3269, NASA Langley Research Center, Hampton, Virginia 23681-0001, October 1992.

[16] J. D. Leatherwood and B. M. Sullivan. Effect of sonic boom asymmetry on subjective loudness. NASA Technical Memorandum NASA-TM-107708, NASA Langley Research Center, Hampton, Virginia 23665-5225, December 1992.

[17] Y. Naka. Subjective evaluation of loudness of sonic booms indoors and outdoors. *Acoustical Science and Technology*, 34(3):225–228, 2013.

[18] J. D. Leatherwood, B. M. Sullivan, K. P. Shepherd, D. A. McCurdy and S. A. Brown. Summary of recent NASA studies of human response to sonic booms. *Journal of the Acoustical Society of America*, 111(1, part 2):586–598, 2002.

[19] A. Marshall. *A preliminary investigation into the perceptual characteristics of low level sonic booms heard outdoors.* MS thesis, Purdue University, 2007.

[20] A. Marshall. *Development of a model of startle resulting from exposure to sonic booms.* PhD thesis, Purdue University, 2012.

[21] D. A. McCurdy, S. A. Brown and R. D. Hilliard. Subjective response of people to simulated sonic booms in their homes. *Journal of the Acoustical Society of America*, 116(3):1573–1584, 2004.

[22] K. D. Kryter, P. J. Johnson and J. R. Young. Psychological experiments on sonic booms conducted at Edwards Air Force Base. Stanford Research Institute Final Research Report 689844, National Sonic Boom Evaluation Office, 1400 Wilson Boulevard, Arlington, Virginia 22209, August 1968.

[23] R. N. Vasudevan and H. G. Leventhall. A study of annoyance due to low frequency noise in the home. *Journal of Low Frequency Noise and Vibration*, 1(3):157–164, 1982.

[24] N. Broner and H. G. Leventhall. A criterion for predicting the annoyance due to higher level, low frequency noise. *Journal of Sound and Vibration*, 84(3):443–448, 1982.

[25] N. Broner and H. G. Leventhall. A modified PNdB for assessment of low frequency noise. *Journal of Sound and Vibration*, 73(2):271–277, 1980.

[26] P. D. Schomer. High-energy impulsive noise assessment. *Journal of the Acoustical Society of America*, 79(1):182–186, 1986.

[27] P. D. Schomer, J. W. Sias and D. Maglieri. A comparative study of human response, indoors, to blast noise and sonic booms. *Noise Control Engineering Journal*, 45(4):169–182, 1997.

[28] P. D. Schomer and J. W. Sias. On spectral weightings to assess human response, indoors, to blast noise and sonic booms. *Noise Control Engineering Journal*, 46(2):57–71, 1998.

[29] J. Vos. Annoyance caused by impulse sounds produced by small, medium-large and large firearms. In *Proceedings of InterNoise 1996*, pp. 2231–2236, Liverpool, England, August 1996.

[30] H. H. Hubbard and K. P. Shepherd. Comparisons of methods for predicting community annoyance due to sonic booms. NASA Technical Memorandum NASA-TM-110289, NASA Langley Research Center, Hampton, Virginia 23681-0001, November 1996.

[31] P. D. Schomer. Human response to house vibrations caused by sonic booms or air blasts. *Journal of the Acoustical Society of America*, 64(1):328–330, 1978.

[32] K. D. Kryter. Laboratory tests of physiological-psychological reactions to sonic booms. *Journal of the Acoustical Society of America*, 39(5):65–72, 1966.

[33] C. W. Nixon and P. N. Borsky. Effects of sonic boom on people: St. Louis, Missouri, 1961-1962. *Journal of the Acoustical Society of America*, 39(5), part 2:51–58, 1966.

[34] C. A. Powell and K. P. Shepherd. Aircraft noise induced building vibration and effects on human response. In *Proceedings of InterNoise 1989*, pp. 567–572, Newport Beach, California, USA, December 1989.

[35] D. J. Maglieri and K. J. Plotkin. Sonic boom. In H. H. Hubbard, editor, *Aeroacoustics of Flight Vehicles: Theory and Practice. Volume 1: Noise Sources*, number 1258 in NASA Reference Publication, chapter 10, pp. 550–556. National Aeronatics and Space Administration, August 1991.

[36] R. Paulsen and J. Kastka. Effects of combined noise and vibration on annoyance. *Journal of Sound and Vibration*, 181(2):295–314, 1995.

[37] E. Öhrström. Effects of exposure to railway noise–a comparison between areas with and without vibration. *Journal of Sound and Vibration*, 205(4):555–560, 1997.

[38] J. M. Fields. Reactions of residents to long-term sonic boom noise environments. NASA Contractor Report (Wyle Laboratories) NASA-CR-201704, NASA Langley Research Center, Hampton, Virginia 23681-0001, June 1997.

[39] J. Rathsam, A. Loubeau and J. Klos. A study in a new test facility on indoor annoyance caused by sonic booms. NASA Technical Memorandum NASA/TM–2012-217332, NASA Langley Research Center, Hampton, Virginia 23681-2199, February 2012.

[40] B. Gardner and K. Martin. *HRTF measurements of a KEMAR dummy-head microphone.* MIT Media Lab, May 1994. [Online.] Available: http://alumni.media.mit.edu/ kdm/hrtfdoc/hrtfdoc.html.

[41] J. Rathsam, J. Klos and A. Loubeau. Influence of floor vibration on indoor sonic boom annoyance. In P. Blanc-Benon, V. W. Sparrow, and D. Dragna, editors, *AIP Conference Proceedings*, Volume 1685, pp. 090014–1–090014–4. AIP Publishing LLC, October 2015. Presented at the *20th International Symposium of Nonlinear Acoustics*, June-July 2015, Ecully, France. Paper number 090014.

[42] M. J. Griffin. *Handbook of Human Vibration.* Academic Press Incorporated, San Diego, California, USA 92101, 2 edition, 1990. ISBN 0-12-303040-4.

[43] J. Rathsam. (email correspondence), August 2014. Engineer and researcher at the Structural Acoustics Branch, NASA Langley Research Center. Contact information: jonathan.rathsam@nasa.gov.

[44] A. Loubeau. (email correspondence), September 2014. Engineer and researcher at the Structural Acoustics Branch, NASA Langley Research Center. Contact information: a.loubeau@nasa.gov.

[45] J. S. Milton and J. C. Arnold. *Introduction to Probability and Statistics: Principles and Applications for Engineering and the Computing Sciences.* McGraw-Hill, Inc., New York, NY 10020, 3 edition, 1995. ISBN 0-07-042623-6.

[46] American National Standards Institute, Inc. *Procedure for the computation of loudness of steady sounds.* Acoustical Society of America, 2007. ANSI S3.4-2007 (revision of ANSI S3.4-2005). Reaffirmed by ANSI on June 15, 2012.

[47] D. Carr and P. Davies. A laboratory study on perception of supersonic aircraft noise as heard indoors. In *Proceedings of InterNoise 2015*, Paper Number 832, pp. 5838–5847, San Francisco, California, USA, August 2015.

[48] D. Carr and P. Davies. An investigation into the effect of playback environment on perception of sonic booms when heard indoors. In P. Blanc-Benon, V. W. Sparrow, and D. Dragna, editors, *AIP Conference Proceedings*, Volume 1685, pp. 090013–1–090013–4. AIP Publishing LLC, October 2015. Presented at the *20th International Symposium of Nonlinear Acoustics*, June-July 2015, Ecully, France. Paper number 090013.

[49] J. S. Bolton. (personal communication), fall 2014. Professor of Mechanical Engineering, Purdue University. Contact information: 765-494-2139, bolton@purdue.edu.

APPENDICES

# A. DESCRIPTION OF METRICS

In this appendix, the exact that were used to generate the sound metrics used in the analysis of the results of the two tests are described. Metrics were generated either by using MATLAB or by using HEAD Analyzer ArtemiS Classic. It should be noted that the versions of ArtemiS software used to generate these metrics were SUITE 6.1.1503.901 and Classic 12.2.0.2.

## A.1 General Descriptions

Stevens' Perceived Level was generated by using an edited version of a MATLAB code developed by Mr. John Louis of Gulfstream.

Table A.1. General overview of methods used to calculate metrics used in the NASA and Purdue tests. Metric acronyms are given in the Nomenclature.

| **Metric** | **Calculation** |
|---|---|
| A- and C-weighted SPL time histories | ArtemiS |
| Moore & Glasberg Loudness time histories | C++ program |
| von Bismarck Sharpness time histories | ArtemiS |
| Zwicker Loudness time histories, $ZN_{max}$ | ArtemiS |
| ASEL | MATLAB |
| Dur | MATLAB |
| $dLN_{max}$, $dSN_{max}$, $dZN_{max}$ | MATLAB |
| H | MATLAB |
| PL | MATLAB |
| $S_{max}$ | MATLAB |
| $SN_E$, $LN_{Et}$ | MATLAB |
| $SN_{max}$, $LN_{max}$ | MATLAB |

Zwicker Loudness time histories were generated by using HEAD Analyzer ArtemiS. Maximum values were also recorded by using ArtemiS. The sound field was specified as diffuse, based on the dimensions of the room [49].

von Bismarck Sharpness time histories were generated by using ArtemiS. They were based on diffuse-field Zwicker Loudness. Maximum values were recorded using MATLAB.

A- and C-weighted Sound Pressure Level (SPL) time histories were generated by using HEAD Analyzer ArtemiS software. They were fast-averaged, with no down-sampling.

Moore & Glasberg loudness time histories were generated by using a C++ program developed by Mr. Andrew Marshall, a former student at Herrick Laboratories. Maximum values were recorded by using MATLAB.

The three Loudness Derivative metrics were generated by using a MATLAB differentiator. A 15-point combined differentiator and low-pass filter was designed by using the function FIRPM, with a transition region from $0.2f_s$ to $0.4f_s$. The sampling frequencies for the loudness time histories (and used in the filter design) were $f_s = 375$ Hz for Zwicker loudness, and 1000 Hz for Moore & Glasberg loudness. The maximum loudness derivative *before* the first loudness peak of each sound was chosen, to account for startle effects.

Sound Exposure Levels (SEL) were generated in MATLAB, using trapezoidal integration of the weighted sound pressure level (SPL) time histories. First, the SPL time histories from ArtemiS (in dB) were taken and converted to pressure squared. Second, the pressure-squared time histories were integrated to produce the sound exposure. Integration was performed between the first time that the SPL exceeded 10 dB below maximum, and the last time that the SPL dropped below 10 dB below maximum. The sound exposure was then converted to dB to produce SEL. Both A-weighted (ASEL) and C-weighted Sound Exposure Levels (CSEL) were calculated.

An alternative algorithm for SEL was also considered. In that algorithm, the pressure time histories were passed through a weighting filter and squared. A moving-average filter was not applied. To find the integration interval, the pressure squared time histories were converted to instantaneous dB ref 20 $\mu$Pa, and the first and last intersections of the SPL time history with 10 dB down from maximum were taken. The pressure squared time histories were then integrated, and the resulting sound exposure was converted to dB ref 400 $\mu$Pa/s. This algorithm was used to calculate alternative ASEL values for the Purdue test data, and the two ASEL metrics were compared. The correlation was almost exactly one-to-one, with $R^2$ values of over 0.999. However, these alternate values were not used in the final analysis. This was because the SPL time histories from ArtemiS were generated using time averaging, whereas the alternative algorithm used only instantaneous SPL and pressure squared time histories (the proper specifications for averaging not being known).

Heaviness was calculated by subtracting ASEL from CSEL.

Duration and Loudness-exceeded metrics were generated in MATLAB. Multiple algorithms were considered, from which one was chosen for each metric. A detailed description of this process is given in the following sections of this appendix.

Integrated Loudness metrics were generated in MATLAB by using trapezoidal integration. The Zwicker and Moore & Glasberg Loudness time histories (in sones) were integrated between the first time that Loudness exceeded half the maximum value, and the last time that Loudness became lower than half the maximum value. Time-Divided Integrated Loudness metrics were also generated, by dividing the Integrated Loudness by the time interval over which integration was performed.

## A.2 A Detailed Description of Duration

The particular Duration metric used in the analysis of the NASA test signals was selected from eight possible definitions of signal duration. Of these eight metrics, four were based on Zwicker loudness and four were based on short-term Moore & Glasberg Loudness. These metrics were generated by using two different methods for determining the noise floor:

1. Manual. In this method, the noise floor was determined by selecting the small segment of background noise at the front end of the signal, and setting the noise floor at three standard deviations above the mean loudness of that segment.
2. Automatic. In this method, the noise floor was set at a fixed value chosen to reflect the noise floor observed in sound recordings from the Purdue test. (The primary metric analysis of the NASA test data took place after the Purdue test was completed.)

Additionally, two different methods were used for defining the actual duration:

1. Plain. In this method, the duration was defined by the first and last times that the loudness time history intersected the noise floor.
2. Extended. In this method, the slopes of the loudness time history at these two times were calculated (using the same differentiator that was used to generate the loudness derivative metrics), the loudness time history was linearly extrapolated down to the time-axis, and the duration was defined by the two times where the extrapolated time history intersected the time-axis. The instantaneous Loudness slope was used for the Moore & Glasberg-based durations, and the 9-point averaged slope was used for the Zwicker-based durations.

The final Duration metric was chosen on the basis of which version contributed most when incorporated into five-metric models, i.e. which produced the highest $R^2$ values. Accordingly, the Zwicker-based Duration metric with an automatic noise floor and plain endpoints was chosen. In the first round of examination, the noise floor was set at 0.3 sones. In the second round of examination (some scaling and filtering issues on the metrics having been corrected), only the two automatic Duration metrics with plain ends were examined. The noise floor was also reset to 0.23 sones.

Four different duration metrics were generated for the Purdue test: two based on Zwicker loudness and two based on short-term Moore & Glasberg loudness. The background noise was significantly more easily visible in the Purdue test sounds than in the NASA test sounds, although it was low enough to be considered negligible (about 0.11

sones Zwicker in the right ear, and about 0.2 sones Zwicker in the left ear). Hence, the noise floor was defined as three standard deviations above the mean loudness of the background noise segments (both before and after the main event). Durations were defined both by the noise floor intersections and by the extrapolated time-axis intersections. As in the durations calculated for the NASA test, the time-axis method incorporated instantaneous slopes in the Moore & Glasberg-based durations, and 9-point averaged slopes in the Zwicker-based durations. Another important observation in the time-axis method is that the Zwicker time-histories contain a significant amount of high-frequency oscillations on the trailing end of the event, which skews the slope averaging. To correct for this, the Zwicker time-histories were smoothed with a 25-point moving average filter before calculating the average trailing-end slope.

The Zwicker-based Duration metric with plain endpoints was chosen for use in the Purdue test. In the first round of examination, the $R^2$ values of the four single-metric Duration models were within 0.1 of each other, with the $R^2$ value of plain Zwicker Duration being the highest (although by a narrow margin). Substituting the other three durations in multiple-metric models did not change the $R^2$ values by more than 0.01. The Moore-&-Glasberg plain Duration outperformed the Zwicker plain Duration in two cases (raising the $R^2$ value of the four-metric models by up to 0.002), underperformed in one case (reducing the $R^2$ value of a four-metric model by 0.003), and had no noticeable effect on the $R^2$ values of the four remaining four-metric models. Thus the Zwicker-based plain Duration appeared to be the best. In the second round of examination (some scaling and filtering issues on the metrics having been corrected), only the two plain Durations were considered. The Moore-&-Glasberg plain Duration raised the $R^2$ value of the $SN_{15}$-based four-metric model (the best model) by 0.008 (i.e. from 0.893 to 0.901), and of the $ZN_{max}$-, ASEL-, $LN_{max}$-, and $LN_{Et}$-, based models by 0.001-0.002. It also reduced the $R^2$ value of the $SN_{max}$-based model by 0.001, and had no noticeable effect on the $R^2$ value of the four-metric model based on PL. This would seem to indicate that Moore & Glasberg-based Duration was generally a better choice for use in Purdue test models, by a small margin. However, given that a Zwicker-based Duration was already shown to result in more highly correlated annoyance models in the NASA test, and that the greatest $R^2$ value of the NASA test models significantly exceeded the greatest $R^2$ value of the Purdue test models, the Zwicker-based Duration was retained in the main part of the Purdue test analysis.

## A.3 A Detailed Description of Percentile Loudness

The term "Percentile Loudness" as it is used in this thesis denotes a Loudness value exceeded a certain percent of the time. Percentile Loudness metrics were calculated in 5% increments from 5-50%. Since Loudness exceeded a percentage of the time requires an estimate of "the time", these Percentile Loudness metrics were generated for each Duration metric described in section A.2. Since the sounds in the tests were all transients, it was important to ensure that Percentile Loudness calculations were performed only on the main events, and not on the background noise. To ensure this, the main event of each signal was extracted from the sound file using the intercepts calculated in the Duration metrics. For noise-floor Durations, an additional 0.1 seconds of sound outside of each intercept was included. For time-axis durations, on the other hand, the background noise was cut off exactly at the intercepts. The final Percentile Loudness metrics used in the analyses for each test were chosen 1) depending on how greatly the correlation of multiple-metric models increased when Percentile Loudness was substituted for Maximum Loudness, 2) in order to be based on the kind of Duration metric that was accepted for the final analysis, whether plain or extrapolated, or with manual or automatic noise floor, and 3) in order to have a percentage closest to 10% or 5%. (This last criterion was used simply because judging by the first two criteria alone did not yield a single five-metric model with a significantly higher $R^2$ value than the others). For the NASA test, the metric chosen was short-term Moore & Glasberg Loudness exceeded 20% of the time, based on Moore & Glasberg Duration with plain ends and an automatic noise floor. For the

Purdue test, the metric chosen was short-term Moore & Glasberg Loudness exceeded 15% of the time, based on Moore & Glasberg Duration with plain ends. (It should be noted that these metrics were based on Moore & Glasberg Duration rather than Zwicker Duration, even though Zwicker Duration was used in both tests. This is because the increase in $R^2$ value from using Zwicker Percentile Loudness instead of $ZN_{max}$ in five-metric models was much less than the increase in $R^2$ value from using short-term Moore & Glasberg Percentile Loudness metrics rather than $SN_{max}$. The method for calculating the Duration metric was still the same.)

# B. DESCRIPTION OF SIMULATION PROCEDURE USED IN THE PURDUE TEST

In the test conducted at Herrick Laboratories (described in Chapter 4), five sounds were generated by using a transmission and simulation code which was developed by previous Herrick student Clothilde Giacomoni, and revised and expanded by the present author and by previous Herrick student Yingxiang Jiang. These five sounds were generated from the original outdoor source signals used in the NASA test, and the simulation code was set up to approximate the indoor sounds received by a subject's ears in the isolated chair in NASA Langley's Interior Effects Room (IER).

To generate the simulated sounds, the inputs to the simulation code were selected to approximate the dimensions and indoor acoustic environment of the IER. Materials were selected to approximate the 60-dB reverberation times of the IER (both the Sabine and Eyring-Norris octave-band times and the reverberation time of the measured room impulse response). However, they do not necessarily reflect the actual materials used to build the IER. The receiver location was set to approximate the position of a subject's head while seated in the vibration-isolated chair. The loudspeaker arrays were represented as two point sources, each at the center of their respective walls; and single impulse responses were generated for each source and summed to produce the full room impulse response. The larger reverberation simulation program allows for the option of two different transmission filters to be applied to the outdoor signal. The least aggressive of these filters was chosen, in order to most closely match the level of the simulated sound with the level of the actual indoor sound. In addition, to more closely match the reverberation time of the IER, the number of reflection paths in each dimension calculated by *ReverbProg* was increased.

A diagram of the IER is included in Figure B.1. This is based on a diagram that appears in a currently unpublished NASA technical report, in which the construction and acoustical properties of the IER are described [7]. The dimensions of the room and the locations of the sources and receiver are measured relative to the origin shown in red.

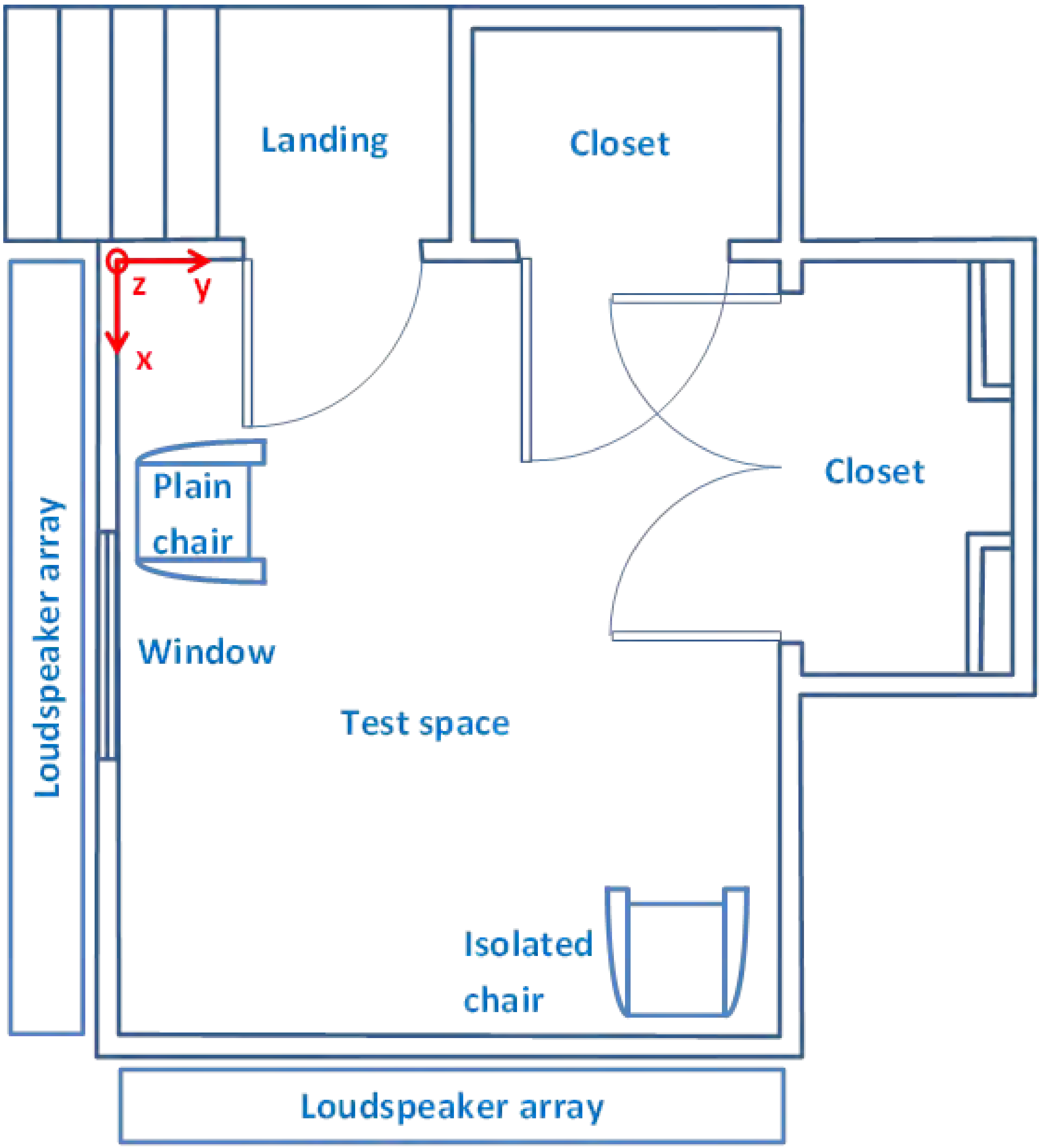


Figure B.1. Diagram of the setup of the Interior Effects Room (IER) at NASA Langley.

The exact specifications sent to the simulation code are as follows:

**Room dimensions** (measured relative to the origin shown in Figure B.1)

$(X, Y, Z) =$ (13 ft 5 in, 11 ft 4 in, 8 ft 4 in)

$\approx$ (4.09 m, 3.45 m, 2.54 m)

**Receiver location** (measured relative to the origin shown in Figure B.1)

$(x_R, y_R, z_R) =$ (12 ft 2 in, 10 ft, 5 ft 5 in)

$\approx$ (3.71 m, 3.05 m, 1.65 m)

**Source locations** (centers of wall)

$(x_{S1}, y_{S1}, z_{S1}) =$ (6 ft 8.5 in, 0 ft, 4 ft 2 in)

$\approx$ (2.04 m, 0 m, 1.27 m)

$(x_{S2}, y_{S2}, z_{S2}) =$ (13 ft 5 in, 5 ft 8 in, 4 ft 2 in)

$\approx$ (4.09 m, 1.73 m, 1.27 m)

**Room materials** (as numbered and described in Giacomoni's database file)

Floor: material 511 (Carpet, heavy, w/impermeable latex on foam rubber)

Ceiling: material 387 (Gypsum board, 5/8” screwed to 1x3studs, 16”oc, ins.)

Walls: material 385 (Gypsum board, 2+2 @ 5/8” on 3-5/8” studs)

# C. INDOOR SIMULATION PROGRAMS

This appendix contains the codes for the revised version of Clothilde Giacomoni's MATLAB programs for simulating indoor sounds.

## C.1 Stage 1: Room Impulse Response

This function is called *ReverbProg_HilbR_rev4*. It was written by Clothilde Giacomoni and revised by the present author. It is the main code for calculating reverberation impulse responses for a room of given dimensions and materials, with a single point source and receivers (microphone or binaural head or both) at given locations.

Inputs for this function may be entered manually, or by calling values from a Microsoft Excel file. Manual inputs are:

- $X$, $Y$, and $Z$: dimensions of room, in feet or meters
- $a$, $b$, and $d$: coordinates of point source relative to low southwest corner of room, in feet or meters
- $x$, $y$, and $z$: coordinates of receiver relative to low southwest corner of room, in feet or meters
- $floorabs$, $ceilabs$, $wwallabs$, $ewallabs$, $nwallabs$, and $swallabs$: reference numbers for materials of each surface in the room: floor, ceiling, and west, east, north, and south walls
- $unitsfm$: specifies English or SI units
- $fs$: sampling frequency, in Hz
- $hangle$: the angle of a binaural head receiver, measured counterclockwise relative to the east point of the compass (i.e. the positive x-axis), in degrees

If only one input is specified, *ReverbProg_HilbR_ref4* interprets the input as a row number in a Microsoft Excel file containing sets of input values, and reads the specified set of inputs out of the file.

Outputs returned by the function vary depending on the number of outputs specified by the user. The first output is always the time vector. The other outputs are: the room impulse response picked up by a microphone (if one other output is specified), the room impulse responses picked up by the left and right ears of a binaural head (if two other outputs are specified), or all three (if three other outputs are specified). Note: this function only returns the room impulse response produced by a single source, and measured by a receiver at a single location. If an impulse response produced by multiple sources is desired, the function must be run once for each source (with the receiver type and location held constant), and the resulting impulse responses must be summed.

**Example:** a command of [t, hL, hR] = ReverbProg_HilbR_rev4(217) reads inputs from line 217 in the Excel input file, and returns the two room impulse responses picked up by a binaural-head, and their time vector.

```
function [t,varargout] = ReverbProg(X,Y,Z,a,b,d,x,y,z,floorabs,ceilabs,wwallabs,ewallabs,nwallabs,
    swallabs,unitsfm,fs,hangle)
% This Fourth Revision of 'HilbR' ReverbProg attempts to streamline the
% program logic by:
%    - assigning the time histories to VARARGOUT, thus eliminating the need
%    for 'hrtfyn'
%    - automatically switching between XLS and manual input using NARGIN
%    - changing the windowing function from Daniel's and Chloe's
%     'fs2rolloff' to Yingxiang's 'smoothcos'
%
% This version also incorporates an expanded version of program
% 'find_hrtf', which allows HRTFs to be used not only at fs = 44.1 kHz, but
% also at any sampling frequency greater than 44.1 kHz.
%
%  NOTE: this version cannot ignore the ear signals if both are requested
%  at the wrong sampling frequency. It will return an error message and
%  stop.
%
% This function takes the dimensions of a room (X,Y,Z), source location
% (a,b,d), receiver location (x,y,z), the materials used to make up each
% surface in the room, and the sampling frequency (fs), and calculates the
% impulse response. The variable 'unitsfm' can be either 1 if the
% dimensions are in meters or 2 if the dimensions are in feet.
%
```

```
% %source location - a distance from west wall to source
%                - b distance from south wall to source
%                - d distance from floor to source
%
% %receiver location - x distance from west wall to receiver
%                  - y distance from south wall to receiver
%                  - z distance from floor to receiver

%% Option of importing input values from Excel file

if nargin == 1
batchnum=X;
[X,Y,Z,a,b,d,x,y,z,floorabs,ceilabs,wwallabs,ewallabs,nwallabs,swallabs,unitsfm,hangle,~,fs]=XLSinput(
     batchnum);
end

fs_hrtf=44100; % Sampling frequency at which head-related transfer functions (HRTFs) were made

%% Main warning- and error-generating codes

% For room dimensions
if X <= 0
error('Parameter ''X'' must be greater than zero.')
elseif Y <= 0
error('Parameter ''Y'' must be greater than zero.')
elseif Z <= 0
error('Parameter ''Z'' must be greater than zero.')

% For source/receiver locations
elseif a > X || a < 0
error('Parameter ''a'' must be between 0 and X.')
elseif x > X || x < 0
error('Parameter ''x'' must be between 0 and X.')
elseif b > Y || b < 0
error('Parameter ''b'' must be between 0 and Y.')
elseif y > Y || y < 0
error('Parameter ''y'' must be between 0 and Y.')
elseif d > Z || d < 0
error('Parameter ''d'' must be between 0 and Z.')
elseif z > Z || z < 0
error('Parameter ''z'' must be between 0 and Z.')

% For HRTFs
elseif fs < fs_hrtf && nargout > 2
```

```
error('Parameter ''fs'' must be 44100 or greater in order to generate ear signals. Consider raising ''
     fs'' or specifying fewer output arguments.');
end

%% Problem setup

%disk='C:\Users\cgiacomo\Desktop\Simulation\DECEMBER';

S=1;              % source power

%cd(disk)
ABS=load('Absorption_Coefficients');
ALPHAS=ABS.ALPHAS;

[RTm,RTf]=T60(X,Y,Z,floorabs,ceilabs,wwallabs,ewallabs,nwallabs,swallabs); %time to decay [seconds]
%disp(['RTf = ' num2str(RTf)])
if unitsfm == 1   % specify units
RT = RTm(4);   % Pick RT at 1kHz
c=343;         % speed of sound [m/s]
elseif unitsfm == 2
RT = RTf(4);   % Pick RT at 1kHz
c=1125;        % speed of sound [ft/s]
else
error('Parameter ''unitsfm'' must be 1 or 2.');
end

if fs == fs_hrtf       % Number of points in impulse response
N=2^nextpow2(fs*RT); % FFT and IFFT functions work most efficiently with powers of 2
elseif fs > fs_hrtf
N=fs*ceil(RT*25)/25; % Frequency domain vector must contain both half-sampling frequencies exactly;
     powers of 2 are non-feasible
end

Nx=ceil(RT*c/X/2);
Ny=ceil(RT*c/Y/2);
Nz=ceil(RT*c/Z/2);

%Nx=ceil(RT*c/X/1.5);
%Ny=ceil(RT*c/Y/1.5);
%Nz=ceil(RT*c/Z/1.5);

f=(0:N/2)*fs/N;    % 1/2 frequency domain [Hz]
nk=length(f);
```

```
%% Reflection coefficients for floor/ceiling/walls

fprintf(1,'%s\n\t','Generating reflection coefficient spectra:');
abs_ind=[floorabs ceilabs wwallabs ewallabs nwallabs swallabs];

R_FCWENS=zeros(6,nk); % Reflection coefficient matrix; 'FCWENS' stands for 'floor, ceiling, west/east/
    north/south walls'

for index=1:6
%disp(['   ' num2str(index) '...'])
fprintf(1,'%d%s',index,'...');

% Absorption coefficient input matrix. This calls Sabine absorptivity
% values from source file in octave bands from 125 Hz to 8 kHz.
% [125 250 500 1k 2k 4k 8k]
alpha_inp = ALPHAS(ALPHAS(:,1)==abs_ind(index),2:end);

% Calculate reflection coefficient octave-band data, and set four
% additional octave-band values (15.6, 31.3, 62.5, 16k) to zero. NOTE:
% taking only the real part effectively confines the alpha values at 1
% or below.
R_inp=[0 0 0 real(sqrt(1-alpha_inp)) 0];

% Program 'myOctHilbert' generates a complex curve of reflection
% coefficients across the entire 1/2-frequency domain
%[~,R_full,~,~]=myOctHilbert(R_inp,RT,fs);
[~,R_full,~,~]=myOctHilbert(R_inp,f);
R_FCWENS(index,:)=R_full; % Insert curve into reflection coefficient matrix
end
fprintf(1,'%s\n\n%s\n\t%s','done!','Generating reflections:','nx = ');

%% Image sources, pathlengths, times, number of reflections, and pressure arrays
counter=1;
ind_lim=3;

pressure=zeros(1,nk);             % set up pressure arrays
pressure_L=zeros(1,nk);
pressure_R=zeros(1,nk);
info_matrix=zeros(1,20);
display=zeros((ind_lim*2-1)^3,20); % set up abbreviated output matrix

for nx=-Nx:Nx
fprintf(1,'%3.0f\n\t\t%5s',nx,'ny = ');
p=2*round((nx/2)+.01);
```

```
ExpE=abs(p/2);                % Number of reflections off east wall
ExpW=abs(round(((nx-1)/2)+.01)); % Number of reflections off west wall
image_x = p*X + (-1)^nx*a;    % image source x coordinate
dis_x = image_x-x;            % image source x coordinate relative to receiver

for ny=-Ny:Ny
fprintf(1,'%3.0f%3s',ny,'...');
q=2*round((ny/2)+.01);
ExpN=abs(q/2);                % Number of reflections off north wall
ExpS=abs(round(((ny-1)/2)+.01)); % Number of reflections off south wall
image_y = q*Y + (-1)^ny*b;    % image source y coordinate
dis_y = image_y-y;            % image source y coordinate relative to receiver

for nz=-Nz:Nz
s=2*round((nz/2)+.01);
ExpC=abs(s/2);                 % Number of reflections off ceiling
ExpF=abs(round(((nz-1)/2)+.01)); % Number of reflections off floor
image_z = s*Z + (-1)^nz*d;     % image source z coordinate
dis_z = image_z-z;             % image source z coordinate relative to receiver

r=sqrt(dis_x^2+dis_y^2+dis_z^2); % pathlength

info_matrix(1:12)=[r r/c nx ny nz ExpE ExpW ExpN ExpS ExpC ExpF ExpE+ExpW+ExpN+ExpS+ExpC+ExpF]; %
    single line of output matrix
%info_matrix(13:15)=[image_x image_y image_z];
info_matrix(13:15)=[dis_x dis_y dis_z];

EE = exp(-1j*2*pi*f*r/c); %EE = e^-jwt where w = 2*pi*f, t = r/c
SS = S/r;

Refl_mult=R_FCWENS(1,:).^ExpF.*R_FCWENS(2,:).^ExpC.*R_FCWENS(3,:).^ExpW.*R_FCWENS(4,:).^ExpE.*R_FCWENS
    (5,:).^ExpN.*R_FCWENS(6,:).^ExpS*SS.*EE;

% This 'if' function selects which responses are calculated
if nargout ~= 3
pressure = pressure + Refl_mult;
end
if nargout > 2
[phi,theta]=LRAngle(dis_x,dis_y,dis_z,hangle); % Program 'LRAngle' calculates the elevation and
    azimuth angle at which the reflection comes in
[hrtf_L,hrtf_R,elev,angL,angR]=find_hrtf(phi,theta,f,'Extended',1,'Measurements'); % Program '
    find_hrtf' calls the appropriate left and right HRTFs

info_matrix(16:20)=[phi theta elev angL angR];
```

```
pressure_L = pressure_L + Refl_mult.*hrtf_L.';
pressure_R = pressure_R + Refl_mult.*hrtf_R.';
end

if (abs(nx) < ind_lim) && (abs(ny) < ind_lim) && (abs(nz) < ind_lim) % excerpts the display matrix
display(counter,:)=info_matrix;
counter=counter+1;
end
end
fprintf(1,'\b\b\b\b\b\b\b');
end
fprintf(1,'\b\b\b\b\b\b\b\b\b\b\b\b');
end
disp([char(13) 'done!' char(13) char(13) 'Calculating impulse responses...'])

%% This section calculates the impulse responses from the pressure spectra.

% Program 'smoothcos' generates a window function with a 1/2 cosine
cur_dir=cd;cd 'R:\mydocuments\Yingxiang revised programs'
window=smoothcos(0.8*fs/2,fs/2,f);
cd(cur_dir);
t=(0:N-1)*1/fs;           % full time domain

if nargout ~= 3 % Microphone signal
H_k_L=pressure.*window; % Left side of spectrum, from 0 to fs/2

% Full spectrum, from zero to one point before fs. Left and right
% sides of spectrum are conjugate symmetric. This is done by taking
% the left side, excluding first and last points (f = 0, fs/2),
% flipping it, and taking the conjugate.
H_k=[H_k_L fliplr(conj(H_k_L(2:end-1)))];

% Inverse Fourier transform to get the impulse response. Calling just
% the real part is not theoretically necessary, but it practically
% helps to streamline operations (as some small imaginary parts may be
% left due to rounding errors).
h_n=real(ifft(H_k));
end
if nargout > 2 % Ear signals
H_k_LL=pressure_L.*window;
H_k_LR=pressure_R.*window;

H_k_LEFT = [H_k_LL fliplr(conj(H_k_LL(2:end-1)))];
```

```
H_k_RIGHT= [H_k_LR fliplr(conj(H_k_LR(2:end-1)))];

h_n_L=real(ifft(H_k_LEFT));
h_n_R=real(ifft(H_k_RIGHT));
end

%% Main output codes

%OutputDTind([X Y Z;a b d;x y z],abs_ind,display,unitsfm); %Prints inputs and "display" matrix into a
    text file

if nargout > 2
figure(1)
plot(t,h_n_R)
title(['Impulse Response Right, RT = ' num2str(RT)])
xlabel('Time [s]')
ylabel('Impulse Response')

figure(2)
plot(t,h_n_L)
title(['Impulse Response Left, RT = ' num2str(RT)])
xlabel('Time [s]')
ylabel('Impulse Response')
end
if nargout ~= 3
figure(3)
plot(t,h_n)
title(['Impulse Response full, RT = ' num2str(RT)])
xlabel('Time [s]')
ylabel('Impulse Response')
end

switch nargout
case 2
varargout={h_n};
case 3
varargout{1}=h_n_L;
varargout{2}=h_n_R;
case 4
varargout{1}=h_n;
varargout{2}=h_n_L;
varargout{3}=h_n_R;
save(['C:\Users\cgiacomo\Documents\MATLAB\Sample IRs\IR ' num2str(batchnum) ', fs ' num2str(fs) '.mat
    '],'t','h_n','h_n_L','h_n_R');
```

```
otherwise
end
end
```

### C.1.1 Import Parameters from File (Optional)

This function is called *XLSinput*. It accepts a single number as the identifier of a row in a file of input parameters for *ReverbProg*, and returns the values in the row for *ReverbProg* to use. This renders *ReverbProg* easier to use than if all 19 input parameters had to be specified manually each time the function was run.

```
function [X,Y,Z,a,b,d,x,y,z,fabs,cabs,wwabs,ewabs,nwabs,swabs,unitsfm,hangle,hrtfyn,fs]=XLSinput(count
    )

filename='Inputs.xlsx';
sheet=1;
xlRange=['A' num2str(count) ':S' num2str(count)];
inputs=xlsread(filename,sheet,xlRange);
X=inputs(1); Y=inputs(2); Z=inputs(3);
a=inputs(4); b=inputs(5); d=inputs(6);
x=inputs(7); y=inputs(8); z=inputs(9);
fabs=inputs(10); cabs=inputs(11);
wwabs=inputs(12); ewabs=inputs(13);
nwabs=inputs(14); swabs=inputs(15);
unitsfm=inputs(16); hangle=inputs(17);
hrtfyn=inputs(18); fs=inputs(19);
end
```

### C.1.2 Reverberation Times

This function is called *T60*. It was written by Clothilde Giacomoni and revised by the present author. It calculates the Sabine or Eyring-Norris octave-band reverberation times of the room specified in the main program.

Inputs to this function are:

- $LL$, $WW$, and $HH$: the length, width, and height of the room (either in feet or in meters)

- *floor*, *ceiling*, *wwall*, *ewall*, *nwall*, and *swall*: reference numbers denoting the materials from which the surfaces in the room (floor, ceiling, and west, east, north, and south walls) are made. Each number references a row in a matrix in which octave-band absorption coefficient magnitudes for a particular material are stored.

Outputs are the reverberation times for the seven octave-band center frequencies: 125, 250, 500, 1000, 2000, 4000, and 8000 Hz. Two arrays of reverberation times are returned: the first, $RTm$, is applicable if the dimensions of the room are in meters; the second, $RTf$, is applicable if the dimensions of the room are in feet.

```
function [RTm,RTf]=T60(LL,WW,HH,floor,ceiling,wwall,ewall,nwall,swall)
%This program calculates the reverberation time (in seconds) for a room of
%length LL, width WW and height HH. The values "floor, ceiling, etc.."
%correspond to the material number in the T60 spreadsheet

V=LL*WW*HH;

FloorA = LL*WW;
CeilA = LL*WW;
WWall = WW*HH;
EWall = WW*HH;
NWall = LL*HH;
SWall = LL*HH;

Surf_Tot = FloorA + CeilA + WWall + EWall + NWall + SWall;

ABS = load('Absorption_Coefficients');
ALPHAS=ABS.ALPHAS;

Floor_alpha = ALPHAS(ALPHAS(:,1)==floor,2:end);
Ceil_alpha = ALPHAS(ALPHAS(:,1)==ceiling,2:end);
WWall_alpha = ALPHAS(ALPHAS(:,1)==wwall,2:end);
EWall_alpha = ALPHAS(ALPHAS(:,1)==ewall,2:end);
NWall_alpha = ALPHAS(ALPHAS(:,1)==nwall,2:end);
SWall_alpha = ALPHAS(ALPHAS(:,1)==swall,2:end);

Floor_sabins = Floor_alpha * FloorA;
Ceil_sabins = Ceil_alpha * CeilA;
WWall_sabins = WWall_alpha * WWall;
EWall_sabins = EWall_alpha * EWall;
```

```
SWall_sabins = SWall_alpha * SWall;
NWall_sabins = NWall_alpha * NWall;

Sabins_tot = Floor_sabins + Ceil_sabins + WWall_sabins + EWall_sabins + SWall_sabins + NWall_sabins;

avg_alpha = Sabins_tot/Surf_Tot;

T60m_sab = (0.16 * V)./(Sabins_tot);
T60f_sab = (0.049 * V)./(Sabins_tot);

T60m_noreyr = zeros(1,7);
T60f_noreyr = zeros(1,7);

for ii=1:7
T60m_noreyr(1,ii) = (0.16*V)./(-Surf_Tot*log(1-avg_alpha(ii)));
T60f_noreyr(1,ii) = (0.049*V)./(-Surf_Tot*log(1-avg_alpha(ii)));
end

RTm = T60m_sab;
RTf = T60f_sab;

for jj=1:7
if avg_alpha(jj) >= 0.2
RTm(1,jj) = T60m_noreyr(1,jj);
RTf(1,jj) = T60f_noreyr(1,jj);
end
end
end
```

### C.1.3 Reflection Coefficient Curve

This function is called *myOctHilbert*. It was written by the present author. It generates minimum-phase reflection coefficient curves for each surface in the room. Program *ReverbProg_HilbR_rev4* calls this function.

Inputs to this function are variable. The single required input is an eleven-element vector containing octave-band absorption- or reflection-coefficient values. Subsequent inputs to the function are for the purpose of defining the frequency domain. A pre-defined frequency vector may be given to the function, or the sampling frequency and reverberation time may be given to the function, which then calculates the frequency vector.

```
function [Tsignal,Fsignal,t,f]=myOctHilbert(curve_inp,varargin)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% This program takes a set of octave-band values of absorption coefficients
% (or some other acoustic property), magnitude only, and constructs a
% smooth continuous complex curve in the frequency domain. It also
% calculates an impulse response from the frequency curve.
%
% The first step in the program is to construct a smooth magnitude curve
% over the half-frequency domain. The magnitude curve is initially
% generated as a continuous piecewise-smooth linear spline curve, using a
% subsidiary program 'Absorbcoef' (which can also generate the frequency
% vector). Both the magnitude curve and its frequency domain are reflected
% across the y-axis for the purpose of Hilbert transforming. Finally, the
% double magnitude curve is smoothed using a moving average filter. This
% is accomplished with another subsidiary function, 'Movavgfilter', and the
% size of the average is set to contain 10 Hz worth of points above and
% below each point being averaged.
%
% The second step is to generate a Hilbert signal for transforming the
% magnitude curve. The MATLAB function 'hilbert' is seriously flawed, so
% so an alternative approach will be used here. A Hilbert signal is
% generated as a Parks-McClellan equiripple finite impulse response
% (FIR) filter curve, using the MATLAB function 'firpm'. The input
% parameters to this function are manually set to produce a filter with
% small ripples and small transition regions.
%
% The third step is to reconstruct a complex curve in the frequency domain.
% To do this, the double magnitude curve is scaled so that its endpoints go
% to 1, and the natural log of the scaled curve is convolved with the
% Hilbert signal, producing minus the phase. The convolution is done using
% program 'mylongconv', which is essentially a fast alternative to the
% MATLAB function 'conv'. To produce the minimum-phase curve itself, the
% right side of the phase curve is combined with the right side of the
% scaled magnitude curve, and the scaling is taken out.
%
% To produce the impulse response, the conjugate of the minimum-phase curve
% is reflected across fs/2 and combined with the original curve. This
% produces a curve across the entire frequency domain, which is then
% inverse Fourier transformed to produce the impulse response. For a
% minimum-phase system, the impulse response should have large oscillations
% on the left side, and smaller oscillations on the right side. This is
```

```
% because minimum-phase systems are causal.
%
% Inputs:
%     curve_inp --  an array containing the octave-band values of the
%                   desired acoustic property. There should be 11
%                   elements in this array.
%     f        --   (optional) the frequency vector
%     RT, fs   --   (optional) the reverberation time and the sampling
%                   frequency. These are used to define the frequency
%                   vector if the frequency vector has not already been
%                   generated.
%
% Outputs:
%    Tsignal   --   the impulse response array, in time domain
%    Fsignal   --   the reconstructed minimum-phase curve, in frequency
%                   domain
%    t         --   the time vector for Tsignal
%    f         --   the frequency vector for Fsignal
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%% PRODUCE SMOOTH MAGNITUDE CURVE IN FREQUENCY DOMAIN
cur_dir=cd; cd 'R:\mydocuments\Yingxiang revised programs'
switch length(varargin)
case 1
f=varargin{1};
fs=f(end)*2;
[curve_amp] = Absorbcoef(curve_inp,f);
case 2
RT=varargin{1};
fs=varargin{2};
[curve_amp,f] = Absorbcoef(curve_inp,fs,RT,'Reverberation_time');
end

% Program 'Absorbcoef' generates a continuous piecewise-smooth curve of
% magnitude values, plus its matching 1/2-frequency vector

nk = length(curve_amp);

%double the vectors for reconstructing
curve_amp_double=[fliplr(curve_amp(2:end)) curve_amp];

% Program 'Movavgfilter' smooths the double magnitude curve
avg_boundary=round(10/f(2));% 10-Hz interval for smoothing
curve_amp_double=Movavgfilter(curve_amp_double,avg_boundary);
```

```
cd(cur_dir);
%% GENERATE THE HILBERT SIGNAL

nh=2047;          % number of points in Hilbert signal
fbound=0.0005;    % transition limits
hamp = [1 1];     % Hilbert signal has amplitude 1 across entire band
h=firpm(nh-1,[fbound 1-fbound],hamp,'Hilbert'); % the Hilbert signal
cutoff=(length(h)-1)/2;

%% RECONSTRUCT THE COMPLEX CURVE IN FREQUENCY DOMAIN

% Scale the double magnitude so that the endpoints go to 1
scalar=curve_amp_double(end);
mag=curve_amp_double/scalar;

phase_reb=mylongconv(log(mag),h); % Convolve log of magnitude with Hilbert signal
phase_reb=-phase_reb(cutoff+1:end-cutoff); % Cut off ends and take minus to get phase

% Assemble complex curves
complex=mag.*exp(1i*phase_reb); % Symmetric curve

Fsignal=complex(nk:end)*scalar; % take out the scaling factor

%% GENERATE THE CORRESPONDING TIME SIGNAL

Tsignal=real(ifft([Fsignal fliplr(conj(Fsignal(2:end-1)))])); %Impulse response
t=(0:length(Tsignal)-1)/fs;
% figure(3)
% plot(t,real(Tsignal),'bo',t,imag(Tsignal),'r')
% grid on;
end
```

## Reflection Coefficient Magnitude Curve

This function is called *Absorbcoef*. It was written by Yingxiang Jiang and revised by the present author. It generates a linear spline curve of absorption or reflection coefficients across a given frequency range. Program *myOctHilbert* calls this function.

Inputs to this function are variable. The single required input is an eleven-element vector containing octave-band absorption- or reflection-coefficient values. Subsequent inputs to the function are for the purpose of defining the frequency domain. A pre-defined frequency vector may be given to the function, or the sampling frequency and frequency increment (or reverberation time) may be given to the function, which then calculates the frequency vector.

```
function [Alpha_vector,f]=Absorbcoef(Alphas,varargin)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%  Written by Yingxiang Jiang
%  Revised and edited by Daniel Carr
%
%  Description: this function takes an array of 11 octave-band values of
%  absorption coefficients (or some other acoustic property) and generates
%  a linear spline curve connecting all the values over a frequency
%  domain from zero to half the sampling rate. The end segments of the
%  curve (beyond the specified octave-band values) are extrapolated as
%  horizontal lines.
%
%  [A]=ABSORBCOEF(Alphas,f) generates the spline curve A across the given
%  frequency domain f, using octave band values contained in the array
%  'Alphas'.
%
%  [A,f]=ABSORBCOEF(Alphas,Fs,dF,'Frequency') generates a frequency domain
%  vector using the given frequency increment dF to set the resolution, and
%  the sampling rate Fs to set the upper bound.
%
%  [A,f]=ABSORBCOEF(Alphas,Fs,T,'Reverberation time') sets the resolution
%  of the frequency domain with a reverberation time value T, rather than a
%  frequency value.
%
%  NOTE: input 'Alphas' should have 11 terms, corresponding to the
%        frequencies of 16, 31.5, 63, 125, 250, 500, 1k, 2k, 4k, 8k, and
%        16k Hz (Center Frequency).
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%
switch length(varargin)
case 1
f=varargin{1};
case 2
Fs=varargin{1};
%Determine the resolution for two cases ('Reverberation_time' or 'Frequency')
if strcmp(varargin{3},'Reverberation time')==1
Resolution=1/varargin{2};
elseif strcmp(varargin{3},'Frequency')==1
Resolution = varargin{2};
```

```
end

fs_hrtf=44100; % Sampling frequency of head-related transfer functions (HRTFs)
if Fs == fs_hrtf % Number of points in impulse response
N=2^nextpow2(Fs/Resolution); % FFT, IFFT functions run most efficiently with powers of 2
elseif Fs > fs_hrtf
N=Fs*ceil(25/Resolution)/25; % f vector must contain both half-sampling
end                          % frequencies exactly; powers of 2 non-feasible
f=(0:N/2)*Fs/N;
end
%%
% Center frequencies of octave bands
f_center=[16 31.5 63 125 250 500 1000 2000 4000 8000 16000];

% Location of the non-zero terms in Alphas
%(assuming non-zero terms are consecutive, number of non-zero terms >= 3)
Nonzero=find(Alphas~=0);

% Absorption value set to 1 if the value in the mat file is greater than 1
Greater_than_1_term=find(Alphas>1);
for number_greater_than_1_term=1:length(Greater_than_1_term)
Term=Greater_than_1_term(number_greater_than_1_term);
Alphas(Term)=1;
end

%%
%Create the Absorption coefficient value for each frequency
Alpha_vector=0;
%Calculate the absorption coefficient value in 'non_zero region'
for ii=Nonzero(1):Nonzero(end-1)
Alpha_vector_index=Linevalue(f,f_center(ii),Alphas(ii),f_center(ii+1),Alphas(ii+1));
Alpha_vector=Alpha_vector+Alpha_vector_index;
end

% Extrapolate ends of Alpha_vector in horizontal lines
Alpha_L=Linevalue(f,0,Alphas(Nonzero(1)),f_center(Nonzero(1)),Alphas(Nonzero(1)));
Alpha_R=Linevalue(f,f_center(Nonzero(end)),Alphas(Nonzero(end)),f(end),Alphas(Nonzero(end)));
Alpha_vector=Alpha_vector+Alpha_L+Alpha_R;
Alpha_vector(end)=Alpha_vector(end-1);
end
```

**Linear Interpolation**

This function is called *Linevalue*. It was written by Yingxiang Jiang. It performs linear interpolation over a given x-domain between two Cartesian coordinates. Program *Absorbcoef* calls this function. Inputs are:

- *X_vector*: the x-vector over which the interpolation is to be made
- *X_p1* and *Y_p1*: the Cartesian coordinates of the point at which the interpolation begins
- *X_p2* and *Y_p2*: the Cartesian coordinates of the point at which the interpolation ends

Output *Y_value* is a vector of the same size as *X_vector*. It contains all zeros except in between the values *X_p1* and *X_p2*.

```
function [Y_value]=Linevalue(X_vector,X_p1,Y_p1,X_p2,Y_p2)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Written by Yingxiang Jiang
% with new description written by Daniel Carr
%
% NOTE: this program originally appeared as a separate file. However,
% since it was not used much apart from being called by 'Absorbcoef',
% Daniel appended it to 'Absorbcoef' as a subsidiary function.
%
% Description: this function performs linear interpolation between two
% given Cartesian points. The two points, p1 and p2, are located within a
% given x-domain. The function generates a line equation from the
% coordinates of p1 and p2, and assigns y-values to the points in the
% x-domain between p1 and p2 to make a continuous curve.
%
% Inputs:
% 1.X_vector: The x vector where the y values are needed
% 2.X_p1: The x value of point 1
% 3.Y_p1: The y value of point 1
% 4.X_p2: The x value of point 2
% 5.Y_p2: The y value of point 2
%
% Outputs:
% 1. Y_value: The Y_value of the input X_vector
%
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Calculate the Y value (The range is restricted by [X_p1,X_p2], the y value out of the range will be
     0)
Y_value=((X_vector>=X_p1)&(X_vector<X_p2)).*(Y_p1+(Y_p2-Y_p1)/(X_p2-X_p1)*(X_vector-X_p1));
end
```

### Moving Average

This function is called *Movavgfilter*. It was written by Yingxiang Jiang and revised by the present author. It performs a moving average on the linear spline curve of reflection coefficient magnitudes generated by function *Absorbcoef*. Program *myOctHilbert* calls this function.

Inputs to this function are:

- $y$: the vector to be filtered
- $n$: the number of points on one side of the filter. The entire filter has $2n + 1$ points.

```
function [yfilt]=Movavgfilter(y,n)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%  Written by Yingxiang Jiang
%  Revised and edited by Daniel Carr
%
%  Description:
%      This function takes a vector of y-values (x-domain not required),
%      and smooths it with a moving average filter containing n points on
%      each side of the point being averaged.
%
%  Inputs:
%  y:  curve of y-values to be filtered
%  n: The number of old points on each side of the point being averaged.
%     The entire filter contains 2n+1 points.
%  Outputs:
%  1. yfilt: The filtered y-curve
%
% Remarks:
%    This function was originally intended to be used in signal-processing
%    applications. Specifically, it was intended to be used in conjunction
```

```
%   with Yingxiang's program 'Absorbcoef', which reconstructs a curve of
%   absorption coefficient (or similar acoustic property) values over a
%   frequency domain.
%
%   For use in this application, Yingxiang recommended that n be set to 50
%   for octave-band reconstruction. Dr. Patricia Davies recommended a
%   value of n that covers 10 Hz worth of points in the frequency domain.
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

yfilt=zeros(size(y));

% Extrapolate the ends of the y curve n points out in a flat line. This
% allows the moving average to run over over the whole original curve,
% rather than stopping when the boundary runs into the endpoint and
% leaving the first and last n points unfiltered.
y(n+1:n+length(y))=y;
y(1:n)=y(n+1);
y(length(y)+1:length(y)+n)=y(end);

% Generate the filtered vector by averaging old points.
% (The number of old points being averaged is 2n+1)
for ii=(n+1):(length(y)-n)
Local_sum=y(ii);
for jj=1:n
Local_sum=Local_sum+y(ii+jj)+y(ii-jj);
end
yfilt(ii-n)=Local_sum/(2*n+1);
end
end
```

### C.1.4 Path Angles

This function is called *LRAngle*. It was written by Clothilde Giacomoni and revised by the present author. It calculates the elevation and azimuthal angles of each sound path relative to a binaural head. Inputs are:

- $x$, $y$, and $z$: the Cartesian coordinates of the sound source relative to the head, in feet or meters

- *hangle*: angle of the head measured counterclockwise relative to the positive x-axis (i.e. the east point of the compass), in degrees

Outputs *phi* and *theta* are the respective elevation and azimuthal angles of the sound path relative to the head, in degrees.

```
function [phi,theta]=LRAngle(x,y,z,hangle)
% This program determines which azimuth and elevation angles of the HRTFs
% to use in a simulation. (x,y,z) is the point in three-space where the
% image source is located relative to the head. The coordinate system is
% specified with positive x pointing east, positive y pointing north, and
% positive z pointing up from the ground. The variable "hangle" represents
% the direction in which the head is facing, measured counterclockwise from
% the positive x-axis.

if hangle > 360 || hangle < -180
error('Parameter ''hangle'' must be between -180 and 360.')
elseif hangle == 360
hangle=0;
end

theta = atan2(y,x)*180/pi; % returns theta value measured counterclockwise from +x axis

if theta <= hangle-360  % transposes theta to measure clockwise from direction head is facing
theta=hangle-360-theta;
elseif theta <= hangle
theta=hangle-theta;
elseif theta <= hangle+360
theta = 360+hangle-theta;
elseif theta > hangle+360
theta=720+hangle-theta;
end

xy=sqrt(x^2+y^2);
phi = atan2(z,xy)*180/pi; % returns phi value measured up from xy plane
end
```

### C.1.5 Head Related Transfer Functions

This function is called *find_hrtf*. It was written by Clothilde Giacomoni and revised by the present author. It calls a set of left- and right-ear head related transfer functions

(HRTFs) corresponding to a given elevation and azimuthal angle of a sound path relative to the listener's head. Inputs are:

- *phi*: elevation angle, in degrees
- *theta*: azimuthal angle, in degrees
- *MIT_or_Extended*: a character string that tells the function whether to select HRTFs from the database produced by MIT Media Labs, or from the low-frequency modified database produced by Giacomoni
- *leftright*: a numerical index that tells the function whether to use HRTFs measured only at the left ear (assuming that the head is entirely symmetrical) or at both ears. This input is only used in conjunction with the original MIT dataset, as Giacomoni's dataset has only functions measured at the left ear. The present author suggests that this feature be revised to select either left- or right-ear measured HRTFs at a time, but not both. This is in keeping with the recommendations of Gardner and Martin on use of the MIT dataset [40].
- *Measurements_or_Transforms*: a character string that tells the function whether to select HRTF impulse responses and Fourier transform them, or to select pre-transformed HRTF frequency responses. The present author suggests that this feature be removed in later versions of the function.

Outputs are:

- *hrtf_L*: the frequency response of the left-ear HRTF, from 0 to $f_s/2$
- *hrtf_R*: the frequency response of the right-ear HRTF, from 0 to $f_s/2$
- *elev*: the elevation angle of the sound path
- *angL*: the azimuthal angle of the sound path relative to the left ear
- *angR*: the azimuthal angle of the sound path relative to the right ear

```
function [hrtf_L,hrtf_R,elev,angL,angR] = find_hrtf(phi,theta,f,MIT_or_Extended,leftright,
    Measurements_or_Transforms)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
% Author: Clothilde 'Chloe' Giacomoni
% Revised and expanded: Daniel Carr
%
% This program is a subsidiary function of program 'ReverbProg'. It
% selects head-related transfer functions (HRTF) for simulating a
% directional binaural sound signal.
%
% A signal comes into the receiver at elevation angle 'phi' and azimuthal
% angle 'theta'. These angles are rounded to the nearest increment
% available in the source files. Using the rounded angles, the appropriate
% HRTF is called and Fourier-transformed into a signal compatible with the
% frequency vector 'f'.
%
% This program is compatible with two sets of HRTF measurements: one by MIT
% Media Lab and one by Chloe. The MIT data is in the public domain, but
% the files have a drastic fall-off in the low-frequency region, which is a
% disadvantage for researchers wishing to examine lower- frequency sounds.
% Chloe has rectified this situation by modifying the MIT files so that the
% frequency response extends in a flat line from 200 Hz on down. Input
% 'MIT_or_Extended' specifies whether the original MIT files or Chloe's
% extended files will be selected.
%
% It should also be noted that the MIT data contains HRTF files for both
% left and right ears, whereas Chloe's extended files are only for left
% ear. Assuming that the head is symmetrical, the response may be
% calculated using only left-ear data (in this case, the right-ear
% response is the left-ear HRTF at 360 - right azimuth angle). This
% assumption must be made when using Chloe's data, but it does not have to
% be made for the MIT data. Hence, the input 'leftright' is used to tell
% the program whether to use left-ear data only or both left and right ear
% data. If Chloe's data are used, this variable is automatically ignored.
%
% If a room is very reverberant, it will have both a large frequency range
% (which results in a high frequency resolution) and a large number of
% reflections. This means that the program will have to call a large
% number of HRTFs and Fourier-transform them into large signals. This
% file-calling and transforming takes a significant amount of time. In an
% attempt to reduce run-time, this program has the option of selecting HRTF
% files that have been pre-transformed to the desired length. These files
% can be much larger than are the original HRTF files, but they eliminate
% the need for the program itself to perform all the transforms while
% running. This option has produced a time-reduction in some cases. Input
% 'Measurements_or_Transforms' specifies whether original or
% pre-transformed HRTF files will be used. (NOTE: at the time of this
```

```
% writing, all batches of pre-transformed HRTFs are made at 44.1 kHz
% sampling rate. Generating separate banks of pre-transformed HRTFs for
% other sampling rates may prove unwieldy.)
%
% Both MIT's and Chloe's HRTFs were made at a sampling rate of 44.1 kHz.
% If a signal with a sampling rate greater than 44.1 kHz is used, this
% program will modify the resolution of the Fourier transform and zero-pad
% the high-frequency end, thus effectively resampling the HRTFs to the
% sampling frequency of the signal. At present, the program is not
% equipped to resample the HRTFs to a lower sampling rate.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

fs = 2*f(end); % Sampling frequency of simulation
fs_hrtf=44100; % Sampling frequency at which HRTFs are made

if fs < fs_hrtf
error('Frequency domain too small; must have a sampling frequency of 44100 Hz or greater.')
elseif strcmp(MIT_or_Extended,'MIT')==0 && strcmp(MIT_or_Extended,'Extended')==0
error('Must specify ''MIT'' or ''Extended''.')
elseif leftright ~= 1 && leftright ~= 2
error('Parameter ''leftright'' must be either 1 or 2.') % A value of 1 uses left-ear only, whereas a
    value of 2 uses both ears.
elseif strcmp(Measurements_or_Transforms,'Measurements')==0 && strcmp(Measurements_or_Transforms,'
    Transforms')==0
error('Must specify ''Measurements'' or ''Transforms''.')
elseif strcmp(MIT_or_Extended,'Extended')==1 && leftright == 2
warning('Command to use right-ear HRTFs ignored. Right-ear HRTFs only available in MIT data.') %#ok<
    WNTAG>
elseif strcmp(Measurements_or_Transforms,'Transforms')==1 && fs ~= fs_hrtf
Measurements_or_Transforms='Measurements';
warning('Command to use transforms ignored. Transforms only available at 44100 Hz sampling.') %#ok<
    WNTAG>
end

elev = 10 * round(phi/10);         % rounds phi to the nearest available elevation value
if elev <= -40, elev = -40; end

if abs(elev) <= 20                 % selects the proper azimuth increment for the given elevation
    angle
ang = 5;
elseif abs(elev) == 30
ang = 6;
elseif abs(elev) == 40
ang = 360/56;
```

```
elseif elev == 50
ang = 8;
elseif elev == 60
ang = 10;
elseif elev == 70
ang = 15;
elseif elev == 80
ang = 30;
elseif elev == 90;
ang = 1;
end

azim = round(ang * round(theta/ang)); % rounds theta to the nearest available azimuth value
if elev == 90, azim = 0; end

azim_L = azim;                  % specifies azimuth angles for left and right ear
azim_R = 360 - azim;            % NOTE: this angle calculated for using left-ear HRTFs only. If
    both left and right-ear HRTFs are used, azim_L holds for both.

if azim_L == 360, azim_L = 0; end
if azim_R == 360, azim_R = 0; end

angL=azim_L;
angR=azim_R;

azim_L = num2str(azim_L);       % gives the numbers the proper format to call the data files
azim_R = num2str(azim_R);

if size(azim_L) < 2
azim_L = ['00' azim_L];
elseif size(azim_L) < 3
azim_L = ['0' azim_L];
end

if size(azim_R) < 2
azim_R = ['00' azim_R];
elseif size(azim_R) < 3
azim_R = ['0' azim_R];
end

if ispc, slash = '\'; else slash = '/'; end % selects the MIT or Chloe's data set directory, in
    Windows or Mac format as needed

filename_L=['L' num2str(elev) 'e' num2str(azim_L) 'a'];
```

```
if strcmp(MIT_or_Extended,'MIT')==1 && leftright == 2 % sets file and field names for right ear based
     on whether one or both ears will be used
filename_R = ['R' num2str(elev) 'e' num2str(azim_L) 'a']; % See 'NOTE' above on calculating azimuth
     angles
fieldname_R='hrtf_R';
else
filename_R = ['L' num2str(elev) 'e' num2str(azim_R) 'a'];
fieldname_R='hrtf_L';
end

if strcmp(Measurements_or_Transforms,'Measurements')==1 % This option calls and transforms the
     original audio files

software_index=version('-release');
if str2double(software_index(1:4))>=2013 % chooses WAV-file-reading function based on version of
     MATLAB
fhandle=@audioread;
else
fhandle=@wavread;
end

fpath=['HRTF' slash MIT_or_Extended slash Measurements_or_Transforms slash 'elev' num2str(elev) slash
     ];

ql = fhandle([fpath filename_L '.wav']); % Reads the HRTFs from the azimuth data files
qr = fhandle([fpath filename_R '.wav']);

if fs == fs_hrtf  % Case 1: HRTFs can be used as is, without resampling
N=2*(length(f)-1);

hrtf_L = fft(ql,N);
hrtf_R = fft(qr,N);

hrtf_L = hrtf_L(1:N/2+1); %excerpts the first half of the spectrum
hrtf_R = hrtf_R(1:N/2+1);

elseif fs > fs_hrtf % Case 2: HRTFs must be upsampled to higher frequency
N=2*length(f(f<fs_hrtf/2));

hrtf_L = fft(ql,N);
hrtf_R = fft(qr,N);

%        figure(5)
```

```
%        subplot(211)
%        plot(f(f<=fs_hrtf/2),abs(hrtf_L(1:N/2+1)))
%        grid on
%        hold on
%        subplot(212)
%        plot(f(f<=fs_hrtf/2),angle(hrtf_L(1:N/2+1)))
%        grid on
%        hold on
%        title 'TEST HRTF Left'
%        xlim([22000 22100])

window=smoothcos(fs_hrtf/2-30,fs_hrtf/2,f);

% First half of spectrum is zero-padded to fs/2 and windowed
hrtf_L = [hrtf_L(1:N/2+1); zeros(length(f)-N/2-1,1)].*window.';
hrtf_R = [hrtf_R(1:N/2+1); zeros(length(f)-N/2-1,1)].*window.';

%        subplot(211)
%        plot(f,abs(hrtf_L),'r')
%        grid on
%        hold on
%        subplot(212)
%        plot(f,angle(hrtf_L),'r')
%        grid on
%        hold on
end

elseif strcmp(Measurements_or_Transforms,'Transforms')==1 && fs==fs_hrtf % This option calls the pre-
     transformed MAT files
N=2*(length(f)-1);

fpath=['HRTF' slash MIT_or_Extended slash Measurements_or_Transforms slash 'N' num2str(N) slash 'elev'
      num2str(elev) slash];

fl=load([fpath filename_L '.mat']); hrtf_L=fl.hrtf_L;
fr=load([fpath filename_R '.mat']); hrtf_R=fr.(fieldname_R);

if(size(hrtf_R,2)~=1), hrtf_R=transpose(hrtf_R);end
if(size(hrtf_L,2)~=1), hrtf_L=transpose(hrtf_L);end
end
end
```

### C.1.6 Cosine Smoothing

This function is called *smoothcos*. It was written by Yingxiang Jiang and revised by the present author. It generates a one-sided half cosine wave window between two points on a given domain vector. Inputs are:

- $f1$ and $f2$: the two endpoints of the cosine wave
- $f$: the domain vector

The resulting window is equal to 1 left of point $f1$, and equal to 0 right of $f2$.

```
function Smooth=smoothcos(f1,f2,f)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Author: Yingxiang Jiang
% Revised: Daniel Carr, 6/28/14
%
%  Inputs:
%  1.f1: Starting point of the smooth curve
%  2.f2: Ending point of the smooth curve
%  3.f:  The domain of the smooth curve
%
%  Outputs:
%  1. The smooth curve
%
%  Function Description: This function gives a curve over the domain vector
%  f.  Every point of the curve less than value f1 is equal to 1; every
%  point of the curve between values f1 and f2 makes a cosine curve going
%  to 0; and every point of the curve equal to or greater than value f2 is
%  equal to 0.
%
% NOTE: This function was originally titled 'smooth'; however, since MATLAB
% itself also comes with a function of that name, the title was changed to
% 'smoothcos' to distinguish it from the other function. THIS MAY BE
% IMPORTANT WHEN DEALING WITH YINGXIANG'S OLD PROGRAMS, AS THEY WILL NO
% LONGER CALL HIS 'SMOOTH' FUNCTION BUT ONLY THE STANDARD MATLAB 'SMOOTH'
% FUNCTION.
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%Calculation%%%
Smooth=(f<f1).*1+((f>=f1)&(f<f2)).*(0.5+0.5*cos(pi/(f2-f1)*(f-f1)))+(f>=f2).*0;
end
```

### C.1.7 Information Read-Out (Optional)

This is an optional program that reads matrices of statistics out of *ReverbProg* and prints them to a file.

```
function OutputDTind(inp_length,inp_abs,display,unitsfm)
%This function displays distance and time values from program
%ReverbProg, with corresponding loop index values, number of reflections
%off of each surface, and total number of reflections.

if unitsfm==1
ru='(m) ';
elseif unitsfm==2
ru='(ft)';
end

N=length(display);

fileID=fopen('DTind.asc','w');
format compact

fprintf(fileID,'%s \n',' X     Y      Z    |   a      b     d    |   x     y     z');
fprintf(fileID,'%s','      ');
fprintf(fileID,'%c',ru);
fprintf(fileID,'%s','      |        ');
fprintf(fileID,'%c',ru);
fprintf(fileID,'%s','     |       ');
fprintf(fileID,'%c',ru);
fprintf(fileID,'\n');
fprintf(fileID,'%s \n','----------------------|---------------------|------------------');
fprintf(fileID,'%c',' ');
fprintf(fileID,'% 3.0f % 3.0f  % 3.0f',inp_length(1,1),inp_length(1,2),inp_length(1,3));
fprintf(fileID,'%s',' | ');
fprintf(fileID,'% 3.0f % 3.0f  % 3.0f',inp_length(2,1),inp_length(2,2),inp_length(2,3));
fprintf(fileID,'%s',' | ');
fprintf(fileID,'% 3.0f % 3.0f  % 3.0f \n',inp_length(3,1),inp_length(3,2),inp_length(3,3));
fprintf(fileID,'\n');
fprintf(fileID,'%s \n',' Fa      Ca      WWa      EWa      NWa      SWa');
fprintf(fileID,'%s \n','----------------------------------------------------------');
fprintf(fileID,'%c',' ');
fprintf(fileID,'% 4.0f   % 4.0f    % 4.0f     % 4.0f     % 4.0f     % 4.0f \n',inp_abs(1),inp_abs(2),
    inp_abs(3),inp_abs(4),inp_abs(5),inp_abs(6));
fprintf(fileID,'\n');
```

```
fprintf(fileID,'%s \n',' n      r           t    |  nx     ny     nz  |  nEW    nWW    nNW    nSW
       nCe    nFl  |  RTot    x      y      z    |    phi      theta  |  elev  azm_L  azm_R');
fprintf(fileID,'%s','       ');
fprintf(fileID,'%c',ru);
fprintf(fileID,'%s','       (s)    |                   |                                      |
            ');
fprintf(fileID,'%c',ru);
fprintf(fileID,'%s',' ');
fprintf(fileID,'%c',ru);
fprintf(fileID,'%s',' ');
fprintf(fileID,'%c',ru);
fprintf(fileID,' |  (deg)     (deg)  |  (deg)  (deg)  (deg)\n');
fprintf(fileID,'%s \n','------------------------------|-----------------------|----------
-------------------------------------|-------------------------------|
---------------------|------------------------');

for n=1:N
fprintf(fileID,'% 4.0f % 10.4f % 10.4f',n,display(n,1),display(n,2));
fprintf(fileID,'%s',' | ');
fprintf(fileID,'% 4.0f  % 4.0f   % 4.0f',display(n,3),display(n,4),display(n,5));
fprintf(fileID,'%s',' | ');
fprintf(fileID,'% 4.0f  %4.0f   % 4.0f   % 4.0f   % 4.0f   % 4.0f',display(n,6),display(n,7),display(n
    ,8),display(n,9),display(n,10),display(n,11));
fprintf(fileID,'%s',' | ');
fprintf(fileID,'% 4.0f  %4.0f   % 4.0f   % 4.0f',display(n,12),display(n,13),display(n,14),display(n
    ,15));
fprintf(fileID,'%s',' | ');
fprintf(fileID,'% 6.2f  % 7.2f',display(n,16),display(n,17));
fprintf(fileID,'%s',' | ');
fprintf(fileID,'% 4.0f  %4.0f   % 4.0f \n',display(n,18),display(n,19),display(n,20));
%fprintf(fileID,'\n');
end

fclose(fileID);
end
```

## C.2 Stage 2: House Transmission and Final Assembly

This function is called *ReverbSimulationProgram_rev3*. It was written by Clothilde Giacomoni and revised by the present author. It filters an outdoor sound using an outdoor-to-indoor transmission filter, passes the proper inputs to function *ReverbProg* (shown above) to generate the room reverberation impulse response, and convolves the indoor signal and the room impulse responses together using function *mylongconv* (shown below).

Inputs to this function are:

- *signal*: the outdoor signal to be simulated indoors
- *XYZ*: a three-element vector containing the dimensions of the room
- *abc*: a three-element vector containing the coordinates of the point monopole indoor source
- *xyz*: a three-element vector containing the coordinates of the receiver
- *unitsfm*: selects whether units of feet or meters will be used in calculating the room impulse responses
- *fs*: the sampling frequency of the signal
- *floorabs, ceilabs, wwallabs, ewallabs, nwallabs, swallabs*: reference numbers designating the materials in the floor, ceiling, and west, east, north, and south walls in the room
- *hangle*: the angle of the head receiver relative to the x-axis
- *h_con*: selects whether a more or less aggressive outdoor-to-indoor transmission filter will be used
- *f_path*: the directory in which the simulated indoor sounds will be saved
- *IR_Name*: the name of the output file containing the room reverberation impulse responses
- *Sim_Name*: the name of the output file containing the simulated indoor sounds

Outputs from this function are saved as files rather than returned as MATLAB variables. The room reverberation impulse responses and the indoor simulated sounds are saved in two files. Two figures, one graphing the transmitted sound (before convolving with the room impulse response) and the other graphing the indoor simulated sounds are also saved.

```
function [] = ReverbSimulationProgram_rev3(signal, XYZ, abc, xyz, unitsfm, fs, floorabs, ceilabs,
    wwallabs, ewallabs, nwallabs, swallabs, hangle, h_con, f_path, IR_Name, Sim_Name)

% This function takes the dimensions of a room (X,Y,Z), source location (a,b,d),
% receiver location (x,y,z), the materials used to make up each surface, and
% the construction of the house and calculates the impulse response and a
% simulation of an indoor sound. The last variable (unitsfm) can be either
% 1 if the dimensions are in meters or 2 if the dimensions are in feet.
%
% %source location - a distance from west wall to source
%                  - b distance from south wall to source
%                  - d distance from floor to source
%
% %receiver location - x distance from west wall to receiver
%                    - y distance from south wall to receiver
%                    - z distance from floor to receiver
%%

%Separate variables regarding room size, source, and receiver

X = XYZ(1);
Y = XYZ(2);
Z = XYZ(3);

a = abc(1);
b = abc(2);
c = abc(3);

x = xyz(1);
y = xyz(2);
z = xyz(3);

%Apply house filter to signal

HCON=load('House_Const');
house_const=HCON.house_const;
B = house_const{1,h_con};
A = house_const{2,h_con};
sig_houseFilt = filter(B,A,signal);
ty = (0:length(sig_houseFilt)-1)/fs;
tq = (0:length(signal)-1)/fs;

%Plot house filtered signal
```

```
%Create Impulse Response of Reverberant Room

[~,h_n,h_n_L,h_n_R] = ReverbProg(X,Y,Z,a,b,c,x,y,z,floorabs,ceilabs,wwallabs,ewallabs,nwallabs,
    swallabs,unitsfm,fs,hangle);

load('Filters','Bhs1','Ahs1','Bls','Als');

ha=filter(Bhs1,Ahs1,h_n);
hLa=filter(Bhs1,Ahs1,h_n_L);
hRa=filter(Bhs1,Ahs1,h_n_R);

h=filter(Bls,Als,ha);
hL=filter(Bls,Als,hLa);
hR=filter(Bls,Als,hRa);

[SIM,tsim] = mylongconv(h,sig_houseFilt,0,0,fs);
[SIM_L,tsimHRTF] = mylongconv(hL,sig_houseFilt,0,0,fs);
[SIM_R,~] = mylongconv(hR,sig_houseFilt,0,0,fs);

H1 = figure('name', 'Low-Passed Signal (Outdoor to Indoor)', 'numbertitle', 'off');
plot(tq,signal,'b',ty,sig_houseFilt,'r',tsim,SIM,':k')
ylabel('Pressure [Pa]')
xlabel('Time [sec]')
legend('Outdoor boom','"Just indoor" boom','Simulated indoor boom')
set(gca,'fontsize',14)

H2 = figure('name', 'Simulated Indoor Reverberation', 'numbertitle', 'off');
subplot(1,3,1)
plot(tsim,SIM,'k','linewidth',2)
ylabel('Pressure [Pa]','fontsize',16)
xlabel('Time [sec]','fontsize',16)
set(gca,'fontsize',14)

subplot(1,3,2)
plot(tsimHRTF,SIM_L,'k','linewidth',2)
ylabel('Pressure [Pa]','fontsize',16)
xlabel('Time [sec]','fontsize',16)
set(gca,'fontsize',14)

subplot(1,3,3)
plot(tsimHRTF,SIM_R,'k','linewidth',2)
ylabel('Pressure [Pa]','fontsize',16)
xlabel('Time [sec]','fontsize',16)
set(gca,'fontsize',14)
```

```
if exist('f_path', 'file') == 0
mkdir(f_path);
end

if ismac == 0;
save_IR = [f_path '\' IR_Name];
save_Sim = [f_path '\' Sim_Name];
save_fig1 = [f_path '\' Sim_Name '_LPFig'];
save_fig2 = [f_path '\' Sim_Name '_SimFig'];
else
save_IR = [f_path '/' IR_Name];
save_Sim = [f_path '/' Sim_Name];
save_fig1 = [f_path '/' Sim_Name '_LPFig'];
save_fig2 = [f_path '/' Sim_Name '_SimFig'];
end

save(save_IR, 'h', 'hL', 'hR')
save(save_Sim, 'SIM', 'SIM_L', 'SIM_R')
saveas(H1, save_fig1, 'fig')
saveas(H2, save_fig2, 'fig')
end
```

### C.2.1 Truncated Final Assembly Function

This function is called *ReverbSimulationProgram_TRUNC*. It is a version of *ReverbSimulationProgram_rev3* that calls pre-defined room impulse responses from files rather than calling new room impulse responses from *ReverbProg*. It also imports the outdoor signals from files rather than as variables defined in MATLAB. This function was used to generate the simulated indoor sounds that were used in the Purdue test.

Inputs to this function are:

- *h_con*: selects whether a more or less aggressive outdoor-to-indoor transmission filter will be used
- *fs*: the sampling frequency of the signal

Outputs are the same as in *ReverbSimulationProgram_rev3*.

```
function [] = ReverbSimulationProgram_TRUNC(fs,h_con)

% This function takes an outdoor sound recording and filters it (using a
% house transmission filter) to make an indoor signal. It then takes the
% impulse response of a given room (already generated) and convolves it
% with the signal to produce the sound at the receiver location.
%
% %source location - a distance from west wall to source
%                 - b distance from south wall to source
%                 - d distance from floor to source
%
% %receiver location - x distance from west wall to receiver
%                   - y distance from south wall to receiver
%                   - z distance from floor to receiver
%%
cur_dir=cd;

[multipliers,signal_list]=xlsread('F:\MASTER\Metrics table (Outdoor master).xls','Sheet1','C2:D81');
%multipliers=xlsread('F:\MASTER\Metrics table (Outdoor master).xls','Sheet1','D2:D81');

signals_selected=[5 17 32 55 76];

inp_path='F:\MASTER\Outdoor signals\';
IR_path='C:\Users\cgiacomo\Documents\MATLAB\Sample IRs\';

IR_num_a = 168;
IR_num_b=171;
f_path=['C:\Users\cgiacomo\Documents\MATLAB\Simulated sounds 1-9-15\IRs ' ...
num2str(IR_num_a) ', ' num2str(IR_num_b) ' LONG'];

IR_Names={'Sig05_isol';...
'Sig17_isol';...
'Sig32_isol';...
'Sig55_isol';...
'Sig76_isol'};

%HA=load([IR_path 'IR 217, fs 48000_LONG']);
%HB=load([IR_path 'IR 220, fs 48000_LONG']);

HA=load([IR_path 'IR ' num2str(IR_num_a) ', fs 48000_LONG']);
HB=load([IR_path 'IR ' num2str(IR_num_b) ', fs 48000_LONG']);

h_n=HA.h_n+HB.h_n;
h_n_L=HA.h_n_L+HB.h_n_L;
```

```
h_n_R=HA.h_n_R+HB.h_n_R;

for count=1:length(signals_selected);
filename=char(signal_list(signals_selected(count)));
multiplier=multipliers(signals_selected(count));

IR_Name=[char(IR_Names(count)) '_hcon' num2str(h_con)];
Sim_Name=IR_Name;

[p_norm,fs_old]=wavread([inp_path filename(2:end-1)]);
p=p_norm*multiplier;
cd R:\mydocuments
signal=myupsample(p,fs_old,fs,4000,9,'f');

%    wavwrite(signal/multiplier,fs,[IR_Name '_resamp']);
%     t1=(0:length(p)-1).'/fs_old;
%     t2=(0:length(signal)-1).'/fs;
%
%     figure(1)
%     plot(t1,p,'b',t2,signal,'r');

%Apply house filter to signal
cd R:\mydocuments\Outdoor_Indoor_Sim
HCON=load('House_Const');
house_const=HCON.house_const;
B = house_const{1,h_con};
A = house_const{2,h_con};
sig_houseFilt = filter(B,A,signal);
ty = (0:length(sig_houseFilt)-1)/fs;
tq = (0:length(signal)-1)/fs;

%    wavwrite(sig_houseFilt/multiplier,fs,[IR_Name '_house']);

load('Filters','Bhs1','Ahs1','Bls','Als');

ha=filter(Bhs1,Ahs1,h_n);
hLa=filter(Bhs1,Ahs1,h_n_L);
hRa=filter(Bhs1,Ahs1,h_n_R);

h=filter(Bls,Als,ha);
hL=filter(Bls,Als,hLa);
hR=filter(Bls,Als,hRa);

%    t=(0:length(h_n)-1)/fs;
```

```
%    figure(1)
%    plot(t,h_n,'b',t,ha,'g',t,h,'r')

[SIM,tsim] = mylongconv(h,sig_houseFilt,0,0,fs);
[SIM_L,tsimHRTF] = mylongconv(hL,sig_houseFilt,0,0,fs);
SIM_R = mylongconv(hR,sig_houseFilt);

%     N=32768;
%     sim=fft(SIM,N); sim=sim(1:(N/2+1));
%     f=(0:N/2)*fs/N;
%
%     figure(1); loglog(f,abs(sim));grid on;

%[Bst,Ast]=butter(3,[490 510]/(fs/2),'stop');
%SIM=filter(Bst,Ast,SIM);



H1 = figure('name', 'Low-Passed Signal (Outdoor to Indoor)', 'numbertitle', 'off');
plot(tq,signal,'b',ty,sig_houseFilt,'r',tsim,SIM,':k')
ylabel('Pressure [Pa]')
xlabel('Time [sec]')
legend('Outdoor boom','"Just indoor" boom','Simulated indoor boom')
set(gca,'fontsize',14)

H2 = figure('name', 'Simulated Indoor Reverberation', 'numbertitle', 'off');
subplot(1,3,1)
plot(tsim,SIM,'k','linewidth',2)
ylabel('Pressure [Pa]','fontsize',16)
xlabel('Time [sec]','fontsize',16)
set(gca,'fontsize',14)

subplot(1,3,2)
plot(tsimHRTF,SIM_L,'k','linewidth',2)
ylabel('Pressure [Pa]','fontsize',16)
xlabel('Time [sec]','fontsize',16)
set(gca,'fontsize',14)

subplot(1,3,3)
plot(tsimHRTF,SIM_R,'k','linewidth',2)
ylabel('Pressure [Pa]','fontsize',16)
xlabel('Time [sec]','fontsize',16)
set(gca,'fontsize',14)
```

```
if exist('f_path', 'file') == 0
mkdir(f_path);
end

%SIM_BIN=[SIM_L.' SIM_R.'];
%wavwrite(SIM/13,fs,[f_path '\Final\' IR_Name '_backIR']);
wavwrite(SIM/13,fs,[f_path '\' IR_Name '_backIR']);
%wavwrite(SIM_BIN/13,fs,[f_path '\More reverb\' IR_Name '_backIR']);

if ismac == 0;
save_IR = [f_path '\' IR_Name];
save_Sim = [f_path '\' Sim_Name];
save_fig1 = [f_path '\' Sim_Name '_LPFig'];
save_fig2 = [f_path '\' Sim_Name '_SimFig'];
else
save_IR = [f_path '/' IR_Name];
save_Sim = [f_path '/' Sim_Name];
save_fig1 = [f_path '/' Sim_Name '_LPFig'];
save_fig2 = [f_path '/' Sim_Name '_SimFig'];
end

save(save_IR, 'h', 'hL', 'hR')
save(save_Sim, 'SIM', 'SIM_L', 'SIM_R')
saveas(H1, save_fig1, 'fig')
saveas(H2, save_fig2, 'fig')
close(H1);close(H2);
end
cd(cur_dir)
end
```

### C.2.2 Long Convolution

This function is called *mylongconv*. It was written by Clothilde Giacomoni and revised by the present author. It performs convolution on two vectors, using a more time-efficient method than that used by the MATLAB function *conv*. It also has the capacity to calculate a time vector for the convolution, given the starting times and sampling frequency of the input signals.

Required inputs to this function are the two signals to be convolved. Optional inputs are the starting times and the sampling frequency of the input signals. Outputs from this function are the result of the convolution and (optional) the corresponding time vector.

```
function [y,tconv] = mylongconv(hn,xn,hstart,xstart,fs)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Author: Clothilde 'Chloe' Giacomoni
% Revised: Daniel Carr
%
% This function performs long convolution of two vectors. The MATLAB
% function 'conv' performs the same task, but it can be slow when working
% with long input vectors. This function speeds up the process.
%
% NOTE: this program is compatible with either row or column vectors as
% inputs. However, it transposes hn and xn to column vectors before
% performing the actual convolution. The two outputs, y and tconv, will be
% row or column vectors depending on the original dimensions of hn.
%
% Inputs:
%   hn, xn: the vectors to be convolved
%   hstart, xstart: the times at which hn and xn start (assuming that hn
%                  and xn are in the time domain)
%   fs: the sampling frequency of hn and xn
%
% Outputs:
%   y: the convolved vector
%   tconv: the time domain of y
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

DIM=size(hn,1);
if DIM==1, hn = hn.'; end % transposes hn and xn to column vectors
if size(xn,1)==1, xn = xn.'; end

if length(hn) > length(xn) % This automatically sets the longer array as xn
ww = hn;
hn = xn;
xn = ww;
end
clear ww

xlen = length(xn);
hlen = length(hn);
ylen = xlen+hlen-1;

N=2^nextpow2(hlen);
```

```
Q = ceil(xlen/N);
Hk=fft(hn,2*N);
xn(xlen+1:Q*N,1)=zeros(Q*N-xlen,1);
for ii=1:Q+1
if ii~= Q+1
Xk=fft(xn((ii-1)*N+1:ii*N),2*N);
else
Xk=fft(xn((ii-1)*N+1:end),2*N);
end
y1=ifft(Hk.*Xk);
if ii == 1
y(1:N,1)=y1(1:N);
y2(1:N,1)=y1(N+1:2*N);
else
y((ii-1)*N+1:ii*N)=y1(1:N,1)+y2(1:N,1);
y2(1:N)=y1(N+1:2*N);
end
end
y=y(1:ylen);
if DIM==1,y=y.';end

% OPTIONAL: time domain for convolution curve
if nargin > 2
hs=hstart*fs; xs=xstart*fs;
ys=hs+xs;
tconv=(ys:ys+ylen-1)/fs;
if DIM ~= 1, tconv=tconv.';end
end
end
```

# D. SIGNALS, RESPONSE DATA, AND METRICS FOR THE NASA SIMULATOR TEST

This appendix contains tables of the signals, the response data, the averaged responses, the metric values, and the correlations between metrics for the NASA test.

## D.1 Signals

Table D.1 contains reference information for the signals used in the NASA test. Included for each signal is its number, its name, the source from which it was taken, the organization by which it was prepared, the type of sound, and the high-pass filtering applied for playback purposes.

*NOTE:* some of the signals used in the NASA test were obtained from private vendors, and the original file names contain all or part of the vendor's name. Since the vendors' names are not to be divulged in this thesis, the portions of the file names containing the vendor's name have been replaced with the designation "Pro#". In these cases, the remainder of the file name has not been altered, so the file may still be easily identified from the table.

Table D.1. Signals used in the NASA test. HP - high-pass filter.

| Signal # | Signal name | Source | Prepared by | Type | HP cutoff frequency (Hz) |
|---|---|---|---|---|---|
| 1 | Boom01-(Fdoor-60) | New recording | Purdue | Car door slam | 6 |
| 2 | Boom02-(Pro1-60) | Andrew Marshall | Purdue | Synthetic boom | 6 |
| 3 | Gunfire2-resamp-25cut | Andrew Marshall | Purdue | Gunfire | 25 |
| 4 | Boom04-(Pro2-60) | Hales Swift | Purdue | Blast | 6 |
| 5 | Boom05-(Pro3-60) | Hales Swift | Purdue | Blast | 6 |
| 6 | Boom06-(fCand3-60) | Andrew Marshall | Purdue | Synthetic boom | 6 |
| 7 | Boom09-(flight4pass4ch10-60) | NASA Dryden | Purdue | Recorded boom | 6 |
| 8 | Boom10-(Fdoor-70) | New recording | Purdue | Car door slam | 6 |
| 9 | Boom11-(Pro1-70) | Andrew Marshall | Purdue | Synthetic boom | 6 |
| 10 | Gunfire2-resamp-25cut | Andrew Marshall | Purdue | Gunfire | 25 |
| 11 | Boom13-(Pro2-70) | Hales Swift | Purdue | Blast | 6 |
| 12 | Boom14-(Pro3-70) | Hales Swift | Purdue | Blast | 6 |
| 13 | Boom15-(fCand2-70) | Andrew Marshall | Purdue | Synthetic boom | 6 |
| 14 | Boom16-(fCand4-70) | Andrew Marshall | Purdue | Synthetic boom | 6 |
| 15 | Boom18-(flight4pass4ch10-70) | NASA Dryden | Purdue | Recorded boom | 6 |
| 16 | Boom19-(Bdoor-75) | New recording | Purdue | Car door slam | 6 |
| 17 | Boom20-(Fdoor-74) | New recording | Purdue | Car door slam | 6 |
| 18 | Gunfire2-resamp-25cut | Andrew Marshall | Purdue | Gunfire | 25 |
| 19 | Boom22-(fCand1-78) | Andrew Marshall | Purdue | Synthetic boom | 6 |
| 20 | Boom23-(fCand3-78) | Andrew Marshall | Purdue | Synthetic boom | 6 |

Table D.1. Continued from previous page.

| Signal # | Signal name | Source | Prepared by | Type | HP cutoff frequency (Hz) |
|---|---|---|---|---|---|
| 21 | Boom24-(fCand5-78) | Andrew Marshall | Purdue | Synthetic boom | 6 |
| 22 | Boom25-(flight1pass1ch5-78) | NASA Dryden | Purdue | Recorded boom | 6 |
| 23 | Boom26-(flight2pass4ch1-71) | NASA Dryden | Purdue | Recorded boom | 6 |
| 24 | Boom27-(flight4pass4ch10-78) | NASA Dryden | Purdue | Recorded boom | 6 |
| 25 | BW8_12k_HPF | Previous test | NASA Langley | Synthetic boom | 6 |
| 26 | BW8_12k_HPF | Previous test | NASA Langley | Synthetic boom | 6 |
| 27 | BW8_12k_HPF | Previous test | NASA Langley | Synthetic boom | 6 |
| 28 | BW8_12k_HPF | Previous test | NASA Langley | Synthetic boom | 6 |
| 29 | Bandpass_27Hz_Order_5_200msec | Previous test | NASA Langley | Synthetic boom | 0 |
| 30 | Bandpass_27Hz_Order_5_200msec | Previous test | NASA Langley | Synthetic boom | 0 |
| 31 | Bandpass_27Hz_Order_5_200msec | Previous test | NASA Langley | Synthetic boom | 0 |
| 32 | Bandpass_27Hz_Order_5_200msec | Previous test | NASA Langley | Synthetic boom | 0 |
| 33 | 03inhouseLBFD3_12k | Previous test | NASA Langley | Synthetic boom | 0 |
| 34 | 03inhouseLBFD3_12k | Previous test | NASA Langley | Synthetic boom | 0 |
| 35 | 03inhouseLBFD3_12k | Previous test | NASA Langley | Synthetic boom | 0 |
| 36 | 03inhouseLBFD3_12k | Previous test | NASA Langley | Synthetic boom | 0 |
| 37 | Bandpass_45Hz_Order_5_200msec | Previous test | NASA Langley | Synthetic boom | 0 |
| 38 | Bandpass_45Hz_Order_5_200msec | Previous test | NASA Langley | Synthetic boom | 0 |
| 39 | Bandpass_45Hz_Order_5_200msec | Previous test | NASA Langley | Synthetic boom | 0 |
| 40 | Bandpass_45Hz_Order_5_200msec | Previous test | NASA Langley | Synthetic boom | 0 |

Table D.1. Continued from previous page.

| Signal # | Signal name | Source | Prepared by | Type | HP cutoff frequency (Hz) |
|---|---|---|---|---|---|
| 41 | Bandpass_45Hz_Order_2_200msec | Previous test | NASA Langley | Synthetic boom | 0 |
| 42 | Bandpass_45Hz_Order_2_200msec | Previous test | NASA Langley | Synthetic boom | 0 |
| 43 | Bandpass_45Hz_Order_2_200msec | Previous test | NASA Langley | Synthetic boom | 0 |
| 44 | Bandpass_45Hz_Order_2_200msec | Previous test | NASA Langley | Synthetic boom | 0 |
| 45 | 38inhousestretchN3_12k_HPFh4Hz3rdorder | Previous test | NASA Langley | Synthetic boom | 4 |
| 46 | 38inhousestretchN3_12k_HPFh4Hz3rdorder | Previous test | NASA Langley | Synthetic boom | 4 |
| 47 | 38inhousestretchN3_12k_HPFh4Hz3rdorder | Previous test | NASA Langley | Synthetic boom | 4 |
| 48 | 38inhousestretchN3_12k_HPFh4Hz3rdorder | Previous test | NASA Langley | Synthetic boom | 4 |
| 49 | HP50_Boom01-(Fdoor-60) | New recording | Purdue | Car door slam | 50 |
| 50 | HP50_Gunfire2-resamp-25cut | Andrew Marshall | Purdue | Gunfire | 50 |
| 51 | HP50_Boom09-(flight4pass4ch10-60) | NASA Dryden | Purdue | Recorded boom | 50 |
| 52 | HP50_Gunfire2-resamp-25cut | Andrew Marshall | Purdue | Gunfire | 50 |
| 53 | HP50_Boom13-(Pro2-70) | Hales Swift | Purdue | Blast | 50 |
| 54 | HP50_Boom19-(Bdoor-75) | New recording | Purdue | Car door slam | 50 |
| 55 | HP50_Gunfire2-resamp-25cut | Andrew Marshall | Purdue | Gunfire | 50 |
| 56 | HP50_Boom25-(flight1pass1ch5-78) | NASA Dryden | Purdue | Recorded boom | 50 |
| 57 | HP50_BW8_12k_HPF | Previous test | NASA Langley | Synthetic boom | 50 |
| 58 | HP50_BW8_12k_HPF | Previous test | NASA Langley | Synthetic boom | 50 |
| 59 | HP50_BW8_12k_HPF | Previous test | NASA Langley | Synthetic boom | 50 |
| 60 | HP50_BW8_12k_HPF | Previous test | NASA Langley | Synthetic boom | 50 |

Table D.1. Continued from previous page.

| Signal # | Signal name | Source | Prepared by | Type | HP cutoff frequency (Hz) |
|---|---|---|---|---|---|
| 61 | HP50_Bandpass_27Hz_Order_5_200msec | Previous test | NASA Langley | Synthetic boom | 50 |
| 62 | HP50_Bandpass_27Hz_Order_5_200msec | Previous test | NASA Langley | Synthetic boom | 50 |
| 63 | HP50_Bandpass_27Hz_Order_5_200msec | Previous test | NASA Langley | Synthetic boom | 50 |
| 64 | HP50_Bandpass_27Hz_Order_5_200msec | Previous test | NASA Langley | Synthetic boom | 50 |
| 65 | HP50_03inhouseLBFD3_12k | Previous test | NASA Langley | Synthetic boom | 50 |
| 66 | HP50_03inhouseLBFD3_12k | Previous test | NASA Langley | Synthetic boom | 50 |
| 67 | HP50_03inhouseLBFD3_12k | Previous test | NASA Langley | Synthetic boom | 50 |
| 68 | HP50_03inhouseLBFD3_12k | Previous test | NASA Langley | Synthetic boom | 50 |
| 69 | HP50_Bandpass_45Hz_Order_5_200msec | Previous test | NASA Langley | Synthetic boom | 50 |
| 70 | HP50_Bandpass_45Hz_Order_5_200msec | Previous test | NASA Langley | Synthetic boom | 50 |
| 71 | HP50_Bandpass_45Hz_Order_5_200msec | Previous test | NASA Langley | Synthetic boom | 50 |
| 72 | HP50_Bandpass_45Hz_Order_5_200msec | Previous test | NASA Langley | Synthetic boom | 50 |
| 73 | HP50_Bandpass_45Hz_Order_2_200msec | Previous test | NASA Langley | Synthetic boom | 50 |
| 74 | HP50_Bandpass_45Hz_Order_2_200msec | Previous test | NASA Langley | Synthetic boom | 50 |
| 75 | HP50_Bandpass_45Hz_Order_2_200msec | Previous test | NASA Langley | Synthetic boom | 50 |
| 76 | HP50_Bandpass_45Hz_Order_2_200msec | Previous test | NASA Langley | Synthetic boom | 50 |
| 77 | HP50_38inhousestretchN3_12k_HPFh4Hz3rdorder | Previous test | NASA Langley | Synthetic boom | 50 |
| 78 | HP50_38inhousestretchN3_12k_HPFh4Hz3rdorder | Previous test | NASA Langley | Synthetic boom | 50 |
| 79 | HP50_38inhousestretchN3_12k_HPFh4Hz3rdorder | Previous test | NASA Langley | Synthetic boom | 50 |
| 80 | HP50_38inhousestretchN3_12k_HPFh4Hz3rdorder | Previous test | NASA Langley | Synthetic boom | 50 |

## D.2 Average and Raw Annoyance Ratings

Tables D.2-D.6 contain the annoyance ratings given during the NASA test. Table D.2 contains the averaged annoyance ratings across all thirty subjects, with separate averaged values for the plain and isolated chairs. Tables D.3 and D.4 contain the ratings given by the first fifteen and last fifteen subjects, respectively, at the plain chair. Tables D.5 and D.6 contain the ratings given by the first fifteen and last fifteen subjects, respectively, at the isolated chair.

Table D.2. Annoyance ratings from the NASA test, averaged across all thirty subjects. Caption $Ann_N$ refers to annoyance ratings given at the non-isolated (plain) chair, and caption $Ann_I$ refers to annoyance ratings given at the isolated chair.

| **Sound** | $Ann_N$ | $Ann_I$ | **Sound** | $Ann_N$ | $Ann_I$ | **Sound** | $Ann_N$ | $Ann_I$ | **Sound** | $Ann_N$ | $Ann_I$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 2.504 | 2.420 | **21** | 5.538 | 5.815 | **41** | 4.571 | 4.444 | **61** | 2.344 | 2.276 |
| **2** | 2.988 | 2.936 | **22** | 6.583 | 6.402 | **42** | 4.932 | 4.963 | **62** | 2.400 | 2.572 |
| **3** | 2.676 | 2.544 | **23** | 4.160 | 4.440 | **43** | 6.026 | 5.958 | **63** | 2.852 | 2.920 |
| **4** | 2.524 | 2.796 | **24** | 6.162 | 6.067 | **44** | 6.668 | 6.757 | **64** | 3.436 | 3.260 |
| **5** | 2.688 | 2.584 | **25** | 2.760 | 2.692 | **45** | 2.804 | 3.044 | **65** | 2.376 | 2.448 |
| **6** | 2.384 | 2.448 | **26** | 3.064 | 2.868 | **46** | 3.596 | 3.724 | **66** | 2.484 | 2.368 |
| **7** | 2.764 | 2.820 | **27** | 4.092 | 3.416 | **47** | 4.851 | 4.560 | **67** | 2.708 | 2.688 |
| **8** | 3.788 | 3.652 | **28** | 4.923 | 4.456 | **48** | 5.957 | 5.551 | **68** | 3.168 | 3.036 |
| **9** | 5.486 | 4.991 | **29** | 3.935 | 3.908 | **49** | 2.424 | 2.512 | **69** | 2.564 | 2.908 |
| **10** | 4.108 | 3.764 | **30** | 5.260 | 5.079 | **50** | 2.700 | 2.684 | **70** | 3.308 | 3.492 |
| **11** | 4.352 | 4.064 | **31** | 6.362 | 6.154 | **51** | 2.836 | 2.764 | **71** | 3.928 | 3.844 |
| **12** | 4.108 | 3.848 | **32** | 7.138 | 7.063 | **52** | 3.796 | 3.768 | **72** | 5.219 | 5.343 |
| **13** | 4.983 | 4.588 | **33** | 2.392 | 2.384 | **53** | 3.560 | 3.640 | **73** | 4.327 | 4.164 |
| **14** | 3.504 | 3.808 | **34** | 2.812 | 2.696 | **54** | 4.415 | 4.575 | **74** | 5.012 | 4.872 |
| **15** | 4.267 | 4.399 | **35** | 3.916 | 3.812 | **55** | 5.334 | 5.342 | **75** | 5.758 | 5.710 |
| **16** | 4.979 | 4.799 | **36** | 5.698 | 5.463 | **56** | 5.526 | 5.563 | **76** | 6.341 | 6.380 |
| **17** | 4.647 | 4.423 | **37** | 3.432 | 3.484 | **57** | 2.520 | 2.552 | **77** | 2.588 | 2.636 |
| **18** | 5.538 | 5.230 | **38** | 4.267 | 3.987 | **58** | 2.824 | 2.580 | **78** | 2.980 | 2.856 |
| **19** | 5.370 | 5.915 | **39** | 5.179 | 5.351 | **59** | 3.284 | 3.124 | **79** | 3.352 | 3.236 |
| **20** | 4.340 | 4.436 | **40** | 6.426 | 6.457 | **60** | 3.759 | 3.772 | **80** | 3.952 | 4.196 |

Table D.3. Annoyance ratings given at the plain chair in the NASA test, subjects 1-15.

| **Sound** | **Sub. 1** | **Sub. 2** | **Sub. 3** | **Sub. 4** | **Sub. 5** | **Sub. 6** | **Sub. 7** | **Sub. 8** | **Sub. 9** | **Sub. 10** | **Sub. 11** | **Sub. 12** | **Sub. 13** | **Sub. 14** | **Sub. 15** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 2.612 | 3.572 | 3.092 | 2.492 | 2.492 | 2.372 | 2.252 | 2.012 | 2.132 | 2.372 | 2.132 | 2.012 | 2.492 | 3.212 | 2.012 |
| **2** | 2.612 | 5.492 | 3.692 | 2.732 | 2.612 | 5.132 | 2.732 | 2.132 | 2.132 | 3.692 | 3.212 | 4.892 | 5.012 | 3.332 | 2.012 |
| **3** | 2.972 | 3.932 | 2.612 | 2.012 | 2.372 | 3.332 | 2.852 | 2.012 | 2.132 | 2.012 | 2.132 | 3.092 | 5.852 | 2.492 | 2.132 |
| **4** | 2.372 | 2.852 | 2.492 | 2.012 | 2.612 | 3.212 | 2.372 | 2.252 | 2.372 | 2.732 | 2.012 | 2.012 | 2.612 | 3.692 | 2.012 |
| **5** | 2.252 | 4.652 | 3.572 | 2.492 | 2.732 | 3.572 | 2.252 | 2.012 | 3.092 | 2.612 | 2.132 | 2.012 | 2.492 | 2.852 | 2.012 |
| **6** | 2.132 | 3.212 | 3.332 | 2.012 | 2.612 | 3.812 | 2.732 | 2.012 | 2.012 | 2.252 | 2.012 | 2.012 | 2.372 | 2.852 | 2.012 |
| **7** | 2.972 | 5.012 | 3.212 | 2.732 | 3.572 | 3.692 | 2.492 | 2.012 | 2.132 | 4.052 | 2.012 | 2.012 | 2.372 | 2.972 | 2.012 |
| **8** | 4.772 | 6.692 | 4.052 | 4.172 | 3.212 | 4.172 | 3.812 | 2.132 | 2.372 | 3.092 | 4.052 | 5.012 | 6.572 | 5.492 | 2.012 |
| **9** | 7.892 | 6.692 | 6.452 | 5.132 | 6.212 | 7.292 | 5.012 | 2.612 | 6.812 | 4.292 | 3.572 | 4.892 | 7.280 | 7.052 | 6.572 |
| **10** | 5.372 | 6.932 | 3.572 | 4.412 | 2.492 | 4.172 | 5.132 | 2.012 | 2.132 | 3.452 | 3.572 | 4.532 | 7.532 | 6.332 | 3.572 |
| **11** | 5.972 | 5.852 | 4.772 | 3.932 | 4.412 | 4.532 | 2.972 | 2.372 | 6.812 | 5.252 | 3.092 | 5.732 | 5.012 | 4.292 | 3.572 |
| **12** | 3.572 | 5.732 | 4.052 | 5.252 | 2.732 | 3.932 | 2.852 | 2.492 | 2.492 | 5.252 | 3.452 | 5.132 | 5.612 | 6.212 | 5.012 |
| **13** | 6.452 | 7.772 | 5.492 | 5.852 | 4.892 | 6.692 | 3.692 | 2.372 | 3.212 | 4.292 | 3.092 | 8.000 | 8.000 | 7.412 | 5.012 |
| **14** | 2.972 | 5.132 | 3.692 | 2.972 | 2.852 | 3.932 | 3.692 | 2.012 | 3.332 | 3.812 | 3.692 | 2.492 | 2.372 | 2.852 | 3.572 |
| **15** | 4.892 | 6.092 | 4.172 | 2.252 | 4.172 | 5.132 | 2.972 | 2.372 | 2.972 | 5.012 | 5.252 | 8.000 | 6.332 | 5.252 | 3.572 |
| **16** | 5.372 | 7.412 | 4.772 | 6.452 | 4.292 | 4.772 | 4.052 | 2.732 | 4.652 | 3.572 | 3.572 | 4.652 | 6.572 | 6.452 | 5.132 |
| **17** | 7.412 | 6.092 | 4.052 | 3.812 | 4.532 | 5.492 | 4.532 | 2.252 | 6.572 | 5.012 | 5.492 | 8.000 | 6.692 | 6.572 | 3.452 |
| **18** | 6.452 | 7.880 | 5.252 | 6.572 | 4.412 | 6.092 | 5.252 | 2.612 | 6.572 | 5.492 | 6.212 | 8.000 | 8.000 | 7.172 | 5.012 |
| **19** | 8.000 | 8.000 | 5.252 | 4.052 | 5.012 | 6.092 | 5.972 | 3.452 | 6.812 | 5.492 | 5.252 | 8.000 | 5.492 | 5.372 | 6.092 |
| **20** | 3.932 | 5.852 | 4.052 | 5.492 | 5.972 | 6.212 | 3.572 | 2.492 | 4.532 | 5.012 | 3.452 | 3.932 | 5.132 | 6.572 | 3.452 |

Table D.3. Continued from previous page.

| Sound | Sub. 1 | Sub. 2 | Sub. 3 | Sub. 4 | Sub. 5 | Sub. 6 | Sub. 7 | Sub. 8 | Sub. 9 | Sub. 10 | Sub. 11 | Sub. 12 | Sub. 13 | Sub. 14 | Sub. 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **21** | 7.892 | 8.000 | 5.492 | 5.972 | 5.612 | 5.612 | 5.372 | 3.212 | 6.452 | 5.012 | 5.252 | 8.000 | 8.000 | 6.692 | 3.572 |
| **22** | 8.000 | 7.880 | 5.612 | 7.532 | 6.092 | 7.772 | 6.440 | 4.532 | 7.172 | 7.292 | 7.292 | 8.000 | 8.000 | 7.052 | 8.000 |
| **23** | 2.732 | 6.452 | 3.452 | 3.572 | 4.772 | 5.012 | 4.652 | 2.372 | 5.372 | 5.612 | 4.772 | 5.012 | 4.652 | 6.092 | 4.892 |
| **24** | 5.252 | 7.292 | 5.732 | 5.972 | 5.012 | 7.532 | 5.492 | 4.412 | 7.172 | 6.092 | 6.332 | 8.000 | 8.000 | 6.812 | 6.572 |
| **25** | 3.212 | 4.052 | 2.852 | 2.252 | 2.732 | 3.692 | 2.732 | 2.372 | 2.252 | 2.372 | 2.132 | 3.572 | 2.132 | 3.212 | 2.012 |
| **26** | 2.852 | 4.772 | 3.572 | 3.452 | 3.092 | 4.652 | 2.852 | 2.012 | 2.252 | 2.492 | 2.252 | 2.852 | 2.732 | 2.852 | 2.012 |
| **27** | 5.012 | 4.652 | 4.652 | 5.252 | 3.212 | 5.372 | 3.452 | 2.372 | 3.332 | 3.092 | 3.092 | 6.572 | 5.132 | 5.852 | 3.572 |
| **28** | 5.012 | 6.692 | 5.252 | 5.612 | 3.692 | 6.932 | 3.332 | 2.012 | 7.172 | 5.012 | 5.012 | 6.932 | 7.412 | 6.692 | 6.452 |
| **29** | 5.012 | 7.760 | 3.692 | 4.532 | 2.852 | 5.852 | 3.572 | 2.372 | 3.932 | 3.212 | 3.812 | 2.732 | 5.372 | 6.932 | 3.452 |
| **30** | 6.572 | 7.892 | 4.652 | 5.252 | 4.652 | 6.932 | 4.532 | 3.212 | 6.812 | 6.212 | 5.612 | 2.492 | 6.692 | 6.812 | 6.572 |
| **31** | 7.532 | 8.000 | 5.372 | 5.252 | 6.692 | 7.412 | 5.732 | 3.932 | 7.172 | 7.532 | 6.692 | 8.000 | 8.000 | 7.292 | 6.452 |
| **32** | 8.000 | 7.772 | 7.772 | 5.132 | 6.212 | 7.172 | 7.172 | 4.052 | 7.640 | 8.000 | 8.000 | 8.000 | 8.000 | 7.772 | 8.000 |
| **33** | 3.332 | 2.852 | 2.972 | 2.132 | 2.372 | 2.492 | 2.492 | 2.012 | 2.012 | 2.372 | 2.012 | 2.612 | 4.892 | 2.492 | 2.012 |
| **34** | 2.612 | 6.692 | 3.332 | 4.172 | 2.252 | 4.532 | 2.492 | 2.132 | 2.252 | 2.492 | 2.012 | 2.012 | 4.052 | 3.932 | 2.012 |
| **35** | 5.132 | 6.572 | 4.292 | 4.412 | 4.772 | 3.932 | 3.092 | 2.492 | 4.292 | 2.852 | 2.372 | 2.852 | 5.372 | 6.452 | 2.012 |
| **36** | 6.812 | 7.772 | 6.692 | 5.492 | 5.012 | 6.332 | 2.372 | 2.012 | 5.732 | 5.732 | 5.492 | 8.000 | 7.160 | 6.692 | 6.092 |
| **37** | 4.052 | 6.332 | 2.972 | 3.092 | 2.492 | 5.132 | 3.572 | 2.132 | 6.572 | 3.572 | 2.252 | 4.892 | 2.492 | 4.292 | 2.012 |
| **38** | 4.292 | 6.452 | 3.812 | 5.612 | 3.092 | 4.892 | 5.132 | 2.252 | 6.692 | 4.172 | 3.932 | 2.372 | 5.132 | 6.692 | 3.692 |
| **39** | 6.212 | 6.572 | 6.452 | 6.452 | 6.212 | 6.812 | 3.212 | 3.212 | 6.812 | 5.252 | 6.212 | 8.000 | 6.572 | 7.052 | 5.012 |
| **40** | 7.412 | 7.172 | 7.052 | 7.172 | 5.972 | 6.212 | 5.732 | 3.932 | 7.412 | 5.732 | 6.572 | 8.000 | 7.532 | 7.292 | 8.000 |

Table D.3. Continued from previous page.

| **Sound** | **Sub. 1** | **Sub. 2** | **Sub. 3** | **Sub. 4** | **Sub. 5** | **Sub. 6** | **Sub. 7** | **Sub. 8** | **Sub. 9** | **Sub. 10** | **Sub. 11** | **Sub. 12** | **Sub. 13** | **Sub. 14** | **Sub. 15** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **41** | 5.492 | 6.452 | 4.772 | 4.772 | 4.652 | 4.652 | 3.932 | 2.492 | 2.492 | 3.932 | 4.292 | 7.052 | 6.932 | 6.332 | 5.012 |
| **42** | 7.292 | 6.572 | 5.972 | 4.052 | 5.132 | 5.252 | 2.252 | 2.972 | 5.612 | 5.132 | 4.292 | 5.012 | 5.852 | 6.572 | 5.132 |
| **43** | 7.892 | 7.760 | 6.092 | 6.812 | 4.172 | 5.492 | 5.612 | 5.012 | 5.732 | 7.172 | 4.892 | 8.000 | 8.000 | 7.052 | 8.000 |
| **44** | 7.892 | 7.412 | 5.732 | 5.252 | 6.092 | 7.412 | 5.492 | 3.572 | 7.760 | 8.000 | 8.000 | 8.000 | 8.000 | 7.772 | 5.132 |
| **45** | 3.332 | 4.892 | 2.732 | 3.452 | 2.252 | 3.452 | 2.612 | 2.732 | 2.252 | 2.852 | 2.492 | 2.012 | 5.132 | 3.212 | 2.132 |
| **46** | 3.932 | 6.092 | 4.172 | 3.332 | 2.852 | 4.412 | 2.492 | 2.852 | 3.332 | 4.052 | 2.732 | 3.452 | 3.812 | 4.772 | 3.572 |
| **47** | 6.812 | 6.572 | 5.732 | 5.252 | 4.892 | 5.612 | 4.052 | 3.092 | 6.932 | 3.692 | 5.612 | 8.000 | 8.000 | 6.812 | 3.692 |
| **48** | 5.612 | 6.332 | 6.332 | 6.212 | 6.212 | 7.532 | 5.732 | 2.972 | 6.692 | 5.012 | 7.652 | 8.000 | 8.000 | 6.572 | 6.572 |
| **49** | 2.972 | 3.812 | 3.452 | 3.332 | 2.252 | 3.092 | 2.732 | 2.012 | 2.012 | 2.012 | 2.252 | 2.012 | 2.252 | 2.612 | 2.012 |
| **50** | 2.732 | 5.132 | 3.092 | 2.612 | 2.732 | 3.452 | 3.572 | 2.012 | 2.132 | 2.372 | 2.012 | 2.012 | 5.492 | 3.212 | 2.012 |
| **51** | 4.052 | 5.012 | 2.612 | 2.132 | 2.252 | 3.212 | 2.732 | 2.012 | 2.132 | 2.852 | 2.132 | 2.012 | 2.492 | 2.852 | 2.012 |
| **52** | 4.052 | 6.692 | 3.692 | 2.972 | 2.732 | 4.892 | 3.092 | 2.012 | 2.132 | 2.732 | 5.612 | 3.092 | 6.932 | 5.132 | 2.012 |
| **53** | 3.692 | 7.760 | 4.052 | 2.492 | 2.372 | 4.052 | 4.292 | 2.372 | 2.132 | 4.532 | 2.372 | 3.212 | 6.452 | 3.692 | 2.012 |
| **54** | 5.012 | 5.972 | 3.812 | 4.532 | 3.932 | 3.452 | 5.252 | 2.012 | 2.252 | 4.772 | 3.932 | 3.092 | 8.000 | 6.572 | 5.012 |
| **55** | 7.052 | 7.412 | 4.892 | 7.052 | 4.412 | 5.972 | 5.252 | 2.252 | 4.172 | 5.372 | 5.372 | 8.000 | 8.000 | 7.172 | 5.132 |
| **56** | 8.000 | 8.000 | 4.892 | 4.532 | 4.892 | 4.892 | 5.012 | 2.852 | 4.652 | 6.332 | 7.052 | 8.000 | 7.532 | 6.692 | 5.012 |
| **57** | 2.372 | 4.652 | 2.852 | 3.092 | 2.492 | 2.492 | 3.572 | 2.012 | 2.132 | 2.372 | 2.012 | 2.012 | 2.972 | 2.732 | 2.012 |
| **58** | 3.212 | 4.652 | 3.452 | 2.492 | 2.372 | 3.692 | 2.732 | 2.492 | 2.732 | 2.252 | 2.132 | 2.492 | 5.252 | 2.372 | 2.012 |
| **59** | 4.052 | 5.732 | 3.572 | 3.212 | 2.372 | 3.812 | 2.612 | 2.012 | 4.532 | 2.372 | 2.372 | 3.932 | 5.492 | 3.332 | 5.012 |
| **60** | 3.332 | 5.972 | 4.652 | 2.852 | 2.492 | 5.852 | 3.692 | 2.252 | 4.532 | 3.332 | 2.132 | 3.092 | 6.452 | 6.332 | 2.012 |

Table D.3. Continued from previous page.

| **Sound** | **Sub. 1** | **Sub. 2** | **Sub. 3** | **Sub. 4** | **Sub. 5** | **Sub. 6** | **Sub. 7** | **Sub. 8** | **Sub. 9** | **Sub. 10** | **Sub. 11** | **Sub. 12** | **Sub. 13** | **Sub. 14** | **Sub. 15** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **61** | 2.012 | 3.332 | 2.732 | 2.252 | 2.372 | 3.452 | 2.132 | 2.012 | 2.012 | 2.252 | 2.012 | 2.012 | 2.612 | 2.492 | 2.012 |
| **62** | 2.372 | 2.732 | 3.572 | 2.732 | 2.492 | 4.052 | 2.252 | 2.012 | 2.132 | 2.132 | 2.132 | 2.012 | 2.612 | 2.372 | 2.012 |
| **63** | 2.012 | 5.852 | 3.212 | 3.212 | 2.732 | 4.532 | 3.452 | 2.492 | 6.572 | 2.372 | 2.132 | 2.012 | 3.692 | 3.212 | 2.012 |
| **64** | 3.692 | 8.000 | 3.932 | 3.572 | 2.492 | 5.132 | 2.852 | 2.012 | 2.132 | 3.572 | 2.132 | 4.772 | 5.252 | 3.692 | 3.452 |
| **65** | 2.132 | 3.692 | 2.492 | 2.972 | 4.772 | 2.372 | 2.132 | 2.012 | 2.132 | 2.732 | 2.012 | 2.012 | 2.492 | 2.372 | 2.012 |
| **66** | 2.852 | 3.452 | 2.492 | 2.492 | 2.612 | 3.092 | 2.612 | 2.012 | 2.372 | 2.372 | 2.012 | 2.012 | 2.132 | 2.492 | 2.012 |
| **67** | 2.372 | 5.252 | 3.332 | 3.452 | 2.012 | 3.452 | 2.252 | 2.012 | 2.252 | 2.252 | 2.132 | 2.732 | 4.772 | 2.252 | 2.012 |
| **68** | 3.212 | 5.612 | 3.332 | 3.092 | 4.052 | 2.852 | 3.692 | 2.012 | 2.732 | 2.372 | 2.252 | 4.772 | 3.212 | 3.932 | 3.572 |
| **69** | 2.972 | 5.252 | 3.092 | 3.332 | 2.252 | 3.812 | 2.012 | 2.132 | 2.132 | 2.132 | 2.132 | 2.012 | 2.612 | 2.852 | 2.012 |
| **70** | 3.092 | 6.572 | 3.332 | 3.452 | 3.692 | 5.972 | 3.332 | 3.092 | 2.252 | 3.572 | 3.452 | 3.692 | 3.812 | 5.252 | 2.012 |
| **71** | 3.572 | 6.332 | 4.412 | 4.172 | 2.852 | 5.852 | 3.092 | 2.492 | 6.812 | 2.852 | 3.332 | 5.012 | 3.452 | 5.012 | 3.572 |
| **72** | 3.092 | 7.880 | 5.252 | 6.452 | 6.932 | 5.372 | 4.892 | 2.732 | 6.812 | 4.172 | 6.932 | 8.000 | 6.932 | 6.932 | 5.012 |
| **73** | 5.132 | 5.252 | 3.692 | 3.812 | 4.532 | 5.372 | 4.292 | 2.492 | 6.332 | 4.772 | 5.972 | 8.000 | 3.692 | 5.492 | 5.132 |
| **74** | 6.812 | 6.452 | 6.092 | 4.652 | 5.132 | 6.212 | 5.612 | 2.732 | 6.932 | 5.012 | 4.892 | 5.852 | 5.732 | 6.572 | 5.012 |
| **75** | 6.812 | 7.640 | 6.212 | 5.252 | 5.132 | 6.920 | 5.372 | 3.572 | 5.492 | 6.692 | 6.572 | 8.000 | 7.052 | 7.532 | 6.452 |
| **76** | 8.000 | 8.000 | 6.452 | 6.092 | 5.852 | 6.932 | 7.292 | 4.172 | 7.652 | 6.572 | 6.572 | 8.000 | 8.000 | 7.772 | 8.000 |
| **77** | 2.132 | 4.412 | 3.212 | 2.012 | 3.452 | 3.812 | 2.612 | 2.012 | 2.012 | 2.132 | 2.012 | 2.492 | 2.612 | 3.092 | 2.012 |
| **78** | 5.012 | 5.012 | 2.732 | 2.852 | 2.372 | 3.812 | 3.692 | 2.012 | 2.252 | 2.852 | 2.132 | 2.012 | 5.252 | 3.692 | 3.452 |
| **79** | 3.572 | 6.332 | 3.332 | 3.572 | 3.092 | 4.172 | 2.852 | 2.132 | 3.092 | 3.332 | 2.132 | 3.692 | 2.732 | 3.332 | 3.572 |
| **80** | 4.172 | 6.212 | 4.772 | 4.052 | 5.372 | 6.092 | 3.932 | 2.732 | 2.852 | 4.292 | 2.132 | 2.612 | 5.372 | 5.372 | 3.452 |

Table D.4. Annoyance ratings given at the plain chair in the NASA test, subjects 16-30.

| **Sound** | **Sub. 16** | **Sub. 17** | **Sub. 18** | **Sub. 19** | **Sub. 20** | **Sub. 21** | **Sub. 22** | **Sub. 23** | **Sub. 24** | **Sub. 25** | **Sub. 26** | **Sub. 27** | **Sub. 28** | **Sub. 29** | **Sub. 30** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 2.852 | 2.012 | 2.012 | 2.012 | 2.252 | 2.492 | 2.012 | 2.372 | 2.012 | 2.372 | 2.012 | 3.332 | 5.012 | 2.252 | 2.852 |
| **2** | 2.252 | 2.012 | 2.492 | 2.132 | 3.092 | 2.252 | 4.892 | 2.372 | 2.012 | 2.252 | 2.012 | 3.332 | 2.012 | 2.372 | 2.732 |
| **3** | 2.732 | 2.492 | 2.012 | 2.132 | 2.492 | 3.092 | 3.092 | 2.012 | 2.012 | 2.252 | 2.012 | 2.732 | 5.012 | 2.252 | 2.012 |
| **4** | 2.012 | 2.012 | 2.612 | 2.012 | 2.252 | 3.572 | 2.372 | 2.732 | 2.012 | 2.132 | 2.012 | 2.612 | 5.012 | 2.612 | 2.132 |
| **5** | 2.612 | 2.012 | 2.372 | 2.012 | 2.252 | 4.172 | 3.092 | 2.972 | 2.012 | 2.012 | 2.012 | 2.492 | 5.012 | 2.372 | 2.492 |
| **6** | 3.572 | 2.012 | 2.132 | 2.252 | 2.492 | 2.132 | 2.012 | 2.252 | 2.012 | 2.252 | 2.012 | 2.732 | 2.012 | 2.252 | 2.012 |
| **7** | 2.372 | 2.492 | 2.012 | 2.132 | 2.492 | 3.932 | 4.052 | 2.012 | 2.012 | 2.012 | 2.012 | 2.492 | 4.772 | 2.492 | 2.372 |
| **8** | 5.852 | 2.252 | 2.372 | 2.372 | 3.572 | 5.612 | 4.532 | 3.572 | 2.012 | 3.332 | 3.452 | 2.372 | 5.012 | 3.572 | 2.132 |
| **9** | 6.800 | 3.572 | 7.292 | 2.492 | 4.772 | 8.000 | 7.760 | 3.212 | 2.012 | 6.812 | 5.612 | 2.372 | 8.000 | 3.452 | 4.652 |
| **10** | 5.972 | 2.132 | 3.692 | 2.492 | 3.332 | 5.132 | 5.012 | 2.852 | 2.012 | 6.212 | 4.652 | 2.732 | 7.052 | 2.732 | 2.012 |
| **11** | 5.732 | 2.132 | 2.252 | 2.132 | 2.972 | 6.212 | 5.372 | 4.532 | 2.132 | 6.212 | 4.892 | 2.492 | 8.000 | 2.972 | 3.932 |
| **12** | 6.932 | 2.732 | 3.932 | 2.012 | 3.332 | 6.332 | 4.052 | 2.972 | 2.012 | 5.372 | 5.492 | 2.852 | 5.012 | 2.972 | 3.452 |
| **13** | 6.572 | 2.732 | 5.252 | 2.852 | 5.252 | 5.732 | 5.012 | 3.212 | 2.012 | 5.252 | 4.892 | 2.492 | 8.000 | 4.652 | 3.332 |
| **14** | 5.612 | 2.372 | 3.572 | 2.372 | 3.452 | 5.252 | 4.412 | 3.332 | 2.012 | 4.772 | 2.852 | 2.612 | 8.000 | 2.612 | 2.492 |
| **15** | 6.812 | 2.732 | 3.572 | 2.612 | 4.052 | 6.452 | 4.772 | 2.852 | 2.012 | 3.692 | 4.292 | 3.092 | 8.000 | 2.492 | 2.132 |
| **16** | 8.000 | 3.572 | 5.132 | 2.372 | 4.892 | 6.332 | 5.612 | 5.132 | 2.012 | 8.000 | 4.772 | 2.612 | 8.000 | 3.452 | 5.012 |
| **17** | 7.772 | 2.492 | 5.132 | 2.732 | 3.812 | 4.412 | 3.572 | 2.732 | 2.012 | 4.052 | 4.652 | 2.372 | 8.000 | 3.692 | 2.012 |
| **18** | 8.000 | 3.932 | 5.372 | 2.972 | 4.892 | 8.000 | 5.012 | 2.732 | 2.012 | 5.732 | 4.772 | 2.732 | 8.000 | 5.372 | 5.612 |
| **19** | 2.492 | 4.052 | 3.692 | 2.852 | 6.212 | 5.132 | 5.012 | 5.012 | 5.012 | 5.612 | 4.052 | 4.172 | 8.000 | 4.412 | 7.052 |
| **20** | 5.132 | 2.492 | 4.772 | 2.852 | 4.292 | 6.092 | 5.012 | 2.252 | 2.012 | 3.932 | 5.132 | 2.612 | 8.000 | 2.852 | 3.092 |

Table D.4. Continued from previous page.

| Sound | Sub. 16 | Sub. 17 | Sub. 18 | Sub. 19 | Sub. 20 | Sub. 21 | Sub. 22 | Sub. 23 | Sub. 24 | Sub. 25 | Sub. 26 | Sub. 27 | Sub. 28 | Sub. 29 | Sub. 30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **21** | 7.172 | 5.732 | 5.252 | 2.972 | 5.372 | 6.800 | 5.132 | 2.732 | 5.132 | 5.252 | 3.452 | 3.932 | 8.000 | 4.292 | 4.772 |
| **22** | 8.000 | 6.572 | 7.172 | 2.972 | 6.212 | 7.640 | 8.000 | 2.852 | 5.012 | 8.000 | 8.000 | 2.852 | 8.000 | 4.172 | 5.372 |
| **23** | 5.492 | 2.492 | 4.412 | 2.372 | 3.452 | 4.772 | 3.452 | 3.092 | 2.012 | 3.812 | 3.212 | 2.372 | 8.000 | 3.572 | 2.852 |
| **24** | 8.000 | 7.292 | 7.772 | 2.732 | 5.492 | 8.000 | 8.000 | 4.772 | 5.012 | 5.372 | 6.572 | 2.372 | 8.000 | 4.772 | 5.012 |
| **25** | 2.972 | 2.972 | 2.492 | 2.612 | 2.492 | 4.052 | 2.372 | 3.332 | 2.012 | 2.372 | 2.012 | 2.492 | 4.892 | 2.132 | 2.012 |
| **26** | 4.292 | 2.372 | 2.252 | 2.252 | 2.852 | 4.532 | 4.532 | 3.452 | 2.012 | 2.252 | 2.012 | 2.852 | 7.280 | 2.252 | 2.012 |
| **27** | 4.652 | 2.372 | 3.692 | 2.252 | 4.412 | 6.332 | 6.452 | 2.732 | 2.132 | 3.572 | 3.332 | 2.852 | 8.000 | 2.492 | 2.852 |
| **28** | 8.000 | 2.852 | 4.172 | 2.492 | 4.652 | 4.532 | 4.772 | 2.732 | 2.012 | 5.372 | 5.852 | 2.612 | 7.280 | 3.692 | 3.452 |
| **29** | 2.012 | 2.732 | 4.532 | 2.372 | 4.052 | 4.652 | 5.012 | 2.972 | 2.012 | 4.292 | 2.012 | 3.212 | 8.000 | 2.372 | 2.732 |
| **30** | 5.012 | 6.572 | 6.692 | 2.612 | 4.532 | 5.852 | 6.212 | 3.572 | 2.012 | 5.252 | 5.252 | 2.612 | 8.000 | 3.572 | 5.132 |
| **31** | 8.000 | 5.012 | 7.772 | 2.852 | 6.692 | 6.332 | 7.760 | 6.572 | 4.292 | 6.812 | 6.092 | 2.492 | 8.000 | 5.852 | 5.252 |
| **32** | 8.000 | 7.052 | 8.000 | 3.812 | 6.812 | 8.000 | 8.000 | 8.000 | 6.560 | 8.000 | 7.772 | 4.052 | 8.000 | 6.692 | 6.692 |
| **33** | 2.012 | 2.012 | 2.012 | 2.252 | 2.732 | 2.012 | 2.012 | 2.132 | 2.012 | 2.372 | 2.012 | 2.732 | 2.012 | 2.372 | 2.012 |
| **34** | 2.252 | 2.612 | 2.372 | 2.372 | 2.492 | 2.372 | 2.132 | 2.012 | 2.012 | 2.492 | 2.012 | 2.372 | 5.012 | 2.852 | 2.012 |
| **35** | 3.812 | 2.732 | 5.252 | 2.612 | 4.052 | 3.212 | 5.012 | 2.852 | 2.012 | 3.812 | 4.892 | 2.612 | 8.000 | 3.332 | 2.372 |
| **36** | 6.572 | 4.052 | 5.492 | 2.852 | 6.332 | 7.292 | 7.412 | 3.092 | 5.012 | 6.812 | 8.000 | 2.612 | 8.000 | 3.692 | 6.332 |
| **37** | 2.732 | 2.612 | 2.252 | 2.492 | 3.092 | 3.332 | 3.692 | 2.372 | 2.012 | 3.932 | 3.452 | 2.612 | 8.000 | 2.252 | 2.252 |
| **38** | 2.732 | 3.332 | 3.692 | 2.732 | 5.492 | 4.532 | 8.000 | 2.732 | 2.012 | 5.252 | 2.012 | 2.612 | 8.000 | 3.452 | 3.212 |
| **39** | 5.852 | 3.572 | 4.532 | 2.972 | 4.652 | 5.132 | 3.092 | 2.612 | 4.412 | 4.532 | 4.412 | 4.052 | 8.000 | 4.172 | 3.332 |
| **40** | 7.412 | 4.292 | 6.932 | 2.972 | 5.852 | 7.532 | 7.292 | 3.452 | 5.012 | 8.000 | 8.000 | 3.692 | 8.000 | 6.692 | 6.452 |

Table D.4. Continued from previous page.

| Sound | Sub. 16 | Sub. 17 | Sub. 18 | Sub. 19 | Sub. 20 | Sub. 21 | Sub. 22 | Sub. 23 | Sub. 24 | Sub. 25 | Sub. 26 | Sub. 27 | Sub. 28 | Sub. 29 | Sub. 30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **41** | 7.640 | 3.092 | 3.812 | 2.972 | 5.012 | 4.772 | 3.572 | 3.332 | 2.012 | 5.012 | 3.452 | 3.092 | 8.000 | 4.292 | 3.812 |
| **42** | 7.532 | 3.572 | 3.692 | 2.732 | 4.772 | 4.652 | 5.972 | 2.492 | 4.652 | 5.252 | 5.492 | 3.092 | 8.000 | 3.932 | 5.012 |
| **43** | 8.000 | 5.012 | 6.332 | 2.732 | 5.132 | 3.692 | 7.532 | 5.972 | 4.652 | 6.692 | 6.572 | 3.692 | 8.000 | 5.012 | 4.052 |
| **44** | 8.000 | 5.372 | 7.772 | 3.452 | 6.332 | 8.000 | 7.892 | 6.812 | 5.372 | 8.000 | 6.572 | 4.052 | 8.000 | 5.852 | 7.052 |
| **45** | 2.852 | 2.012 | 2.252 | 2.492 | 2.852 | 2.612 | 2.852 | 2.492 | 2.012 | 2.012 | 2.012 | 2.732 | 4.172 | 3.212 | 2.012 |
| **46** | 6.332 | 2.492 | 4.172 | 2.372 | 3.692 | 2.972 | 2.852 | 2.852 | 2.012 | 4.412 | 2.012 | 2.732 | 8.000 | 2.852 | 2.252 |
| **47** | 5.852 | 3.572 | 2.372 | 2.732 | 4.772 | 5.012 | 2.492 | 2.612 | 2.012 | 5.372 | 4.652 | 2.732 | 8.000 | 4.772 | 3.812 |
| **48** | 8.000 | 3.572 | 6.812 | 2.372 | 5.852 | 8.000 | 8.000 | 2.732 | 2.012 | 8.000 | 4.772 | 4.412 | 8.000 | 5.492 | 5.252 |
| **49** | 2.252 | 2.252 | 2.012 | 2.012 | 2.612 | 3.092 | 2.012 | 2.372 | 2.012 | 2.012 | 2.012 | 2.372 | 2.732 | 2.132 | 2.012 |
| **50** | 2.012 | 2.012 | 2.252 | 2.252 | 2.372 | 2.732 | 2.012 | 2.612 | 2.012 | 2.252 | 2.012 | 2.612 | 5.012 | 2.252 | 2.012 |
| **51** | 6.212 | 2.132 | 2.252 | 2.252 | 2.972 | 4.532 | 2.252 | 3.092 | 2.012 | 2.612 | 2.012 | 2.612 | 5.012 | 2.372 | 2.252 |
| **52** | 4.412 | 2.852 | 3.452 | 2.132 | 3.212 | 3.932 | 3.452 | 2.972 | 2.012 | 5.132 | 3.212 | 3.332 | 8.000 | 3.572 | 4.412 |
| **53** | 2.492 | 2.492 | 5.132 | 2.132 | 2.372 | 5.012 | 4.652 | 3.212 | 2.012 | 2.732 | 3.572 | 2.852 | 7.652 | 2.732 | 2.252 |
| **54** | 8.000 | 3.332 | 3.572 | 2.732 | 3.212 | 3.572 | 5.012 | 3.692 | 4.532 | 6.572 | 4.892 | 2.732 | 8.000 | 2.852 | 2.132 |
| **55** | 7.412 | 2.852 | 4.052 | 2.852 | 4.772 | 7.172 | 3.452 | 2.852 | 5.132 | 6.572 | 8.000 | 2.372 | 8.000 | 4.772 | 2.252 |
| **56** | 5.612 | 4.172 | 4.412 | 2.852 | 5.372 | 8.000 | 7.172 | 5.852 | 5.132 | 4.772 | 6.212 | 2.852 | 8.000 | 3.932 | 3.092 |
| **57** | 3.452 | 2.132 | 2.012 | 2.252 | 2.732 | 2.132 | 2.012 | 2.012 | 2.012 | 2.372 | 2.012 | 2.972 | 3.572 | 2.132 | 2.012 |
| **58** | 2.372 | 2.012 | 2.492 | 2.252 | 2.732 | 3.332 | 2.372 | 2.012 | 2.012 | 2.372 | 2.012 | 2.972 | 7.292 | 2.132 | 2.012 |
| **59** | 3.332 | 2.132 | 2.732 | 2.132 | 3.572 | 3.572 | 2.252 | 2.972 | 2.012 | 2.492 | 2.012 | 2.492 | 7.880 | 2.492 | 2.012 |
| **60** | 6.560 | 2.252 | 3.692 | 2.372 | 3.452 | 3.572 | 4.772 | 2.252 | 2.012 | 2.492 | 3.932 | 2.612 | 8.000 | 3.332 | 2.492 |

Table D.4. Continued from previous page.

| Sound | Sub. 16 | Sub. 17 | Sub. 18 | Sub. 19 | Sub. 20 | Sub. 21 | Sub. 22 | Sub. 23 | Sub. 24 | Sub. 25 | Sub. 26 | Sub. 27 | Sub. 28 | Sub. 29 | Sub. 30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **61** | 2.612 | 2.012 | 2.252 | 2.012 | 2.492 | 2.252 | 3.572 | 2.012 | 2.012 | 2.012 | 2.252 | 2.372 | 2.732 | 2.012 | 2.012 |
| **62** | 2.012 | 2.132 | 2.372 | 2.132 | 2.492 | 2.252 | 2.012 | 2.252 | 2.012 | 2.012 | 2.012 | 2.972 | 3.692 | 2.012 | 2.012 |
| **63** | 2.012 | 2.012 | 2.252 | 2.372 | 3.092 | 2.372 | 2.012 | 2.252 | 2.012 | 2.372 | 2.012 | 2.372 | 4.772 | 2.132 | 2.012 |
| **64** | 2.372 | 3.092 | 3.932 | 2.732 | 2.852 | 6.812 | 3.092 | 2.492 | 2.012 | 2.612 | 2.012 | 2.612 | 5.012 | 2.492 | 2.252 |
| **65** | 2.372 | 2.012 | 2.012 | 2.012 | 2.252 | 2.972 | 2.132 | 2.132 | 2.012 | 2.012 | 2.012 | 2.612 | 2.012 | 2.372 | 2.012 |
| **66** | 3.452 | 2.252 | 2.252 | 2.372 | 2.372 | 2.492 | 2.252 | 2.012 | 2.012 | 2.012 | 2.012 | 2.732 | 5.012 | 2.252 | 2.012 |
| **67** | 4.532 | 2.012 | 2.132 | 2.012 | 2.972 | 2.972 | 2.372 | 3.092 | 2.012 | 2.132 | 2.012 | 2.612 | 2.732 | 3.092 | 2.012 |
| **68** | 5.972 | 2.252 | 2.492 | 2.612 | 2.492 | 3.572 | 2.252 | 2.972 | 2.012 | 2.372 | 2.012 | 2.372 | 5.012 | 2.852 | 3.092 |
| **69** | 3.452 | 2.252 | 2.012 | 2.132 | 2.372 | 2.492 | 2.612 | 3.332 | 2.012 | 2.252 | 2.012 | 2.972 | 2.012 | 2.252 | 2.012 |
| **70** | 2.372 | 2.252 | 2.132 | 2.252 | 4.172 | 3.572 | 2.372 | 2.972 | 2.012 | 3.692 | 2.012 | 2.732 | 5.012 | 2.732 | 2.372 |
| **71** | 3.452 | 3.572 | 2.732 | 2.732 | 4.412 | 5.012 | 4.652 | 2.852 | 2.012 | 3.212 | 4.532 | 2.492 | 8.000 | 2.612 | 2.732 |
| **72** | 7.292 | 3.572 | 4.412 | 2.972 | 4.052 | 6.092 | 7.532 | 3.452 | 2.012 | 5.972 | 2.012 | 2.972 | 8.000 | 5.012 | 3.812 |
| **73** | 4.772 | 2.492 | 3.452 | 2.852 | 4.052 | 6.572 | 4.772 | 2.972 | 2.012 | 3.932 | 2.012 | 2.612 | 8.000 | 2.852 | 2.492 |
| **74** | 7.172 | 2.852 | 4.772 | 2.852 | 4.892 | 3.812 | 5.012 | 2.492 | 2.012 | 5.852 | 6.572 | 3.452 | 8.000 | 3.212 | 3.692 |
| **75** | 8.000 | 5.012 | 7.412 | 2.972 | 4.532 | 5.012 | 6.572 | 3.332 | 2.012 | 6.692 | 4.292 | 2.852 | 8.000 | 4.652 | 6.692 |
| **76** | 8.000 | 5.012 | 7.892 | 3.332 | 6.332 | 6.332 | 7.172 | 2.732 | 2.012 | 8.000 | 6.452 | 3.692 | 8.000 | 5.252 | 4.652 |
| **77** | 2.732 | 2.132 | 2.372 | 2.612 | 2.492 | 2.492 | 2.012 | 2.012 | 2.012 | 2.492 | 2.012 | 2.732 | 5.012 | 2.492 | 2.012 |
| **78** | 3.572 | 2.012 | 3.212 | 2.372 | 3.092 | 2.852 | 2.372 | 2.732 | 2.012 | 2.252 | 2.012 | 2.492 | 5.012 | 2.252 | 2.012 |
| **79** | 6.332 | 2.852 | 4.052 | 2.852 | 3.572 | 2.972 | 2.852 | 2.612 | 2.012 | 4.292 | 2.012 | 2.252 | 5.012 | 2.492 | 3.452 |
| **80** | 3.572 | 3.332 | 2.972 | 2.852 | 4.052 | 4.892 | 4.532 | 2.492 | 2.012 | 3.332 | 3.092 | 2.252 | 8.000 | 4.052 | 3.692 |

Table D.5. Annoyance ratings given at the isolated chair in the NASA test, subjects 1-15.

| **Sound** | **Sub. 1** | **Sub. 2** | **Sub. 3** | **Sub. 4** | **Sub. 5** | **Sub. 6** | **Sub. 7** | **Sub. 8** | **Sub. 9** | **Sub. 10** | **Sub. 11** | **Sub. 12** | **Sub. 13** | **Sub. 14** | **Sub. 15** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 2.252 | 3.332 | 3.212 | 2.972 | 2.252 | 2.732 | 2.372 | 2.012 | 2.252 | 2.012 | 2.132 | 2.012 | 2.732 | 3.092 | 2.012 |
| **2** | 2.372 | 4.172 | 4.652 | 3.572 | 2.372 | 5.732 | 2.372 | 3.092 | 2.252 | 2.252 | 2.012 | 3.452 | 3.332 | 6.212 | 2.012 |
| **3** | 2.012 | 3.212 | 2.972 | 3.812 | 2.612 | 2.252 | 2.372 | 2.372 | 2.132 | 2.252 | 2.252 | 2.012 | 2.732 | 3.212 | 2.012 |
| **4** | 2.492 | 2.732 | 2.372 | 3.932 | 3.812 | 4.172 | 3.092 | 2.012 | 2.132 | 2.252 | 2.252 | 2.012 | 5.852 | 3.692 | 2.012 |
| **5** | 2.012 | 4.532 | 3.692 | 2.972 | 2.612 | 3.332 | 2.252 | 2.012 | 2.372 | 2.612 | 2.012 | 2.012 | 3.332 | 2.852 | 2.012 |
| **6** | 2.012 | 3.332 | 2.012 | 2.372 | 2.492 | 3.332 | 2.012 | 3.212 | 2.012 | 2.012 | 2.012 | 2.012 | 3.452 | 2.852 | 3.452 |
| **7** | 2.612 | 5.132 | 3.452 | 3.092 | 2.372 | 3.572 | 2.852 | 2.012 | 2.132 | 3.212 | 2.132 | 2.492 | 2.852 | 4.052 | 2.012 |
| **8** | 5.012 | 6.092 | 5.372 | 4.892 | 4.292 | 3.092 | 2.612 | 2.012 | 2.372 | 3.572 | 4.412 | 2.012 | 5.012 | 4.772 | 2.012 |
| **9** | 6.452 | 7.292 | 5.372 | 6.692 | 4.652 | 6.572 | 4.652 | 2.252 | 5.492 | 3.812 | 5.132 | 3.572 | 8.000 | 6.692 | 4.892 |
| **10** | 6.452 | 7.652 | 3.692 | 3.332 | 3.212 | 4.412 | 3.812 | 2.012 | 2.852 | 2.492 | 3.692 | 4.172 | 4.172 | 4.412 | 2.012 |
| **11** | 3.692 | 6.812 | 4.892 | 5.972 | 3.092 | 4.172 | 3.692 | 2.372 | 4.172 | 5.012 | 3.812 | 7.052 | 6.812 | 4.772 | 2.012 |
| **12** | 3.692 | 3.812 | 4.772 | 5.852 | 2.852 | 4.292 | 2.492 | 2.492 | 3.452 | 4.172 | 4.772 | 4.172 | 6.572 | 6.692 | 3.452 |
| **13** | 4.652 | 6.332 | 5.252 | 6.452 | 6.092 | 4.532 | 2.612 | 2.132 | 3.572 | 4.052 | 4.052 | 4.892 | 6.572 | 7.052 | 3.572 |
| **14** | 4.772 | 5.132 | 4.532 | 4.892 | 2.612 | 5.972 | 3.572 | 2.492 | 2.372 | 3.332 | 3.812 | 2.492 | 6.452 | 3.452 | 5.012 |
| **15** | 3.452 | 7.172 | 4.892 | 4.052 | 3.692 | 4.892 | 3.332 | 2.012 | 2.972 | 4.532 | 6.092 | 8.000 | 5.492 | 5.012 | 5.012 |
| **16** | 5.012 | 6.212 | 4.772 | 5.972 | 3.932 | 5.372 | 4.652 | 2.132 | 3.332 | 2.492 | 5.852 | 6.572 | 8.000 | 6.572 | 5.132 |
| **17** | 2.492 | 6.572 | 4.532 | 6.572 | 3.692 | 5.852 | 2.972 | 2.732 | 2.732 | 3.452 | 3.812 | 8.000 | 6.932 | 6.572 | 3.452 |
| **18** | 7.760 | 7.772 | 6.092 | 7.412 | 4.772 | 5.132 | 2.972 | 2.852 | 5.012 | 5.012 | 6.332 | 6.332 | 8.000 | 7.052 | 5.012 |
| **19** | 7.772 | 7.892 | 5.732 | 4.532 | 6.812 | 6.092 | 3.692 | 3.572 | 4.772 | 7.172 | 6.572 | 8.000 | 7.772 | 6.812 | 6.572 |
| **20** | 3.452 | 5.372 | 5.492 | 6.092 | 6.092 | 5.492 | 2.972 | 2.372 | 2.612 | 5.012 | 2.612 | 3.572 | 6.452 | 6.812 | 5.012 |

Table D.5. Continued from previous page.

| Sound | Sub. 1 | Sub. 2 | Sub. 3 | Sub. 4 | Sub. 5 | Sub. 6 | Sub. 7 | Sub. 8 | Sub. 9 | Sub. 10 | Sub. 11 | Sub. 12 | Sub. 13 | Sub. 14 | Sub. 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **21** | 7.652 | 7.772 | 6.092 | 6.212 | 4.892 | 6.332 | 5.252 | 4.172 | 4.412 | 6.572 | 7.532 | 8.000 | 8.000 | 6.932 | 5.132 |
| **22** | 8.000 | 7.412 | 6.212 | 7.292 | 5.852 | 7.652 | 5.492 | 3.452 | 6.212 | 7.292 | 8.000 | 8.000 | 7.772 | 6.812 | 6.452 |
| **23** | 4.652 | 5.852 | 4.532 | 5.492 | 4.292 | 5.012 | 4.532 | 2.132 | 2.852 | 5.612 | 3.812 | 3.572 | 7.652 | 5.972 | 3.572 |
| **24** | 5.372 | 7.052 | 6.812 | 7.652 | 5.372 | 7.772 | 5.732 | 3.932 | 4.772 | 6.932 | 6.452 | 8.000 | 8.000 | 7.172 | 6.452 |
| **25** | 2.132 | 3.572 | 3.332 | 3.452 | 2.612 | 3.812 | 2.132 | 2.012 | 2.252 | 2.252 | 2.372 | 2.012 | 4.052 | 2.972 | 2.012 |
| **26** | 3.212 | 5.012 | 3.572 | 5.012 | 2.252 | 3.812 | 2.372 | 2.012 | 2.132 | 2.852 | 2.252 | 2.012 | 5.132 | 3.332 | 2.012 |
| **27** | 2.852 | 5.852 | 4.532 | 5.012 | 2.612 | 5.252 | 2.252 | 2.612 | 3.332 | 3.212 | 2.132 | 5.252 | 2.972 | 4.412 | 2.132 |
| **28** | 5.012 | 6.452 | 6.332 | 5.012 | 2.732 | 6.332 | 2.852 | 2.612 | 6.332 | 3.452 | 3.812 | 3.332 | 7.052 | 6.692 | 3.572 |
| **29** | 2.372 | 7.292 | 4.412 | 4.892 | 5.492 | 7.052 | 4.412 | 3.092 | 2.252 | 3.572 | 3.212 | 5.012 | 7.652 | 6.692 | 2.012 |
| **30** | 3.932 | 7.640 | 5.012 | 6.092 | 5.972 | 4.652 | 3.812 | 2.612 | 5.132 | 5.732 | 5.852 | 5.132 | 6.452 | 6.692 | 4.892 |
| **31** | 6.812 | 7.412 | 6.692 | 6.572 | 5.972 | 7.532 | 6.092 | 3.332 | 6.092 | 5.012 | 5.012 | 7.292 | 8.000 | 7.172 | 6.452 |
| **32** | 8.000 | 8.000 | 7.412 | 8.000 | 6.692 | 7.412 | 6.692 | 3.812 | 7.292 | 6.692 | 8.000 | 8.000 | 8.000 | 7.532 | 8.000 |
| **33** | 2.252 | 3.452 | 3.212 | 2.972 | 2.132 | 3.812 | 2.372 | 2.012 | 2.132 | 2.132 | 2.012 | 2.012 | 3.092 | 3.812 | 2.012 |
| **34** | 3.452 | 3.572 | 3.452 | 3.452 | 2.132 | 2.492 | 2.612 | 2.492 | 2.372 | 2.012 | 2.132 | 2.012 | 4.892 | 2.612 | 3.452 |
| **35** | 4.412 | 5.252 | 4.892 | 5.852 | 2.492 | 4.292 | 2.852 | 2.012 | 2.972 | 4.292 | 3.572 | 3.452 | 6.452 | 6.572 | 2.012 |
| **36** | 6.692 | 6.812 | 6.692 | 7.532 | 6.452 | 5.732 | 2.972 | 2.012 | 3.812 | 4.052 | 6.572 | 7.412 | 7.172 | 6.572 | 5.012 |
| **37** | 2.252 | 6.932 | 3.212 | 3.692 | 4.892 | 4.292 | 4.052 | 2.372 | 2.492 | 3.452 | 4.052 | 3.332 | 3.932 | 5.252 | 2.012 |
| **38** | 3.212 | 6.332 | 3.932 | 5.012 | 2.732 | 5.132 | 3.812 | 2.012 | 3.932 | 3.452 | 4.892 | 2.612 | 4.652 | 6.212 | 3.452 |
| **39** | 4.052 | 6.932 | 6.572 | 6.452 | 6.320 | 6.572 | 5.252 | 3.212 | 5.252 | 5.012 | 6.692 | 6.932 | 6.812 | 6.932 | 5.012 |
| **40** | 6.812 | 7.760 | 6.812 | 6.812 | 6.332 | 6.332 | 5.012 | 3.332 | 6.692 | 6.572 | 5.852 | 8.000 | 8.000 | 7.532 | 6.572 |

Table D.5. Continued from previous page.

| **Sound** | **Sub. 1** | **Sub. 2** | **Sub. 3** | **Sub. 4** | **Sub. 5** | **Sub. 6** | **Sub. 7** | **Sub. 8** | **Sub. 9** | **Sub. 10** | **Sub. 11** | **Sub. 12** | **Sub. 13** | **Sub. 14** | **Sub. 15** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **41** | 4.892 | 7.772 | 4.052 | 6.212 | 4.052 | 5.492 | 3.932 | 2.492 | 2.252 | 4.172 | 5.612 | 4.892 | 5.252 | 6.572 | 5.012 |
| **42** | 5.732 | 7.760 | 5.372 | 5.492 | 4.052 | 5.852 | 3.572 | 2.852 | 5.012 | 5.012 | 6.452 | 7.412 | 6.932 | 6.452 | 5.012 |
| **43** | 6.812 | 7.880 | 5.372 | 6.692 | 5.252 | 6.332 | 5.732 | 3.812 | 5.252 | 3.812 | 6.692 | 8.000 | 8.000 | 6.932 | 8.000 |
| **44** | 6.572 | 8.000 | 5.852 | 7.052 | 4.892 | 6.932 | 6.452 | 5.252 | 7.412 | 8.000 | 8.000 | 8.000 | 8.000 | 7.772 | 5.012 |
| **45** | 2.252 | 3.692 | 2.372 | 3.572 | 2.252 | 5.012 | 2.732 | 2.372 | 2.372 | 3.452 | 2.132 | 3.572 | 3.212 | 3.332 | 2.012 |
| **46** | 3.452 | 5.612 | 5.012 | 5.372 | 3.212 | 4.532 | 2.732 | 2.372 | 3.932 | 3.452 | 4.652 | 2.612 | 4.172 | 5.132 | 3.572 |
| **47** | 3.332 | 7.172 | 5.132 | 6.932 | 3.932 | 4.652 | 2.732 | 2.492 | 4.772 | 3.572 | 6.092 | 4.892 | 8.000 | 6.572 | 5.132 |
| **48** | 4.772 | 6.092 | 6.812 | 7.172 | 3.692 | 6.572 | 2.852 | 2.012 | 4.172 | 5.012 | 7.052 | 8.000 | 5.132 | 7.052 | 6.572 |
| **49** | 2.012 | 3.572 | 2.372 | 3.092 | 2.492 | 3.332 | 2.612 | 2.012 | 2.132 | 2.012 | 2.012 | 3.332 | 3.692 | 2.732 | 2.012 |
| **50** | 3.572 | 3.332 | 3.212 | 2.252 | 3.932 | 4.172 | 2.372 | 2.012 | 2.372 | 2.252 | 2.012 | 2.012 | 2.732 | 3.332 | 2.012 |
| **51** | 2.252 | 5.252 | 3.332 | 2.492 | 2.372 | 2.732 | 2.252 | 2.012 | 2.132 | 3.332 | 2.132 | 2.012 | 4.772 | 4.652 | 2.012 |
| **52** | 3.692 | 5.612 | 3.452 | 2.972 | 2.732 | 3.812 | 2.732 | 2.012 | 3.572 | 2.372 | 4.652 | 3.572 | 7.292 | 6.332 | 3.452 |
| **53** | 3.092 | 6.092 | 3.452 | 3.692 | 2.732 | 4.412 | 3.692 | 2.012 | 2.252 | 5.252 | 3.692 | 3.452 | 5.372 | 4.412 | 2.012 |
| **54** | 6.452 | 6.212 | 4.532 | 4.652 | 3.092 | 4.892 | 3.452 | 2.372 | 3.812 | 3.452 | 4.772 | 5.012 | 8.000 | 6.572 | 5.012 |
| **55** | 6.932 | 7.880 | 5.852 | 3.092 | 4.892 | 5.012 | 3.212 | 2.732 | 4.292 | 5.012 | 5.252 | 8.000 | 8.000 | 6.812 | 5.132 |
| **56** | 7.532 | 8.000 | 4.772 | 5.372 | 4.052 | 6.332 | 3.452 | 2.492 | 5.132 | 5.972 | 7.652 | 8.000 | 7.172 | 7.052 | 4.892 |
| **57** | 2.492 | 3.692 | 2.492 | 2.852 | 2.132 | 3.332 | 2.012 | 2.012 | 2.132 | 2.132 | 2.132 | 2.012 | 2.492 | 2.732 | 2.012 |
| **58** | 2.132 | 3.692 | 3.092 | 2.732 | 2.732 | 4.292 | 2.852 | 2.012 | 2.132 | 2.732 | 2.132 | 2.012 | 2.732 | 3.212 | 2.012 |
| **59** | 4.652 | 5.012 | 3.692 | 2.732 | 3.092 | 4.292 | 2.492 | 2.012 | 2.372 | 2.732 | 2.852 | 2.012 | 3.692 | 3.812 | 2.012 |
| **60** | 4.292 | 5.972 | 5.612 | 3.812 | 3.212 | 3.452 | 2.612 | 2.012 | 4.292 | 3.812 | 4.532 | 2.852 | 5.012 | 6.572 | 2.012 |

Table D.5. Continued from previous page.

| **Sound** | **Sub. 1** | **Sub. 2** | **Sub. 3** | **Sub. 4** | **Sub. 5** | **Sub. 6** | **Sub. 7** | **Sub. 8** | **Sub. 9** | **Sub. 10** | **Sub. 11** | **Sub. 12** | **Sub. 13** | **Sub. 14** | **Sub. 15** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **61** | 2.012 | 2.372 | 2.492 | 2.852 | 2.252 | 2.732 | 2.252 | 2.012 | 2.252 | 2.852 | 2.252 | 2.012 | 2.012 | 2.612 | 2.012 |
| **62** | 2.012 | 3.212 | 3.332 | 3.572 | 2.492 | 4.172 | 2.252 | 2.012 | 2.132 | 2.132 | 2.252 | 2.012 | 2.372 | 2.852 | 2.012 |
| **63** | 2.612 | 5.012 | 3.332 | 3.572 | 4.052 | 5.972 | 3.092 | 2.012 | 2.372 | 2.252 | 2.372 | 2.012 | 2.972 | 3.212 | 2.012 |
| **64** | 2.372 | 5.372 | 2.852 | 5.012 | 3.332 | 4.892 | 2.252 | 3.092 | 2.372 | 3.212 | 2.492 | 2.852 | 4.892 | 3.452 | 3.572 |
| **65** | 2.012 | 4.532 | 2.612 | 2.132 | 2.372 | 2.612 | 2.012 | 2.012 | 2.132 | 2.012 | 2.012 | 2.012 | 2.132 | 2.612 | 2.012 |
| **66** | 2.252 | 3.452 | 2.492 | 2.492 | 2.252 | 2.852 | 2.612 | 2.012 | 2.012 | 2.372 | 2.012 | 2.012 | 2.492 | 2.852 | 2.012 |
| **67** | 2.252 | 4.892 | 3.452 | 3.092 | 2.012 | 3.332 | 2.492 | 2.492 | 2.372 | 2.252 | 2.132 | 2.972 | 3.452 | 3.332 | 2.012 |
| **68** | 2.372 | 5.972 | 3.212 | 3.332 | 4.412 | 3.452 | 2.852 | 2.372 | 2.372 | 2.732 | 2.732 | 3.092 | 2.732 | 4.172 | 2.012 |
| **69** | 2.252 | 4.892 | 3.092 | 4.772 | 2.732 | 4.652 | 2.012 | 2.612 | 2.372 | 2.012 | 2.132 | 2.372 | 2.852 | 3.332 | 3.572 |
| **70** | 3.332 | 5.252 | 3.572 | 4.652 | 3.332 | 5.012 | 4.412 | 2.252 | 2.972 | 3.572 | 3.692 | 2.012 | 5.732 | 4.772 | 2.012 |
| **71** | 2.612 | 7.412 | 4.652 | 6.332 | 4.292 | 5.252 | 2.252 | 2.612 | 4.052 | 2.132 | 3.212 | 3.572 | 5.012 | 5.492 | 3.452 |
| **72** | 5.132 | 7.400 | 5.492 | 4.892 | 6.212 | 6.332 | 6.212 | 2.852 | 5.612 | 5.012 | 6.572 | 8.000 | 6.212 | 6.932 | 6.452 |
| **73** | 5.252 | 6.452 | 3.932 | 5.012 | 3.692 | 5.852 | 3.212 | 2.612 | 2.612 | 2.852 | 5.492 | 5.372 | 5.012 | 5.012 | 4.892 |
| **74** | 6.812 | 6.452 | 5.492 | 5.972 | 4.052 | 4.532 | 5.252 | 2.492 | 4.772 | 6.452 | 5.732 | 6.212 | 6.572 | 6.812 | 3.452 |
| **75** | 5.372 | 7.412 | 6.332 | 6.572 | 5.132 | 6.812 | 5.372 | 4.412 | 6.812 | 5.012 | 6.692 | 8.000 | 8.000 | 6.932 | 5.132 |
| **76** | 8.000 | 8.000 | 6.212 | 6.692 | 6.572 | 7.412 | 5.252 | 4.292 | 6.572 | 7.532 | 8.000 | 8.000 | 8.000 | 7.532 | 8.000 |
| **77** | 2.372 | 4.772 | 2.612 | 2.012 | 2.012 | 3.092 | 2.852 | 2.252 | 2.252 | 3.212 | 2.012 | 2.852 | 2.732 | 3.572 | 2.012 |
| **78** | 2.732 | 4.412 | 2.252 | 3.092 | 2.492 | 5.252 | 2.732 | 2.252 | 2.372 | 3.452 | 2.372 | 2.012 | 2.972 | 3.452 | 2.012 |
| **79** | 3.692 | 5.852 | 3.332 | 2.972 | 3.332 | 4.052 | 3.452 | 2.012 | 3.332 | 2.372 | 2.492 | 2.132 | 6.332 | 2.972 | 2.012 |
| **80** | 3.812 | 5.972 | 4.772 | 4.532 | 4.652 | 5.612 | 4.172 | 2.012 | 3.332 | 2.612 | 3.932 | 7.172 | 6.692 | 5.012 | 3.452 |

Table D.6. Annoyance ratings given at the isolated chair in the NASA test, subjects 16-30.

| **Sound** | **Sub. 16** | **Sub. 17** | **Sub. 18** | **Sub. 19** | **Sub. 20** | **Sub. 21** | **Sub. 22** | **Sub. 23** | **Sub. 24** | **Sub. 25** | **Sub. 26** | **Sub. 27** | **Sub. 28** | **Sub. 29** | **Sub. 30** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 2.972 | 2.012 | 2.132 | 2.012 | 3.812 | 2.492 | 2.612 | 2.252 | 2.012 | 2.012 | 2.012 | 2.372 | 2.012 | 2.252 | 2.252 |
| **2** | 2.252 | 2.492 | 2.492 | 2.132 | 2.612 | 2.732 | 2.372 | 2.372 | 2.012 | 2.972 | 2.012 | 2.372 | 5.132 | 2.252 | 2.012 |
| **3** | 3.212 | 2.012 | 2.252 | 2.012 | 2.852 | 2.132 | 3.692 | 2.012 | 2.012 | 2.012 | 2.012 | 2.612 | 5.012 | 2.132 | 2.132 |
| **4** | 4.292 | 2.012 | 2.252 | 2.132 | 2.372 | 3.452 | 2.132 | 2.252 | 2.012 | 2.612 | 2.012 | 2.372 | 5.012 | 2.132 | 2.012 |
| **5** | 2.252 | 2.012 | 2.252 | 2.012 | 2.372 | 2.492 | 3.572 | 2.012 | 2.012 | 2.372 | 2.012 | 2.372 | 5.000 | 2.132 | 2.012 |
| **6** | 2.732 | 2.012 | 2.132 | 2.012 | 2.252 | 2.012 | 5.012 | 2.012 | 2.012 | 2.012 | 2.012 | 2.252 | 2.012 | 2.372 | 2.012 |
| **7** | 2.132 | 2.252 | 2.492 | 2.252 | 3.092 | 2.492 | 2.612 | 2.372 | 2.012 | 2.372 | 3.692 | 2.732 | 5.132 | 2.252 | 2.732 |
| **8** | 5.012 | 3.092 | 3.332 | 2.252 | 3.572 | 4.412 | 3.332 | 2.732 | 2.012 | 5.372 | 2.012 | 2.372 | 5.012 | 2.612 | 4.892 |
| **9** | 6.332 | 3.452 | 3.932 | 2.612 | 4.172 | 6.092 | 7.172 | 2.372 | 3.452 | 4.652 | 5.372 | 2.612 | 8.000 | 4.172 | 3.812 |
| **10** | 5.492 | 2.852 | 3.452 | 2.732 | 3.212 | 4.652 | 3.212 | 2.252 | 2.012 | 3.572 | 5.132 | 2.732 | 8.000 | 2.852 | 2.372 |
| **11** | 6.212 | 2.132 | 2.612 | 2.492 | 3.932 | 4.172 | 3.812 | 2.852 | 2.012 | 3.812 | 3.692 | 2.612 | 5.012 | 2.972 | 5.252 |
| **12** | 3.572 | 2.852 | 3.212 | 2.132 | 2.492 | 5.372 | 3.452 | 3.092 | 2.012 | 5.132 | 2.012 | 2.612 | 8.000 | 2.612 | 3.332 |
| **13** | 5.732 | 2.372 | 4.532 | 2.492 | 3.932 | 6.932 | 3.932 | 3.332 | 4.652 | 5.252 | 4.892 | 2.492 | 8.000 | 3.812 | 3.452 |
| **14** | 5.252 | 2.372 | 3.332 | 2.732 | 3.812 | 5.972 | 3.572 | 2.612 | 2.012 | 3.812 | 2.012 | 2.252 | 8.000 | 2.252 | 3.332 |
| **15** | 5.972 | 3.452 | 2.492 | 3.212 | 4.772 | 4.052 | 5.012 | 3.572 | 2.012 | 3.932 | 5.372 | 2.612 | 8.000 | 3.212 | 3.692 |
| **16** | 8.000 | 2.732 | 5.372 | 2.852 | 3.212 | 5.252 | 5.132 | 2.732 | 2.012 | 5.372 | 5.012 | 3.212 | 8.000 | 4.052 | 5.012 |
| **17** | 7.160 | 2.492 | 2.492 | 2.732 | 3.212 | 5.492 | 4.412 | 2.252 | 4.172 | 5.252 | 5.252 | 2.732 | 8.000 | 3.332 | 3.332 |
| **18** | 8.000 | 2.492 | 5.372 | 3.692 | 4.892 | 3.812 | 5.012 | 4.892 | 2.012 | 7.652 | 4.652 | 2.972 | 8.000 | 3.692 | 2.252 |
| **19** | 8.000 | 5.012 | 5.132 | 5.372 | 4.892 | 6.572 | 5.852 | 4.892 | 4.892 | 5.372 | 5.012 | 4.172 | 8.000 | 5.132 | 5.372 |
| **20** | 6.692 | 4.412 | 4.532 | 3.092 | 3.452 | 5.852 | 4.532 | 3.452 | 2.012 | 4.532 | 3.692 | 2.612 | 8.000 | 4.292 | 2.492 |

Table D.6. Continued from previous page.

| Sound | Sub. 16 | Sub. 17 | Sub. 18 | Sub. 19 | Sub. 20 | Sub. 21 | Sub. 22 | Sub. 23 | Sub. 24 | Sub. 25 | Sub. 26 | Sub. 27 | Sub. 28 | Sub. 29 | Sub. 30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **21** | 7.292 | 6.572 | 5.252 | 3.332 | 5.132 | 6.332 | 4.652 | 3.692 | 5.372 | 5.372 | 4.892 | 2.852 | 8.000 | 4.652 | 6.092 |
| **22** | 5.732 | 6.452 | 5.612 | 3.572 | 4.532 | 8.000 | 7.172 | 6.572 | 4.652 | 7.172 | 8.000 | 2.612 | 8.000 | 4.772 | 7.292 |
| **23** | 5.012 | 3.092 | 5.372 | 2.972 | 3.572 | 3.932 | 4.532 | 4.772 | 3.692 | 4.172 | 4.052 | 2.492 | 8.000 | 2.972 | 5.012 |
| **24** | 7.532 | 5.492 | 6.212 | 2.372 | 5.012 | 7.892 | 7.172 | 6.452 | 4.292 | 5.372 | 7.292 | 2.492 | 8.000 | 4.532 | 4.412 |
| **25** | 2.012 | 2.012 | 2.372 | 2.612 | 2.372 | 2.612 | 5.132 | 2.732 | 2.012 | 2.012 | 2.012 | 2.732 | 5.012 | 2.132 | 2.012 |
| **26** | 3.452 | 2.012 | 3.212 | 2.372 | 2.972 | 2.252 | 2.612 | 2.012 | 2.012 | 2.492 | 2.012 | 2.492 | 5.012 | 2.132 | 2.012 |
| **27** | 4.172 | 2.852 | 3.332 | 3.212 | 2.852 | 5.012 | 5.012 | 2.372 | 2.012 | 3.212 | 2.012 | 2.252 | 5.000 | 2.252 | 2.492 |
| **28** | 5.852 | 3.212 | 4.052 | 3.452 | 4.412 | 6.572 | 6.092 | 2.972 | 2.012 | 4.652 | 2.492 | 2.612 | 8.000 | 2.372 | 3.332 |
| **29** | 2.492 | 3.932 | 3.692 | 2.252 | 2.852 | 5.492 | 2.972 | 2.492 | 2.012 | 2.252 | 2.012 | 2.852 | 8.000 | 2.372 | 2.132 |
| **30** | 5.012 | 5.492 | 5.252 | 2.972 | 4.532 | 7.160 | 3.572 | 3.452 | 2.012 | 6.932 | 6.092 | 2.492 | 8.000 | 4.892 | 4.892 |
| **31** | 5.612 | 5.132 | 6.332 | 4.772 | 3.932 | 8.000 | 7.292 | 5.132 | 5.252 | 8.000 | 7.052 | 3.692 | 8.000 | 5.372 | 5.612 |
| **32** | 8.000 | 6.452 | 7.052 | 4.052 | 6.212 | 8.000 | 8.000 | 7.172 | 6.212 | 8.000 | 7.880 | 4.172 | 8.000 | 5.852 | 7.292 |
| **33** | 2.012 | 2.012 | 2.492 | 2.372 | 2.372 | 2.132 | 2.132 | 2.132 | 2.012 | 2.012 | 2.012 | 2.372 | 2.012 | 2.012 | 2.012 |
| **34** | 2.372 | 2.252 | 3.332 | 2.372 | 2.852 | 2.132 | 2.372 | 2.012 | 2.012 | 2.012 | 2.012 | 2.732 | 5.012 | 2.252 | 2.012 |
| **35** | 5.252 | 3.572 | 3.812 | 2.492 | 4.172 | 4.652 | 4.412 | 2.972 | 2.012 | 3.812 | 3.452 | 2.852 | 5.012 | 2.252 | 2.252 |
| **36** | 8.000 | 4.292 | 7.412 | 2.852 | 4.052 | 5.732 | 5.732 | 4.772 | 3.332 | 6.572 | 6.692 | 2.612 | 8.000 | 3.572 | 4.772 |
| **37** | 2.252 | 2.492 | 3.212 | 2.732 | 2.852 | 5.492 | 3.212 | 2.372 | 2.012 | 4.532 | 2.012 | 2.492 | 8.000 | 2.492 | 2.132 |
| **38** | 2.972 | 3.572 | 4.172 | 3.920 | 4.412 | 2.012 | 3.332 | 6.092 | 2.012 | 3.932 | 3.812 | 2.612 | 8.000 | 3.572 | 3.812 |
| **39** | 7.292 | 5.012 | 3.332 | 2.852 | 3.932 | 6.452 | 5.612 | 3.452 | 4.172 | 5.252 | 5.492 | 3.332 | 8.000 | 5.132 | 3.212 |
| **40** | 8.000 | 6.572 | 6.212 | 2.972 | 5.012 | 7.892 | 7.052 | 6.812 | 5.012 | 8.000 | 8.000 | 4.052 | 8.000 | 5.852 | 5.852 |

Table D.6. Continued from previous page.

| **Sound** | **Sub. 16** | **Sub. 17** | **Sub. 18** | **Sub. 19** | **Sub. 20** | **Sub. 21** | **Sub. 22** | **Sub. 23** | **Sub. 24** | **Sub. 25** | **Sub. 26** | **Sub. 27** | **Sub. 28** | **Sub. 29** | **Sub. 30** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **41** | 7.052 | 2.612 | 2.972 | 3.212 | 3.452 | 6.452 | 4.532 | 2.732 | 2.012 | 3.692 | 3.452 | 2.492 | 8.000 | 3.212 | 4.772 |
| **42** | 6.212 | 5.012 | 3.332 | 3.212 | 4.052 | 3.452 | 5.612 | 3.212 | 2.012 | 6.332 | 5.012 | 2.732 | 8.000 | 3.452 | 4.292 |
| **43** | 7.532 | 4.292 | 2.852 | 3.572 | 4.652 | 6.932 | 5.612 | 6.212 | 5.252 | 6.812 | 6.932 | 3.932 | 8.000 | 5.132 | 6.452 |
| **44** | 8.000 | 6.692 | 6.692 | 5.492 | 5.612 | 7.412 | 7.172 | 6.452 | 5.732 | 8.000 | 7.292 | 3.812 | 8.000 | 6.332 | 6.812 |
| **45** | 4.292 | 2.372 | 2.612 | 2.612 | 2.492 | 3.932 | 6.452 | 2.132 | 2.012 | 3.092 | 3.092 | 2.492 | 5.012 | 2.252 | 2.132 |
| **46** | 4.412 | 2.372 | 3.692 | 2.372 | 4.292 | 3.812 | 4.292 | 2.492 | 2.012 | 3.092 | 2.732 | 2.612 | 8.000 | 2.492 | 3.212 |
| **47** | 6.572 | 4.052 | 4.292 | 3.452 | 3.692 | 5.252 | 4.532 | 3.452 | 2.012 | 4.772 | 5.372 | 2.252 | 5.012 | 3.572 | 3.092 |
| **48** | 8.000 | 6.452 | 5.132 | 2.972 | 4.052 | 6.572 | 7.772 | 5.492 | 4.652 | 7.292 | 6.092 | 2.372 | 8.000 | 4.652 | 4.052 |
| **49** | 2.972 | 2.012 | 2.372 | 2.012 | 2.372 | 2.492 | 4.292 | 2.492 | 2.012 | 2.012 | 2.012 | 2.732 | 2.012 | 2.132 | 2.012 |
| **50** | 2.252 | 2.012 | 2.252 | 2.132 | 3.092 | 4.772 | 2.012 | 2.252 | 2.012 | 2.012 | 2.012 | 2.732 | 5.132 | 2.252 | 2.012 |
| **51** | 2.492 | 2.012 | 2.372 | 2.252 | 2.972 | 4.052 | 2.372 | 2.012 | 2.012 | 2.492 | 2.012 | 2.612 | 5.012 | 2.492 | 2.012 |
| **52** | 6.092 | 2.732 | 3.692 | 2.492 | 3.572 | 4.772 | 4.052 | 2.852 | 2.012 | 5.132 | 4.052 | 2.612 | 5.012 | 3.212 | 2.492 |
| **53** | 6.332 | 2.732 | 4.772 | 2.012 | 2.972 | 3.452 | 4.412 | 2.612 | 2.012 | 3.812 | 5.132 | 2.612 | 5.012 | 2.252 | 3.452 |
| **54** | 8.000 | 3.572 | 3.692 | 3.692 | 3.452 | 3.452 | 5.252 | 3.332 | 2.012 | 6.572 | 4.892 | 2.492 | 8.000 | 3.452 | 3.092 |
| **55** | 7.292 | 4.172 | 3.692 | 2.852 | 4.412 | 6.692 | 4.172 | 5.012 | 5.252 | 6.452 | 7.532 | 2.492 | 8.000 | 3.692 | 6.452 |
| **56** | 6.452 | 5.012 | 6.692 | 3.692 | 4.892 | 6.932 | 6.452 | 3.572 | 3.692 | 5.252 | 6.572 | 2.852 | 8.000 | 3.812 | 5.132 |
| **57** | 2.252 | 2.252 | 2.732 | 2.732 | 2.252 | 2.252 | 5.012 | 2.012 | 2.012 | 2.732 | 2.012 | 2.492 | 5.012 | 2.132 | 2.012 |
| **58** | 2.252 | 2.012 | 2.372 | 2.012 | 2.612 | 3.092 | 5.012 | 2.012 | 2.012 | 2.252 | 2.012 | 2.612 | 2.012 | 2.372 | 2.252 |
| **59** | 5.012 | 2.372 | 2.732 | 3.332 | 3.812 | 4.172 | 3.932 | 2.012 | 2.012 | 2.972 | 2.012 | 2.612 | 5.012 | 2.132 | 2.132 |
| **60** | 4.652 | 2.492 | 3.092 | 2.372 | 4.412 | 3.572 | 4.412 | 3.572 | 2.012 | 5.012 | 2.132 | 2.492 | 8.000 | 2.372 | 2.492 |

Table D.6. Continued from previous page.

| **Sound** | **Sub. 16** | **Sub. 17** | **Sub. 18** | **Sub. 19** | **Sub. 20** | **Sub. 21** | **Sub. 22** | **Sub. 23** | **Sub. 24** | **Sub. 25** | **Sub. 26** | **Sub. 27** | **Sub. 28** | **Sub. 29** | **Sub. 30** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **61** | 2.012 | 2.012 | 2.612 | 2.492 | 2.252 | 2.252 | 2.732 | 2.132 | 2.012 | 2.252 | 2.012 | 2.492 | 2.012 | 2.012 | 2.012 |
| **62** | 2.252 | 2.012 | 3.692 | 2.252 | 2.612 | 5.012 | 2.372 | 3.212 | 2.012 | 2.252 | 2.012 | 2.612 | 2.012 | 2.012 | 2.012 |
| **63** | 2.372 | 2.012 | 3.212 | 2.252 | 2.612 | 5.252 | 2.972 | 2.132 | 2.012 | 2.492 | 2.012 | 2.372 | 5.012 | 2.012 | 2.012 |
| **64** | 2.732 | 2.852 | 3.332 | 2.252 | 3.812 | 2.012 | 3.572 | 3.092 | 2.012 | 3.092 | 2.012 | 2.732 | 8.000 | 2.132 | 2.132 |
| **65** | 2.132 | 2.012 | 2.972 | 2.012 | 2.372 | 2.132 | 4.892 | 2.132 | 2.012 | 2.012 | 2.012 | 2.492 | 5.012 | 2.012 | 2.012 |
| **66** | 2.372 | 2.012 | 3.332 | 2.852 | 2.372 | 2.372 | 2.852 | 2.012 | 2.012 | 2.012 | 2.012 | 2.612 | 2.012 | 2.012 | 2.012 |
| **67** | 2.492 | 2.012 | 2.372 | 2.252 | 2.492 | 3.812 | 2.372 | 2.012 | 2.012 | 2.612 | 2.012 | 2.612 | 5.012 | 2.012 | 2.012 |
| **68** | 2.372 | 2.492 | 2.492 | 2.372 | 2.732 | 2.492 | 2.852 | 2.132 | 2.012 | 2.612 | 3.332 | 2.492 | 8.000 | 2.852 | 2.012 |
| **69** | 2.372 | 2.012 | 3.092 | 2.012 | 3.692 | 2.612 | 4.052 | 3.092 | 2.012 | 2.492 | 2.012 | 3.212 | 4.892 | 2.012 | 2.012 |
| **70** | 2.492 | 3.572 | 2.612 | 2.372 | 3.572 | 4.892 | 4.892 | 2.132 | 2.012 | 2.972 | 2.012 | 2.252 | 8.000 | 2.372 | 2.012 |
| **71** | 3.452 | 2.252 | 2.612 | 2.972 | 3.572 | 5.012 | 3.452 | 2.732 | 2.012 | 3.932 | 4.532 | 2.852 | 8.000 | 3.212 | 2.372 |
| **72** | 6.812 | 3.572 | 3.692 | 2.612 | 4.052 | 7.052 | 5.132 | 4.532 | 3.332 | 5.372 | 4.052 | 2.852 | 8.000 | 4.892 | 5.012 |
| **73** | 5.372 | 2.852 | 3.812 | 2.972 | 3.572 | 5.252 | 4.532 | 3.452 | 2.012 | 3.572 | 3.452 | 2.732 | 8.000 | 2.852 | 3.212 |
| **74** | 6.692 | 3.572 | 3.812 | 2.972 | 4.052 | 4.652 | 4.412 | 2.492 | 4.892 | 5.252 | 4.892 | 2.252 | 8.000 | 3.212 | 3.932 |
| **75** | 8.000 | 5.012 | 4.532 | 2.612 | 4.652 | 4.652 | 5.132 | 3.692 | 5.252 | 5.252 | 5.372 | 3.212 | 8.000 | 5.492 | 6.452 |
| **76** | 8.000 | 5.012 | 3.452 | 3.572 | 5.132 | 7.400 | 6.572 | 2.972 | 5.252 | 7.160 | 7.052 | 3.932 | 8.000 | 5.012 | 6.812 |
| **77** | 2.252 | 2.012 | 2.612 | 2.492 | 2.612 | 2.252 | 3.332 | 2.852 | 2.012 | 2.372 | 2.012 | 2.372 | 5.000 | 2.252 | 2.012 |
| **78** | 4.172 | 2.012 | 3.572 | 2.372 | 3.092 | 3.692 | 2.972 | 2.012 | 2.012 | 2.132 | 2.012 | 2.492 | 5.132 | 2.132 | 2.012 |
| **79** | 3.452 | 2.132 | 3.692 | 2.732 | 2.852 | 4.772 | 4.772 | 2.492 | 2.012 | 3.572 | 2.012 | 2.732 | 5.012 | 2.132 | 2.372 |
| **80** | 5.492 | 3.572 | 3.692 | 2.372 | 3.092 | 5.492 | 6.332 | 2.012 | 4.292 | 2.492 | 3.572 | 2.492 | 8.000 | 2.852 | 2.372 |

## D.3 Playback Order

Table D.7 contains the playback orders used in each run of the NASA test. The NASA test was conducted in fifteen runs, with each run containing two subjects each. The column headings in the table correspond to the numbers of the subjects in the run. The row headings in the table correspond to the signals that were played first, second, etc., in the test run. Numbers in the body of the table correspond to the master numbers of the sounds.

Table D.7. Playback orders in the NASA test.

| **Order** | **Subjects** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **played** | **1-2** | **3-4** | **5-6** | **7-8** | **9-10** | **11-12** | **13-14** | **15-16** | **17-18** | **19-20** | **21-22** | **23-24** | **25-26** | **27-28** | **29-30** |
| **1** | 6 | 69 | 45 | 34 | 31 | 80 | 72 | 43 | 43 | 54 | 35 | 78 | 36 | 15 | 45 |
| **2** | 3 | 19 | 32 | 65 | 45 | 4 | 13 | 54 | 63 | 33 | 2 | 48 | 65 | 77 | 29 |
| **3** | 4 | 6 | 24 | 72 | 69 | 27 | 53 | 76 | 13 | 23 | 7 | 9 | 46 | 55 | 59 |
| **4** | 66 | 5 | 74 | 7 | 15 | 13 | 14 | 14 | 8 | 60 | 57 | 20 | 48 | 57 | 34 |
| **5** | 53 | 22 | 26 | 75 | 67 | 17 | 1 | 25 | 16 | 20 | 14 | 19 | 51 | 53 | 60 |
| **6** | 43 | 13 | 71 | 64 | 79 | 42 | 6 | 59 | 52 | 76 | 20 | 63 | 18 | 30 | 36 |
| **7** | 79 | 79 | 59 | 41 | 50 | 79 | 74 | 8 | 42 | 47 | 13 | 29 | 68 | 2 | 61 |
| **8** | 14 | 72 | 54 | 22 | 73 | 6 | 71 | 49 | 79 | 49 | 62 | 18 | 15 | 51 | 13 |
| **9** | 45 | 26 | 40 | 14 | 66 | 71 | 57 | 28 | 17 | 45 | 8 | 2 | 62 | 32 | 43 |
| **10** | 34 | 55 | 21 | 39 | 32 | 38 | 28 | 5 | 72 | 7 | 61 | 69 | 67 | 17 | 53 |
| **11** | 68 | 30 | 68 | 9 | 13 | 26 | 52 | 48 | 41 | 16 | 49 | 61 | 10 | 58 | 31 |
| **12** | 51 | 62 | 46 | 28 | 6 | 67 | 26 | 19 | 15 | 67 | 79 | 44 | 71 | 75 | 28 |
| **13** | 16 | 43 | 37 | 74 | 72 | 30 | 12 | 73 | 9 | 40 | 22 | 6 | 24 | 24 | 24 |
| **14** | 27 | 71 | 51 | 38 | 49 | 73 | 59 | 70 | 46 | 75 | 37 | 14 | 63 | 11 | 10 |
| **15** | 28 | 46 | 3 | 68 | 37 | 28 | 3 | 52 | 61 | 71 | 9 | 49 | 32 | 67 | 6 |
| **16** | 77 | 63 | 57 | 5 | 30 | 74 | 70 | 16 | 29 | 31 | 27 | 75 | 9 | 72 | 39 |
| **17** | 41 | 40 | 29 | 80 | 11 | 29 | 75 | 23 | 1 | 30 | 42 | 25 | 44 | 61 | 18 |
| **18** | 64 | 76 | 65 | 40 | 75 | 70 | 42 | 47 | 39 | 78 | 21 | 71 | 41 | 52 | 57 |
| **19** | 48 | 9 | 77 | 45 | 58 | 55 | 49 | 7 | 80 | 6 | 45 | 37 | 43 | 7 | 78 |
| **20** | 5 | 54 | 76 | 63 | 36 | 62 | 80 | 2 | 36 | 80 | 32 | 10 | 54 | 3 | 52 |

Table D.7. Continued from previous page.

| **Order** | **Subjects** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **played** | **1-2** | **3-4** | **5-6** | **7-8** | **9-10** | **11-12** | **13-14** | **15-16** | **17-18** | **19-20** | **21-22** | **23-24** | **25-26** | **27-28** | **29-30** |
| **21** | 61 | 64 | 12 | 48 | 57 | 22 | 69 | 74 | 59 | 70 | 69 | 73 | 47 | 37 | 17 |
| **22** | 75 | 48 | 44 | 69 | 21 | 11 | 48 | 69 | 14 | 1 | 18 | 55 | 6 | 74 | 42 |
| **23** | 26 | 51 | 69 | 3 | 64 | 53 | 68 | 35 | 77 | 65 | 52 | 22 | 72 | 43 | 50 |
| **24** | 8 | 74 | 78 | 33 | 12 | 59 | 33 | 34 | 28 | 43 | 66 | 46 | 42 | 56 | 67 |
| **25** | 32 | 16 | 72 | 67 | 17 | 7 | 63 | 44 | 51 | 77 | 59 | 53 | 11 | 28 | 65 |
| **26** | 11 | 32 | 61 | 51 | 71 | 54 | 47 | 60 | 11 | 28 | 24 | 27 | 27 | 27 | 19 |
| **27** | 44 | 37 | 33 | 24 | 34 | 3 | 77 | 79 | 31 | 26 | 16 | 24 | 59 | 9 | 71 |
| **28** | 76 | 20 | 52 | 58 | 76 | 63 | 66 | 58 | 10 | 55 | 33 | 35 | 45 | 34 | 62 |
| **29** | 54 | 42 | 31 | 46 | 68 | 43 | 16 | 9 | 20 | 57 | 26 | 54 | 80 | 80 | 1 |
| **30** | 72 | 12 | 43 | 62 | 65 | 78 | 56 | 78 | 57 | 44 | 23 | 15 | 21 | 33 | 46 |
| **31** | 63 | 47 | 16 | 8 | 18 | 60 | 38 | 77 | 60 | 5 | 74 | 74 | 13 | 36 | 33 |
| **32** | 1 | 39 | 2 | 56 | 29 | 34 | 45 | 61 | 62 | 63 | 80 | 80 | 3 | 26 | 35 |
| **33** | 50 | 58 | 47 | 47 | 53 | 52 | 31 | 17 | 74 | 10 | 67 | 62 | 31 | 19 | 79 |
| **34** | 37 | 67 | 17 | 79 | 62 | 65 | 2 | 67 | 70 | 27 | 68 | 3 | 76 | 48 | 26 |
| **35** | 55 | 77 | 58 | 16 | 9 | 39 | 34 | 80 | 23 | 72 | 43 | 47 | 28 | 5 | 49 |
| **36** | 18 | 27 | 70 | 78 | 19 | 9 | 46 | 6 | 68 | 15 | 30 | 56 | 35 | 38 | 76 |
| **37** | 46 | 41 | 41 | 11 | 60 | 2 | 36 | 18 | 12 | 22 | 46 | 43 | 2 | 68 | 9 |
| **38** | 69 | 80 | 6 | 52 | 4 | 69 | 22 | 66 | 58 | 3 | 65 | 28 | 30 | 70 | 64 |
| **39** | 67 | 36 | 62 | 19 | 16 | 5 | 24 | 31 | 4 | 50 | 53 | 12 | 55 | 6 | 54 |
| **40** | 70 | 35 | 10 | 1 | 23 | 36 | 65 | 32 | 32 | 56 | 48 | 7 | 39 | 59 | 58 |

Table D.7. Continued from previous page.

| Order | Subjects | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **played** | **1-2** | **3-4** | **5-6** | **7-8** | **9-10** | **11-12** | **13-14** | **15-16** | **17-18** | **19-20** | **21-22** | **23-24** | **25-26** | **27-28** | **29-30** |
| **41** | 22 | 52 | 15 | 30 | 47 | 33 | 15 | 62 | 67 | 29 | 36 | 58 | 57 | 10 | 55 |
| **42** | 23 | 28 | 14 | 43 | 51 | 47 | 43 | 55 | 7 | 11 | 58 | 72 | 78 | 25 | 68 |
| **43** | 49 | 78 | 4 | 2 | 42 | 35 | 78 | 22 | 30 | 36 | 77 | 68 | 33 | 63 | 12 |
| **44** | 7 | 1 | 18 | 25 | 24 | 51 | 73 | 51 | 76 | 13 | 3 | 52 | 16 | 49 | 66 |
| **45** | 30 | 4 | 19 | 17 | 44 | 48 | 55 | 53 | 65 | 12 | 56 | 33 | 69 | 1 | 69 |
| **46** | 57 | 18 | 1 | 61 | 39 | 45 | 79 | 46 | 45 | 53 | 50 | 21 | 56 | 16 | 22 |
| **47** | 60 | 33 | 64 | 59 | 27 | 18 | 17 | 15 | 71 | 2 | 25 | 38 | 12 | 22 | 75 |
| **48** | 9 | 21 | 66 | 60 | 3 | 32 | 41 | 12 | 37 | 34 | 15 | 40 | 4 | 13 | 63 |
| **49** | 10 | 25 | 63 | 6 | 25 | 20 | 40 | 36 | 49 | 21 | 38 | 36 | 58 | 31 | 25 |
| **50** | 65 | 73 | 67 | 23 | 1 | 14 | 5 | 26 | 47 | 32 | 63 | 39 | 60 | 44 | 72 |
| **51** | 42 | 61 | 11 | 35 | 8 | 76 | 7 | 1 | 35 | 69 | 11 | 76 | 29 | 40 | 74 |
| **52** | 40 | 11 | 34 | 29 | 28 | 50 | 58 | 11 | 56 | 46 | 40 | 30 | 22 | 45 | 77 |
| **53** | 38 | 10 | 20 | 55 | 80 | 58 | 76 | 29 | 22 | 41 | 6 | 34 | 37 | 18 | 21 |
| **54** | 80 | 8 | 48 | 26 | 54 | 56 | 19 | 3 | 53 | 64 | 75 | 64 | 74 | 35 | 5 |
| **55** | 24 | 59 | 60 | 71 | 35 | 24 | 21 | 64 | 73 | 35 | 78 | 42 | 75 | 46 | 14 |
| **56** | 35 | 56 | 13 | 44 | 40 | 10 | 8 | 37 | 19 | 14 | 19 | 31 | 25 | 65 | 8 |
| **57** | 78 | 50 | 22 | 31 | 48 | 40 | 11 | 57 | 27 | 8 | 1 | 41 | 1 | 41 | 37 |
| **58** | 31 | 29 | 23 | 37 | 78 | 57 | 54 | 68 | 78 | 37 | 34 | 60 | 64 | 20 | 41 |
| **59** | 36 | 70 | 9 | 36 | 10 | 64 | 30 | 4 | 64 | 17 | 47 | 23 | 70 | 78 | 7 |
| **60** | 15 | 17 | 35 | 66 | 20 | 68 | 20 | 42 | 48 | 73 | 51 | 67 | 40 | 4 | 32 |

Table D.7. Continued from previous page.

| **Order** | **Subjects** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **played** | **1-2** | **3-4** | **5-6** | **7-8** | **9-10** | **11-12** | **13-14** | **15-16** | **17-18** | **19-20** | **21-22** | **23-24** | **25-26** | **27-28** | **29-30** |
| **61** | 59 | 38 | 42 | 18 | 55 | 16 | 37 | 63 | 26 | 79 | 17 | 32 | 5 | 8 | 44 |
| **62** | 62 | 68 | 50 | 50 | 14 | 31 | 25 | 30 | 69 | 38 | 64 | 45 | 8 | 23 | 11 |
| **63** | 2 | 45 | 28 | 15 | 59 | 66 | 61 | 10 | 38 | 48 | 39 | 65 | 14 | 66 | 38 |
| **64** | 17 | 14 | 7 | 76 | 56 | 1 | 50 | 56 | 18 | 74 | 70 | 51 | 7 | 79 | 4 |
| **65** | 12 | 34 | 38 | 42 | 77 | 44 | 39 | 50 | 25 | 51 | 71 | 66 | 61 | 62 | 51 |
| **66** | 47 | 65 | 30 | 4 | 74 | 75 | 51 | 71 | 24 | 4 | 4 | 11 | 17 | 21 | 23 |
| **67** | 29 | 31 | 8 | 12 | 70 | 21 | 18 | 45 | 55 | 68 | 73 | 26 | 26 | 39 | 15 |
| **68** | 20 | 23 | 79 | 54 | 7 | 25 | 29 | 20 | 50 | 9 | 29 | 77 | 66 | 50 | 27 |
| **69** | 25 | 15 | 25 | 73 | 41 | 37 | 62 | 33 | 44 | 18 | 54 | 57 | 19 | 76 | 3 |
| **70** | 21 | 7 | 56 | 20 | 46 | 15 | 9 | 39 | 54 | 19 | 28 | 16 | 73 | 69 | 48 |
| **71** | 19 | 75 | 49 | 77 | 61 | 61 | 64 | 27 | 5 | 25 | 10 | 4 | 20 | 71 | 40 |
| **72** | 39 | 60 | 73 | 70 | 63 | 19 | 44 | 13 | 3 | 66 | 31 | 13 | 53 | 64 | 30 |
| **73** | 73 | 66 | 75 | 13 | 5 | 8 | 35 | 65 | 6 | 62 | 12 | 79 | 77 | 42 | 16 |
| **74** | 33 | 24 | 39 | 32 | 22 | 46 | 67 | 24 | 34 | 58 | 55 | 70 | 34 | 12 | 20 |
| **75** | 52 | 44 | 36 | 27 | 38 | 12 | 23 | 72 | 40 | 42 | 41 | 5 | 52 | 14 | 47 |
| **76** | 58 | 53 | 55 | 57 | 26 | 41 | 32 | 21 | 2 | 39 | 44 | 1 | 50 | 29 | 2 |
| **77** | 13 | 2 | 5 | 53 | 52 | 23 | 27 | 41 | 66 | 59 | 5 | 50 | 23 | 47 | 70 |
| **78** | 74 | 3 | 27 | 49 | 43 | 77 | 10 | 38 | 21 | 24 | 76 | 59 | 38 | 73 | 73 |
| **79** | 56 | 57 | 53 | 10 | 2 | 49 | 60 | 40 | 33 | 52 | 72 | 17 | 79 | 60 | 80 |
| **80** | 71 | 49 | 80 | 21 | 33 | 72 | 4 | 75 | 75 | 61 | 60 | 8 | 49 | 54 | 56 |

### D.4 Metrics

Tables D.8 and D.9 contains all major metrics used in the NASA test, for sounds recorded at the plain and isolated chairs respectively.

Table D.10 contains correlation values between all major metrics used in the NASA test. These correlations were calculated for entire groups of metrics, for both the plain-chair and the isolated-chair sounds.

Table D.8. Metrics calculated for NASA test sounds recorded at the plain chair. Metric acronyms are given in Table 3.1.

| **Sound** | **PL** (dB) | **ZN**$_{max}$ (sone) | **ASEL** (dB) | **SN**$_{20}$ (sone) | **SN**$_{E}$ (sone·s) | **SN**$_{max}$ (sone) | **LN**$_{max}$ (sone) | **dZN**$_{max}$ (sone/s) | **dSN**$_{max}$ (sone/s) | **dLN**$_{max}$ (sone/s) | **S**$_{max}$ (acum) | **Dur** (s) | **H** (dB) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 60.7 | 7.40 | 46.3 | 6.47 | 1.49 | 9.14 | 6.29 | 181 | 257 | 60 | 0.559 | 0.600 | 22.2 |
| **2** | 60.8 | 5.97 | 46.1 | 4.84 | 1.31 | 5.78 | 4.52 | 158 | 170 | 37 | 0.577 | 0.803 | 34.0 |
| **3** | 60.4 | 6.95 | 46.2 | 6.75 | 1.66 | 8.69 | 6.34 | 238 | 273 | 60 | 0.599 | 0.576 | 15.4 |
| **4** | 60.0 | 6.10 | 45.4 | 3.24 | 1.16 | 7.09 | 4.90 | 244 | 278 | 56 | 0.573 | 0.864 | 25.7 |
| **5** | 60.0 | 6.18 | 45.4 | 3.08 | 1.02 | 6.51 | 4.39 | 193 | 224 | 47 | 0.588 | 0.851 | 27.2 |
| **6** | 60.6 | 6.33 | 46.4 | 4.09 | 0.92 | 6.38 | 4.26 | 173 | 201 | 46 | 0.385 | 0.611 | 24.2 |
| **7** | 59.5 | 5.84 | 45.9 | 4.85 | 1.81 | 5.65 | 4.78 | 198 | 214 | 40 | 0.387 | 0.872 | 22.5 |
| **8** | 70.3 | 14.48 | 55.9 | 10.84 | 2.88 | 16.72 | 11.70 | 335 | 462 | 110 | 0.586 | 0.840 | 22.3 |
| **9** | 69.8 | 10.85 | 53.8 | 8.07 | 2.35 | 9.57 | 7.83 | 275 | 276 | 62 | 0.612 | 0.952 | 34.3 |
| **10** | 70.1 | 14.13 | 56.3 | 11.53 | 3.33 | 16.46 | 12.20 | 453 | 490 | 112 | 0.633 | 0.861 | 15.4 |
| **11** | 69.4 | 11.83 | 54.6 | 5.65 | 2.31 | 12.91 | 9.10 | 451 | 488 | 101 | 0.438 | 1.061 | 26.0 |
| **12** | 69.6 | 12.05 | 54.4 | 5.85 | 2.03 | 11.85 | 8.12 | 351 | 388 | 84 | 0.415 | 1.035 | 27.4 |
| **13** | 69.3 | 11.41 | 53.6 | 6.03 | 1.72 | 10.69 | 7.48 | 218 | 286 | 79 | 0.523 | 0.883 | 33.3 |
| **14** | 70.2 | 11.27 | 56.2 | 7.78 | 2.91 | 9.56 | 7.97 | 258 | 324 | 70 | 0.324 | 1.005 | 22.8 |
| **15** | 68.9 | 11.22 | 55.3 | 8.30 | 3.54 | 10.56 | 9.00 | 364 | 384 | 74 | 0.390 | 1.083 | 22.6 |
| **16** | 74.6 | 18.57 | 60.0 | 11.51 | 3.41 | 21.42 | 14.12 | 549 | 630 | 150 | 0.560 | 0.984 | 23.6 |
| **17** | 74.2 | 18.68 | 59.8 | 11.77 | 3.68 | 21.01 | 14.76 | 425 | 576 | 138 | 0.606 | 0.992 | 22.4 |
| **18** | 78.0 | 24.11 | 64.3 | 16.07 | 5.52 | 26.25 | 19.63 | 745 | 756 | 178 | 0.672 | 1.059 | 15.5 |
| **19** | 77.5 | 20.67 | 64.5 | 15.05 | 6.24 | 19.93 | 16.37 | 844 | 769 | 145 | 0.418 | 1.085 | 20.6 |
| **20** | 77.9 | 20.60 | 61.8 | 9.81 | 2.80 | 17.99 | 12.29 | 458 | 518 | 122 | 0.457 | 0.880 | 24.6 |

Table D.8. Continued from previous page.

| **Sound** | **PL (dB)** | **ZN$_{max}$ (sone)** | **ASEL (dB)** | **SN$_{20}$ (sone)** | **SN$_E$ (sone·s)** | **SN$_{max}$ (sone)** | **LN$_{max}$ (sone)** | **dZN$_{max}$ (sone/s)** | **dSN$_{max}$ (sone/s)** | **dLN$_{max}$ (sone/s)** | **S$_{max}$ (acum)** | **Dur (s)** | **H (dB)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **21** | 77.5 | 20.67 | 64.5 | 15.13 | 6.27 | 20.22 | 16.54 | 854 | 782 | 147 | 0.423 | 1.088 | 20.6 |
| **22** | 77.2 | 20.28 | 61.3 | 6.80 | 4.84 | 17.83 | 14.59 | 651 | 629 | 128 | 0.481 | 1.963 | 29.2 |
| **23** | 70.7 | 13.59 | 57.4 | 10.09 | 3.61 | 15.17 | 11.62 | 633 | 640 | 120 | 0.476 | 1.101 | 21.7 |
| **24** | 76.5 | 19.15 | 62.6 | 13.21 | 5.90 | 17.05 | 14.64 | 585 | 594 | 116 | 0.574 | 1.229 | 22.9 |
| **25** | 60.8 | 6.06 | 47.3 | 4.30 | 1.19 | 4.89 | 4.05 | 74 | 96 | 31 | 0.462 | 0.768 | 25.0 |
| **26** | 65.3 | 8.21 | 51.1 | 5.79 | 1.64 | 6.72 | 5.55 | 98 | 133 | 41 | 0.401 | 0.845 | 25.1 |
| **27** | 69.7 | 10.94 | 54.9 | 7.44 | 2.20 | 8.52 | 7.16 | 135 | 164 | 56 | 0.367 | 0.965 | 25.2 |
| **28** | 74.2 | 14.90 | 58.5 | 9.26 | 3.00 | 11.54 | 9.72 | 171 | 210 | 71 | 0.399 | 1.043 | 25.4 |
| **29** | 64.5 | 7.64 | 50.3 | 2.50 | 0.97 | 3.08 | 2.46 | 87 | 71 | 20 | 0.487 | 1.021 | 36.9 |
| **30** | 70.5 | 11.80 | 54.3 | 3.94 | 1.60 | 4.77 | 3.93 | 120 | 98 | 30 | 0.573 | 1.069 | 36.9 |
| **31** | 76.1 | 17.97 | 58.4 | 5.96 | 2.55 | 7.57 | 6.13 | 178 | 162 | 51 | 0.637 | 1.117 | 37.0 |
| **32** | 81.4 | 28.76 | 62.5 | 9.65 | 4.08 | 13.21 | 10.71 | 315 | 232 | 79 | 0.746 | 1.192 | 37.0 |
| **33** | 56.4 | 4.86 | 43.1 | 2.93 | 0.76 | 4.16 | 3.05 | 57 | 66 | 22 | 0.565 | 0.720 | 32.4 |
| **34** | 60.8 | 6.57 | 47.1 | 3.87 | 1.07 | 5.60 | 4.15 | 75 | 88 | 28 | 0.466 | 0.848 | 32.4 |
| **35** | 65.9 | 9.86 | 51.0 | 5.52 | 1.76 | 9.24 | 6.90 | 203 | 249 | 56 | 0.725 | 0.944 | 32.4 |
| **36** | 70.0 | 12.84 | 54.8 | 6.45 | 2.24 | 11.37 | 8.52 | 176 | 221 | 67 | 0.732 | 1.048 | 32.4 |
| **37** | 65.9 | 8.44 | 52.4 | 3.16 | 1.09 | 3.88 | 3.16 | 68 | 96 | 26 | 0.317 | 0.904 | 31.7 |
| **38** | 71.5 | 12.16 | 56.4 | 4.65 | 1.64 | 6.16 | 4.76 | 118 | 138 | 42 | 0.261 | 0.960 | 31.8 |
| **39** | 76.6 | 17.62 | 60.3 | 6.43 | 2.38 | 8.59 | 6.75 | 167 | 200 | 56 | 0.340 | 1.021 | 31.8 |
| **40** | 81.7 | 26.67 | 64.3 | 9.25 | 3.57 | 12.35 | 10.06 | 225 | 297 | 82 | 0.372 | 1.072 | 31.9 |

Table D.8. Continued from previous page.

| **Sound** | **PL** (dB) | **ZN**$_{max}$ (sone) | **ASEL** (dB) | **SN**$_{20}$ (sone) | **SN**$_{E}$ (sone·s) | **SN**$_{max}$ (sone) | **LN**$_{max}$ (sone) | **dZN**$_{max}$ (sone/s) | **dSN**$_{max}$ (sone/s) | **dLN**$_{max}$ (sone/s) | **S**$_{max}$ (acum) | **Dur** (s) | **H** (dB) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **41** | 74.3 | 14.29 | 59.9 | 9.58 | 3.83 | 12.62 | 10.45 | 401 | 462 | 92 | 0.310 | 1.075 | 20.7 |
| **42** | 78.6 | 18.88 | 63.8 | 12.14 | 4.97 | 16.12 | 13.41 | 516 | 582 | 117 | 0.318 | 1.125 | 20.8 |
| **43** | 82.8 | 25.05 | 67.7 | 15.42 | 6.50 | 20.61 | 17.36 | 667 | 736 | 150 | 0.357 | 1.152 | 20.9 |
| **44** | 87.0 | 33.50 | 71.6 | 19.44 | 8.36 | 26.41 | 22.21 | 866 | 926 | 192 | 0.375 | 1.176 | 21.0 |
| **45** | 61.1 | 6.16 | 47.5 | 3.85 | 1.34 | 5.24 | 4.08 | 100 | 131 | 30 | 0.379 | 0.899 | 30.1 |
| **46** | 65.5 | 8.36 | 51.4 | 5.22 | 1.85 | 7.05 | 5.56 | 135 | 166 | 41 | 0.308 | 0.965 | 30.1 |
| **47** | 70.1 | 12.03 | 55.3 | 6.98 | 2.67 | 10.18 | 8.05 | 169 | 212 | 53 | 0.410 | 1.037 | 30.2 |
| **48** | 74.6 | 15.23 | 59.0 | 9.40 | 3.46 | 12.32 | 10.04 | 261 | 270 | 77 | 0.424 | 1.096 | 30.4 |
| **49** | 60.2 | 7.27 | 46.1 | 6.45 | 1.48 | 9.05 | 6.23 | 178 | 261 | 60 | 0.548 | 0.587 | 16.8 |
| **50** | 60.3 | 6.90 | 46.2 | 6.78 | 1.65 | 8.66 | 6.33 | 239 | 276 | 60 | 0.632 | 0.573 | 15.0 |
| **51** | 58.9 | 5.77 | 45.7 | 4.81 | 1.80 | 5.66 | 4.75 | 196 | 217 | 39 | 0.425 | 0.856 | 16.7 |
| **52** | 70.0 | 14.04 | 56.3 | 11.55 | 3.34 | 16.39 | 12.18 | 450 | 492 | 112 | 0.636 | 0.864 | 15.0 |
| **53** | 68.3 | 11.60 | 54.4 | 5.59 | 2.29 | 12.71 | 8.99 | 443 | 484 | 99 | 0.448 | 1.061 | 18.3 |
| **54** | 73.5 | 18.31 | 59.8 | 11.42 | 3.40 | 21.19 | 14.03 | 546 | 614 | 148 | 0.568 | 0.981 | 16.7 |
| **55** | 77.8 | 24.08 | 64.3 | 16.05 | 5.53 | 26.20 | 19.63 | 741 | 758 | 177 | 0.679 | 1.056 | 15.0 |
| **56** | 75.0 | 18.34 | 60.8 | 6.37 | 4.71 | 17.19 | 14.08 | 636 | 615 | 124 | 0.429 | 1.912 | 20.6 |
| **57** | 60.4 | 6.10 | 47.2 | 4.27 | 1.20 | 4.86 | 4.03 | 75 | 100 | 31 | 0.609 | 0.704 | 20.5 |
| **58** | 64.8 | 8.25 | 51.2 | 5.58 | 1.62 | 6.43 | 5.36 | 96 | 127 | 40 | 0.497 | 0.813 | 20.5 |
| **59** | 69.4 | 11.24 | 55.1 | 7.24 | 2.16 | 8.42 | 7.05 | 127 | 163 | 53 | 0.369 | 0.949 | 20.6 |
| **60** | 73.9 | 15.13 | 59.0 | 8.60 | 2.83 | 10.88 | 9.15 | 164 | 208 | 68 | 0.343 | 1.043 | 20.6 |

Table D.8. Continued from previous page.

| **Sound** | **PL** (dB) | **ZN$_{max}$** (sone) | **ASEL** (dB) | **SN$_{20}$** (sone) | **SN$_{E}$** (sone·s) | **SN$_{max}$** (sone) | **LN$_{max}$** (sone) | **dZN$_{max}$** (sone/s) | **dSN$_{max}$** (sone/s) | **dLN$_{max}$** (sone/s) | **S$_{max}$** (acum) | **Dur** (s) | **H** (dB) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **61** | 48.3 | 2.57 | 39.6 | 0.81 | 0.22 | 1.00 | 0.73 | 21 | 23 | 6 | 0.373 | 0.792 | 35.0 |
| **62** | 53.6 | 4.03 | 43.5 | 1.13 | 0.35 | 1.46 | 1.10 | 43 | 32 | 9 | 0.342 | 0.861 | 35.0 |
| **63** | 59.0 | 5.87 | 47.5 | 1.66 | 0.54 | 2.14 | 1.66 | 54 | 44 | 14 | 0.226 | 0.931 | 35.1 |
| **64** | 64.6 | 8.11 | 51.5 | 2.38 | 0.81 | 3.13 | 2.44 | 61 | 62 | 20 | 0.221 | 0.997 | 35.1 |
| **65** | 54.5 | 4.57 | 41.8 | 2.68 | 0.67 | 3.74 | 2.72 | 53 | 61 | 19 | 0.597 | 0.592 | 22.1 |
| **66** | 58.5 | 6.04 | 45.7 | 3.38 | 0.92 | 4.91 | 3.60 | 74 | 83 | 25 | 0.576 | 0.709 | 22.2 |
| **67** | 62.6 | 8.38 | 49.6 | 4.27 | 1.23 | 6.39 | 4.71 | 97 | 110 | 32 | 0.465 | 0.877 | 22.3 |
| **68** | 66.8 | 11.30 | 53.5 | 5.01 | 1.63 | 8.20 | 6.11 | 123 | 144 | 41 | 0.392 | 1.043 | 22.4 |
| **69** | 61.0 | 6.25 | 48.8 | 2.68 | 0.91 | 3.18 | 2.62 | 62 | 75 | 20 | 0.394 | 0.835 | 28.5 |
| **70** | 65.8 | 8.57 | 52.8 | 3.66 | 1.32 | 4.53 | 3.74 | 86 | 100 | 29 | 0.330 | 0.888 | 28.5 |
| **71** | 70.6 | 12.17 | 56.7 | 4.97 | 1.86 | 6.16 | 5.13 | 114 | 140 | 40 | 0.298 | 0.936 | 28.5 |
| **72** | 75.5 | 17.37 | 60.6 | 7.27 | 2.77 | 9.32 | 7.62 | 168 | 196 | 59 | 0.305 | 1.008 | 28.5 |
| **73** | 73.7 | 14.08 | 59.7 | 9.61 | 3.81 | 12.51 | 10.37 | 389 | 461 | 91 | 0.317 | 1.072 | 18.6 |
| **74** | 77.9 | 18.50 | 63.6 | 12.04 | 4.92 | 15.91 | 13.25 | 500 | 581 | 116 | 0.322 | 1.125 | 18.7 |
| **75** | 82.0 | 24.52 | 67.5 | 15.13 | 6.38 | 20.22 | 16.99 | 643 | 732 | 147 | 0.340 | 1.152 | 18.7 |
| **76** | 86.2 | 32.52 | 71.4 | 19.35 | 8.30 | 26.01 | 21.94 | 834 | 921 | 188 | 0.372 | 1.173 | 18.7 |
| **77** | 59.4 | 5.82 | 46.4 | 3.67 | 1.28 | 5.04 | 3.91 | 98 | 122 | 28 | 0.471 | 0.757 | 21.7 |
| **78** | 63.4 | 7.62 | 50.3 | 4.77 | 1.69 | 6.50 | 5.09 | 124 | 158 | 36 | 0.370 | 0.925 | 21.7 |
| **79** | 67.6 | 10.18 | 54.3 | 6.07 | 2.20 | 8.35 | 6.57 | 158 | 201 | 47 | 0.332 | 1.027 | 21.8 |
| **80** | 71.7 | 13.74 | 58.2 | 7.80 | 2.88 | 10.67 | 8.46 | 202 | 254 | 60 | 0.276 | 1.077 | 21.9 |

Table D.9. Metrics calculated for NASA test sounds recorded at the isolated chair. Metric acronyms are given in Table 3.1.

| **Sound** | **PL** (dB) | **ZN**$_{max}$ (sone) | **ASEL** (dB) | **SN**$_{20}$ (sone) | **SN**$_{E}$ (sone·s) | **SN**$_{max}$ (sone) | **LN**$_{max}$ (sone) | **dZN**$_{max}$ (sone/s) | **dSN**$_{max}$ (sone/s) | **dLN**$_{max}$ (sone/s) | **S**$_{max}$ (acum) | **Dur** (s) | **H** (dB) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 61.0 | 7.36 | 46.7 | 6.37 | 1.47 | 9.12 | 6.17 | 181 | 247 | 66 | 0.620 | 0.584 | 23.0 |
| **2** | 62.0 | 6.16 | 47.2 | 5.08 | 1.33 | 6.08 | 4.59 | 136 | 160 | 40 | 0.568 | 0.840 | 34.5 |
| **3** | 60.6 | 7.35 | 46.8 | 6.57 | 1.53 | 9.28 | 6.40 | 174 | 226 | 63 | 0.665 | 0.563 | 14.4 |
| **4** | 60.8 | 6.22 | 46.6 | 3.51 | 1.18 | 7.44 | 4.88 | 235 | 219 | 55 | 0.665 | 0.845 | 26.2 |
| **5** | 60.7 | 6.04 | 46.5 | 3.28 | 1.07 | 6.63 | 4.42 | 179 | 182 | 49 | 0.667 | 0.843 | 27.9 |
| **6** | 60.5 | 6.19 | 46.0 | 4.24 | 0.91 | 6.31 | 4.12 | 149 | 172 | 46 | 0.582 | 0.629 | 26.0 |
| **7** | 61.0 | 6.48 | 47.5 | 4.91 | 1.92 | 5.73 | 4.87 | 159 | 166 | 41 | 0.380 | 0.931 | 22.7 |
| **8** | 70.5 | 14.31 | 56.2 | 10.51 | 2.82 | 16.55 | 11.44 | 330 | 438 | 120 | 0.612 | 0.795 | 23.4 |
| **9** | 71.6 | 11.68 | 55.1 | 8.30 | 2.46 | 10.57 | 8.18 | 210 | 230 | 73 | 0.599 | 0.960 | 34.6 |
| **10** | 70.3 | 14.77 | 56.8 | 11.35 | 3.11 | 17.42 | 12.21 | 321 | 407 | 117 | 0.691 | 0.709 | 14.5 |
| **11** | 70.4 | 12.21 | 55.7 | 5.78 | 2.32 | 13.53 | 9.15 | 412 | 398 | 100 | 0.434 | 1.045 | 26.6 |
| **12** | 70.2 | 11.95 | 55.4 | 5.92 | 2.20 | 12.04 | 8.24 | 319 | 325 | 89 | 0.435 | 1.024 | 28.2 |
| **13** | 71.3 | 13.13 | 55.2 | 6.66 | 1.87 | 11.79 | 8.02 | 223 | 238 | 79 | 0.547 | 0.901 | 33.2 |
| **14** | 70.0 | 11.26 | 56.1 | 7.86 | 3.01 | 9.63 | 8.00 | 258 | 275 | 67 | 0.355 | 0.941 | 23.9 |
| **15** | 70.7 | 12.61 | 56.8 | 8.60 | 3.72 | 10.77 | 9.19 | 295 | 305 | 76 | 0.451 | 1.093 | 23.0 |
| **16** | 75.6 | 19.45 | 60.9 | 12.56 | 3.63 | 21.05 | 14.71 | 564 | 514 | 151 | 0.530 | 0.851 | 24.0 |
| **17** | 74.4 | 18.70 | 59.9 | 12.45 | 3.60 | 20.77 | 14.44 | 424 | 537 | 149 | 0.579 | 0.917 | 23.6 |
| **18** | 78.2 | 25.04 | 64.7 | 15.90 | 5.15 | 27.71 | 19.59 | 522 | 629 | 185 | 0.716 | 0.856 | 14.6 |
| **19** | 78.0 | 21.05 | 64.5 | 15.53 | 6.33 | 19.45 | 16.31 | 580 | 559 | 138 | 0.405 | 1.029 | 21.9 |
| **20** | 77.8 | 21.32 | 61.5 | 10.17 | 2.84 | 17.45 | 11.96 | 412 | 452 | 126 | 0.593 | 0.877 | 26.4 |

Table D.9. Continued from previous page.

| **Sound** | **PL** (dB) | **ZN$_{max}$** (sone) | **ASEL** (dB) | **SN$_{20}$** (sone) | **SN$_E$** (sone·s) | **SN$_{max}$** (sone) | **LN$_{max}$** (sone) | **dZN$_{max}$** (sone/s) | **dSN$_{max}$** (sone/s) | **dLN$_{max}$** (sone/s) | **S$_{max}$** (acum) | **Dur** (s) | **H** (dB) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **21** | 77.9 | 21.04 | 64.4 | 15.66 | 6.38 | 19.78 | 16.52 | 594 | 570 | 140 | 0.416 | 1.029 | 21.8 |
| **22** | 78.7 | 20.58 | 62.0 | 7.16 | 4.82 | 17.61 | 14.40 | 516 | 511 | 129 | 0.454 | 1.989 | 30.3 |
| **23** | 70.9 | 13.22 | 57.2 | 10.18 | 3.60 | 15.21 | 11.34 | 456 | 490 | 116 | 0.474 | 1.077 | 23.2 |
| **24** | 78.6 | 21.88 | 64.1 | 13.82 | 6.19 | 17.73 | 15.07 | 487 | 481 | 120 | 0.444 | 1.245 | 23.2 |
| **25** | 60.3 | 6.06 | 46.7 | 4.04 | 1.21 | 5.06 | 3.99 | 70 | 89 | 31 | 0.675 | 0.739 | 26.1 |
| **26** | 64.8 | 8.07 | 50.6 | 5.44 | 1.66 | 6.95 | 5.47 | 95 | 117 | 41 | 0.542 | 0.845 | 26.2 |
| **27** | 69.3 | 10.63 | 54.4 | 7.14 | 2.23 | 8.77 | 7.09 | 141 | 154 | 55 | 0.452 | 0.904 | 26.3 |
| **28** | 73.9 | 14.41 | 58.2 | 9.75 | 3.04 | 11.88 | 9.64 | 165 | 195 | 70 | 0.419 | 0.952 | 26.6 |
| **29** | 65.9 | 8.33 | 51.5 | 2.67 | 1.06 | 3.19 | 2.64 | 101 | 72 | 20 | 0.422 | 1.043 | 37.4 |
| **30** | 71.9 | 13.02 | 55.5 | 4.30 | 1.75 | 5.11 | 4.33 | 128 | 117 | 31 | 0.542 | 1.104 | 37.5 |
| **31** | 77.4 | 20.04 | 59.7 | 6.48 | 2.74 | 7.77 | 6.48 | 161 | 170 | 52 | 0.636 | 1.163 | 37.5 |
| **32** | 82.7 | 31.62 | 63.9 | 10.20 | 4.39 | 13.68 | 11.17 | 321 | 282 | 82 | 0.735 | 1.235 | 37.6 |
| **33** | 57.1 | 4.76 | 43.9 | 2.78 | 0.70 | 4.51 | 3.13 | 64 | 64 | 23 | 0.603 | 0.747 | 33.4 |
| **34** | 61.4 | 6.46 | 47.8 | 3.71 | 0.99 | 6.00 | 4.24 | 84 | 82 | 31 | 0.628 | 0.819 | 33.5 |
| **35** | 66.6 | 9.59 | 51.8 | 6.39 | 1.68 | 9.78 | 7.04 | 217 | 236 | 52 | 0.740 | 0.885 | 33.5 |
| **36** | 70.9 | 12.34 | 55.6 | 6.83 | 2.18 | 12.09 | 8.70 | 285 | 246 | 65 | 0.717 | 0.973 | 33.6 |
| **37** | 68.8 | 10.96 | 54.9 | 3.53 | 1.33 | 4.74 | 3.63 | 139 | 133 | 35 | 0.319 | 0.957 | 31.2 |
| **38** | 74.3 | 16.15 | 58.8 | 5.15 | 1.96 | 7.16 | 5.38 | 172 | 194 | 52 | 0.287 | 1.027 | 31.3 |
| **39** | 79.1 | 22.79 | 62.7 | 7.29 | 2.89 | 10.16 | 7.79 | 260 | 287 | 75 | 0.352 | 1.091 | 31.3 |
| **40** | 83.9 | 32.91 | 66.6 | 10.56 | 4.25 | 14.58 | 11.47 | 342 | 418 | 106 | 0.413 | 1.123 | 31.4 |

Table D.9. Continued from previous page.

| **Sound** | **PL** (dB) | **ZN**$_{max}$ (sone) | **ASEL** (dB) | **SN**$_{20}$ (sone) | **SN**$_{E}$ (sone·s) | **SN**$_{max}$ (sone) | **LN**$_{max}$ (sone) | **dZN**$_{max}$ (sone/s) | **dSN**$_{max}$ (sone/s) | **dLN**$_{max}$ (sone/s) | **S**$_{max}$ (acum) | **Dur** (s) | **H** (dB) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **41** | 73.9 | 14.31 | 59.9 | 9.80 | 3.90 | 12.48 | 10.35 | 338 | 373 | 89 | 0.312 | 1.013 | 22.0 |
| **42** | 78.1 | 18.88 | 63.8 | 12.54 | 5.08 | 15.99 | 13.35 | 439 | 474 | 113 | 0.322 | 1.077 | 22.1 |
| **43** | 82.4 | 25.11 | 67.7 | 16.24 | 6.69 | 20.57 | 17.32 | 595 | 599 | 146 | 0.357 | 1.120 | 22.2 |
| **44** | 86.7 | 33.63 | 71.6 | 20.64 | 8.71 | 26.27 | 22.25 | 751 | 764 | 185 | 0.386 | 1.157 | 22.4 |
| **45** | 61.7 | 5.96 | 48.3 | 4.03 | 1.38 | 4.86 | 4.02 | 119 | 129 | 31 | 0.401 | 0.880 | 30.9 |
| **46** | 66.3 | 8.13 | 52.2 | 5.44 | 1.91 | 6.68 | 5.52 | 164 | 169 | 42 | 0.316 | 0.941 | 30.9 |
| **47** | 71.2 | 11.57 | 56.1 | 7.45 | 2.76 | 9.54 | 7.92 | 231 | 211 | 56 | 0.412 | 0.989 | 31.0 |
| **48** | 76.0 | 14.89 | 59.9 | 9.67 | 3.56 | 11.67 | 9.96 | 321 | 267 | 78 | 0.413 | 1.051 | 31.1 |
| **49** | 60.3 | 7.21 | 46.5 | 6.29 | 1.45 | 9.03 | 6.11 | 179 | 243 | 66 | 0.693 | 0.565 | 16.6 |
| **50** | 60.4 | 7.33 | 46.7 | 6.54 | 1.53 | 9.25 | 6.39 | 174 | 231 | 62 | 0.756 | 0.563 | 13.3 |
| **51** | 60.4 | 6.26 | 47.3 | 4.86 | 1.90 | 5.66 | 4.82 | 156 | 164 | 40 | 0.454 | 0.915 | 16.9 |
| **52** | 70.1 | 14.69 | 56.7 | 11.39 | 3.10 | 17.34 | 12.19 | 319 | 409 | 116 | 0.720 | 0.712 | 13.4 |
| **53** | 69.1 | 11.48 | 55.3 | 5.72 | 2.27 | 13.29 | 8.95 | 411 | 384 | 97 | 0.462 | 1.043 | 19.0 |
| **54** | 74.6 | 19.03 | 60.7 | 12.12 | 3.58 | 20.87 | 14.59 | 560 | 510 | 149 | 0.654 | 0.824 | 17.0 |
| **55** | 78.0 | 24.87 | 64.7 | 15.89 | 5.14 | 27.60 | 19.55 | 516 | 634 | 184 | 0.725 | 0.867 | 13.5 |
| **56** | 75.1 | 18.73 | 60.8 | 6.69 | 4.66 | 16.83 | 13.84 | 491 | 506 | 125 | 0.409 | 1.920 | 22.5 |
| **57** | 59.5 | 6.05 | 46.5 | 3.99 | 1.20 | 5.02 | 3.95 | 70 | 87 | 30 | 0.672 | 0.691 | 20.8 |
| **58** | 63.9 | 7.98 | 50.5 | 5.23 | 1.61 | 6.62 | 5.25 | 92 | 116 | 40 | 0.606 | 0.747 | 20.8 |
| **59** | 68.4 | 10.65 | 54.4 | 6.81 | 2.15 | 8.66 | 6.92 | 114 | 148 | 51 | 0.498 | 0.859 | 20.9 |
| **60** | 73.0 | 14.15 | 58.3 | 8.75 | 2.82 | 11.17 | 8.98 | 151 | 190 | 67 | 0.522 | 0.888 | 21.0 |

Table D.9. Continued from previous page.

| **Sound** | **PL** (dB) | **ZN$_{max}$** (sone) | **ASEL** (dB) | **SN$_{20}$** (sone) | **SN$_E$** (sone·s) | **SN$_{max}$** (sone) | **LN$_{max}$** (sone) | **dZN$_{max}$** (sone/s) | **dSN$_{max}$** (sone/s) | **dLN$_{max}$** (sone/s) | **S$_{max}$** (acum) | **Dur** (s) | **H** (dB) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **61** | 50.7 | 3.08 | 40.9 | 0.86 | 0.26 | 1.06 | 0.79 | 36 | 32 | 8 | 0.423 | 0.835 | 34.8 |
| **62** | 56.1 | 4.51 | 45.0 | 1.27 | 0.43 | 1.56 | 1.20 | 45 | 50 | 11 | 0.328 | 0.915 | 34.8 |
| **63** | 61.5 | 6.50 | 49.0 | 1.82 | 0.67 | 2.31 | 1.85 | 64 | 65 | 17 | 0.246 | 0.971 | 34.9 |
| **64** | 67.0 | 9.11 | 52.9 | 2.62 | 1.00 | 3.40 | 2.72 | 100 | 95 | 24 | 0.240 | 1.032 | 34.9 |
| **65** | 54.6 | 4.27 | 42.2 | 2.46 | 0.60 | 3.91 | 2.72 | 60 | 61 | 21 | 0.695 | 0.568 | 22.9 |
| **66** | 58.6 | 5.66 | 46.1 | 3.13 | 0.82 | 5.11 | 3.58 | 76 | 79 | 27 | 0.826 | 0.664 | 23.0 |
| **67** | 62.7 | 7.57 | 50.0 | 3.98 | 1.10 | 6.62 | 4.67 | 101 | 104 | 35 | 0.698 | 0.768 | 23.1 |
| **68** | 66.8 | 10.22 | 53.8 | 4.87 | 1.48 | 8.49 | 6.04 | 135 | 133 | 45 | 0.564 | 0.837 | 23.3 |
| **69** | 63.9 | 8.05 | 51.4 | 2.91 | 1.09 | 3.57 | 2.86 | 94 | 84 | 26 | 0.466 | 0.877 | 28.9 |
| **70** | 68.9 | 11.64 | 55.4 | 4.06 | 1.56 | 5.07 | 4.13 | 131 | 121 | 37 | 0.346 | 0.923 | 28.9 |
| **71** | 73.9 | 16.71 | 59.3 | 5.59 | 2.19 | 7.14 | 5.76 | 193 | 173 | 52 | 0.286 | 0.981 | 28.9 |
| **72** | 78.3 | 23.80 | 63.2 | 8.21 | 3.24 | 10.53 | 8.56 | 258 | 263 | 77 | 0.316 | 1.048 | 28.9 |
| **73** | 73.1 | 13.97 | 59.6 | 9.92 | 3.86 | 12.17 | 10.19 | 330 | 371 | 86 | 0.341 | 0.997 | 19.3 |
| **74** | 77.2 | 18.23 | 63.4 | 12.29 | 5.00 | 15.55 | 13.06 | 413 | 471 | 109 | 0.320 | 1.035 | 19.3 |
| **75** | 81.4 | 24.05 | 67.3 | 15.75 | 6.52 | 19.97 | 16.84 | 557 | 594 | 138 | 0.337 | 1.101 | 19.3 |
| **76** | 85.5 | 31.84 | 71.3 | 20.24 | 8.56 | 25.57 | 21.74 | 717 | 753 | 177 | 0.373 | 1.149 | 19.4 |
| **77** | 59.5 | 5.40 | 46.9 | 3.82 | 1.29 | 4.46 | 3.72 | 118 | 125 | 29 | 0.663 | 0.768 | 22.4 |
| **78** | 63.6 | 7.09 | 50.8 | 4.98 | 1.71 | 5.79 | 4.86 | 157 | 162 | 38 | 0.549 | 0.840 | 22.5 |
| **79** | 67.7 | 9.40 | 54.7 | 6.35 | 2.24 | 7.46 | 6.29 | 198 | 208 | 49 | 0.520 | 0.899 | 22.7 |
| **80** | 71.9 | 12.54 | 58.6 | 8.18 | 2.94 | 9.61 | 8.14 | 264 | 261 | 63 | 0.326 | 0.960 | 22.8 |

Table D.10. Correlations between all metrics calculated for NASA test signals, in $R^2$ values. Numbers in (parentheses) refer to correlations where the correlation coefficient is negative. Metric acronyms are given in Table 3.1.

| | **PL** | **ZN**$_{max}$ | **ASEL** | **SN**$_{20}$ | **SN**$_{E}$ | **SN**$_{max}$ | **LN**$_{max}$ | **dZN**$_{max}$ | **dSN**$_{max}$ | **dLN**$_{max}$ | **S**$_{max}$ | **Dur** | **H** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PL** | 1 | 0.898 | 0.977 | 0.673 | 0.745 | 0.632 | 0.700 | 0.560 | 0.555 | 0.621 | (0.039) | 0.391 | (0.017) |
| **ZN**$_{max}$ | | 1 | 0.895 | 0.723 | 0.787 | 0.700 | 0.758 | 0.613 | 0.611 | 0.687 | (0.009) | 0.317 | (0.027) |
| **ASEL** | | | 1 | 0.730 | 0.806 | 0.679 | 0.755 | 0.620 | 0.615 | 0.672 | (0.058) | 0.384 | (0.039) |
| **SN**$_{20}$ | | | | 1 | 0.887 | 0.876 | 0.926 | 0.762 | 0.799 | 0.854 | $2.8\times10^{-6}$ | 0.098 | (0.242) |
| **SN**$_{E}$ | | | | | 1 | 0.786 | 0.901 | 0.814 | 0.802 | 0.789 | (0.021) | 0.314 | (0.147) |
| **SN**$_{max}$ | | | | | | 1 | 0.972 | 0.854 | 0.898 | 0.984 | 0.012 | 0.166 | (0.248) |
| **LN**$_{max}$ | | | | | | | 1 | 0.879 | 0.906 | 0.959 | 0.001 | 0.226 | (0.228) |
| **dZN**$_{max}$ | | | | | | | | 1 | 0.968 | 0.897 | ($4.5\times10^{-4}$) | 0.264 | (0.199) |
| **dSN**$_{max}$ | | | | | | | | | 1 | 0.938 | ($1.2\times10^{-4}$) | 0.213 | (0.256) |
| **dLN**$_{max}$ | | | | | | | | | | 1 | 0.005 | 0.179 | (0.25) |
| **S**$_{max}$ | | | | | | | | | | | 1 | (0.122) | (0.023) |
| **Dur** | | | | | | | | | | | | 1 | 0.027 |
| **H** | | | | | | | | | | | | | 1 |

# E. SIGNALS, RESPONSE DATA, AND METRICS FOR THE PURDUE EARPHONE TEST

This appendix contains tables of the signals, the response data, the averaged responses, the metric values, and the correlations between metrics for the Purdue test.

## E.1 Signals

Tables E.1 and E.2 contain descriptions of the sounds used in Parts 1 and 2, respectively. Note that sounds having the same number in Parts 1 and 2 are not necessarily the same, unlike in the NASA test. This is due to removing some sounds and substituting multiple versions of other sounds.

Tables E.3-E.5 contain descriptions of the windowing on each sounds. All windowing was done with 1/2-cosine ramps. For most sounds, the tops of the ramps were defined by pressure; i.e. the ramp on the front of the signal was set to reach the top at the time when the signal first exceeded a certain pressure, and the ramp on the back of the signal was set to begin attenuating at the time when the signal last fell below a certain pressure. These pressure values (or "thresholds") were not necessarily the same for both ends of a given signal. However, for six signals in Part 2 of the test, the tops of the windows were defined by time. These times were based on the original signal, and do not reflect the final length of the sound used in the test. The windowing specifications for these signals are contained in Table E.5, apart from the rest of the windowing information for Part 2 sounds in Table E.4. An illustration of the general windowing procedure is given in Figure E.1.

Tables E.6-E.9 contain descriptions of linear predictions on the ends of select signals. This procedure was used to reduce background noise. The prediction itself is defined by a start time, an order (the number of points in the prediction), and a length (in seconds). Predictions on the leading edges of signals were calculated with the signal flipped backwards, so the start times for leading-edge predictions are also "flipped". The predictions were spliced onto the original signal with a linear transition smoothed with a moving average filter. For most of the transition regions, a small margin was specified so that the entire transition is contained within the nominal length after smoothing, and the linear region is slightly shorter than the nominal length. However, if the margin was specified as zero, then the smoothing renders the total length of the transition slightly greater than the nominal length. An illustration of the splicing procedure is given in Figure E.2.

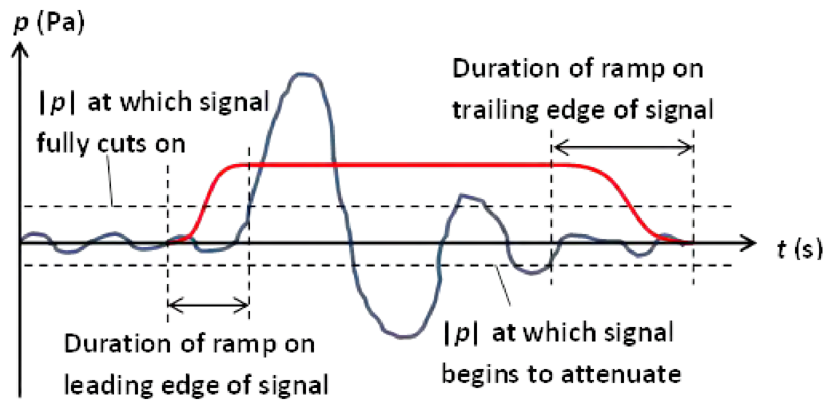


Figure E.1. Schematic of general windowing procedure used in the Purdue test.

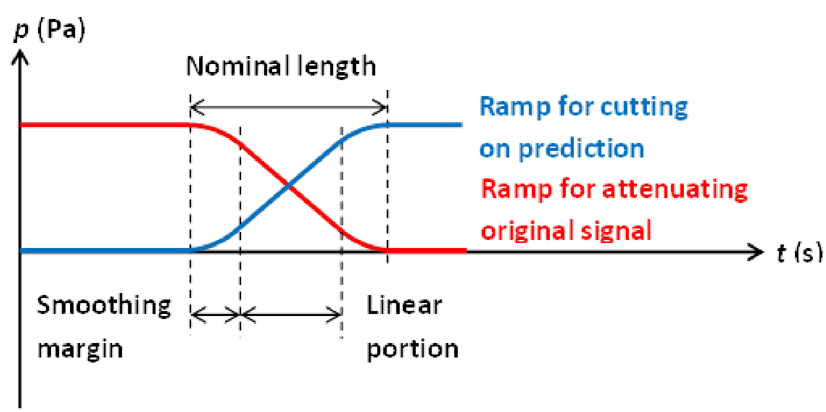


Figure E.2. Schematic of splicing procedure used for signals with linear predictions in the Purdue test. In this example, a margin is specified so that the smooth portions on the ends of the ramp are contained within the nominal length of the ramp.

Table E.1. Signals in the Purdue test, Part 1. HP - high-pass filter.

| **Sound number (Purdue test)** | **Sound name (Purdue test)** | **Sound number (NASA test)** | **Sound type** | **HP cutoff frequency (Hz)** | **Recording method** |
|---|---|---|---|---|---|
| 1 | Sig_M_nonisol_01.wav | 1 | Car door slam | 6 | Microphone |
| 2 | Sig_M_nonisol_02.wav | 2 | Synthetic boom | 6 | Microphone |
| 3 | Sig_M_nonisol_03.wav | 3 | Gunfire | 25 | Microphone |
| 4 | Sig_M_nonisol_04.wav | 4 | Blast | 6 | Microphone |
| 5 | Sig_M_nonisol_05.wav | 5 | Blast | 6 | Microphone |
| 6 | Sig_M_nonisol_06.wav | 6 | Synthetic boom | 6 | Microphone |
| 7 | Sig_M_nonisol_08.wav | 8 | Car door slam | 6 | Microphone |
| 8 | Sig_M_nonisol_09.wav | 9 | Synthetic boom | 6 | Microphone |
| 9 | Sig_M_nonisol_10.wav | 10 | Gunfire | 25 | Microphone |
| 10 | Sig_M_nonisol_11.wav | 11 | Blast | 6 | Microphone |
| 11 | Sig_M_nonisol_12.wav | 12 | Blast | 6 | Microphone |
| 12 | Sig_M_nonisol_13.wav | 13 | Synthetic boom | 6 | Microphone |
| 13 | Sig_M_nonisol_14.wav | 14 | Synthetic boom | 6 | Microphone |
| 14 | Sig_M_nonisol_15.wav | 15 | Recorded boom | 6 | Microphone |
| 15 | Sig_M_nonisol_16.wav | 16 | Car door slam | 6 | Microphone |
| 16 | Sig_M_nonisol_17.wav | 17 | Car door slam | 6 | Microphone |
| 17 | Sig_M_nonisol_18.wav | 18 | Gunfire | 25 | Microphone |
| 18 | Sig_M_nonisol_19.wav | 19 | Synthetic boom | 6 | Microphone |
| 19 | Sig_M_nonisol_20.wav | 20 | Synthetic boom | 6 | Microphone |
| 20 | Sig_M_nonisol_21.wav | 21 | Synthetic boom | 6 | Microphone |

Table E.1. Continued from previous page.

| **Sound number (Purdue test)** | **Sound name (Purdue test)** | **Sound number (NASA test)** | **Sound type** | **HP cutoff frequency (Hz)** | **Recording method** |
|---|---|---|---|---|---|
| 21 | Sig_M_nonisol_22.wav | 22 | Recorded boom | 6 | Microphone |
| 22 | Sig_M_nonisol_23.wav | 23 | Recorded boom | 6 | Microphone |
| 23 | Sig_M_nonisol_24.wav | 24 | Recorded boom | 6 | Microphone |
| 24 | Sig_M_nonisol_25.wav | 25 | Synthetic boom | 0 | Microphone |
| 25 | Sig_M_nonisol_26.wav | 26 | Synthetic boom | 0 | Microphone |
| 26 | Sig_M_nonisol_27.wav | 27 | Synthetic boom | 0 | Microphone |
| 27 | Sig_M_nonisol_28.wav | 28 | Synthetic boom | 0 | Microphone |
| 28 | Sig_M_nonisol_29.wav | 29 | Synthetic boom | 0 | Microphone |
| 29 | Sig_M_nonisol_30.wav | 30 | Synthetic boom | 0 | Microphone |
| 30 | Sig_M_nonisol_31.wav | 31 | Synthetic boom | 0 | Microphone |
| 31 | Sig_M_nonisol_32.wav | 32 | Synthetic boom | 0 | Microphone |
| 32 | Sig_M_nonisol_33.wav | 33 | Synthetic boom | 0 | Microphone |
| 33 | Sig_M_nonisol_34.wav | 34 | Synthetic boom | 0 | Microphone |
| 34 | Sig_M_nonisol_36.wav | 36 | Synthetic boom | 0 | Microphone |
| 35 | Sig_M_nonisol_37.wav | 37 | Synthetic boom | 0 | Microphone |
| 36 | Sig_M_nonisol_38.wav | 38 | Synthetic boom | 0 | Microphone |
| 37 | Sig_M_nonisol_39.wav | 39 | Synthetic boom | 0 | Microphone |
| 38 | Sig_M_nonisol_40.wav | 40 | Synthetic boom | 0 | Microphone |
| 39 | Sig_M_nonisol_41.wav | 41 | Synthetic boom | 0 | Microphone |
| 40 | Sig_M_nonisol_42.wav | 42 | Synthetic boom | 0 | Microphone |

Table E.1. Continued from previous page.

| **Sound number (Purdue test)** | **Sound name (Purdue test)** | **Sound number (NASA test)** | **Sound type** | **HP cutoff frequency (Hz)** | **Recording method** |
|---|---|---|---|---|---|
| 41 | Sig_M_nonisol_43.wav | 43 | Synthetic boom | 0 | Microphone |
| 42 | Sig_M_nonisol_44.wav | 44 | Synthetic boom | 0 | Microphone |
| 43 | Sig_M_nonisol_46.wav | 46 | Synthetic boom | 4 | Microphone |
| 44 | Sig_M_nonisol_47.wav | 47 | Synthetic boom | 4 | Microphone |
| 45 | Sig_M_nonisol_48.wav | 48 | Synthetic boom | 4 | Microphone |
| 46 | Sig_M_nonisol_49.wav | 49 | Car door slam | 50 | Microphone |
| 47 | Sig_M_nonisol_50.wav | 50 | Gunfire | 50 | Microphone |
| 48 | Sig_M_nonisol_51.wav | 51 | Recorded boom | 50 | Microphone |
| 49 | Sig_M_nonisol_52.wav | 52 | Gunfire | 50 | Microphone |
| 50 | Sig_M_nonisol_53.wav | 53 | Blast | 50 | Microphone |
| 51 | Sig_M_nonisol_54.wav | 54 | Car door slam | 50 | Microphone |
| 52 | Sig_M_nonisol_55.wav | 55 | Gunfire | 50 | Microphone |
| 53 | Sig_M_nonisol_56.wav | 56 | Recorded boom | 50 | Microphone |
| 54 | Sig_M_nonisol_57.wav | 57 | Synthetic boom | 50 | Microphone |
| 55 | Sig_M_nonisol_59.wav | 59 | Synthetic boom | 50 | Microphone |
| 56 | Sig_M_nonisol_60.wav | 60 | Synthetic boom | 50 | Microphone |
| 57 | Sig_M_nonisol_61.wav | 61 | Synthetic boom | 50 | Microphone |
| 58 | Sig_M_nonisol_62.wav | 62 | Synthetic boom | 50 | Microphone |
| 59 | Sig_M_nonisol_63.wav | 63 | Synthetic boom | 50 | Microphone |
| 60 | Sig_M_nonisol_65.wav | 65 | Synthetic boom | 50 | Microphone |

Table E.1. Continued from previous page.

| Sound number (Purdue test) | Sound name (Purdue test) | Sound number (NASA test) | Sound type | HP cutoff frequency (Hz) | Recording method |
|---|---|---|---|---|---|
| 61 | Sig_M_nonisol_66.wav | 66 | Synthetic boom | 50 | Microphone |
| 62 | Sig_M_nonisol_67.wav | 67 | Synthetic boom | 50 | Microphone |
| 63 | Sig_M_nonisol_68.wav | 68 | Synthetic boom | 50 | Microphone |
| 64 | Sig_M_nonisol_69.wav | 69 | Synthetic boom | 50 | Microphone |
| 65 | Sig_M_nonisol_70.wav | 70 | Synthetic boom | 50 | Microphone |
| 66 | Sig_M_nonisol_71.wav | 71 | Synthetic boom | 50 | Microphone |
| 67 | Sig_M_nonisol_72.wav | 72 | Synthetic boom | 50 | Microphone |
| 68 | Sig_M_nonisol_73.wav | 73 | Synthetic boom | 50 | Microphone |
| 69 | Sig_M_nonisol_74.wav | 74 | Synthetic boom | 50 | Microphone |
| 70 | Sig_M_nonisol_75.wav | 75 | Synthetic boom | 50 | Microphone |
| 71 | Sig_M_nonisol_76.wav | 76 | Synthetic boom | 50 | Microphone |
| 72 | Sig_M_nonisol_77.wav | 77 | Synthetic boom | 50 | Microphone |
| 73 | Sig_M_nonisol_78.wav | 78 | Synthetic boom | 50 | Microphone |
| 74 | Sig_M_nonisol_79.wav | 79 | Synthetic boom | 50 | Microphone |
| 75 | Sig_M_nonisol_80.wav | 80 | Synthetic boom | 50 | Microphone |
| 76 | Sig05_H_nonisol.wav | 5 | Blast | 6 | Head |
| 77 | Sig17_H_nonisol.wav | 17 | Car door slam | 6 | Head |
| 78 | Sig32_H_nonisol.wav | 32 | Recorded boom | 0 | Head |
| 79 | Sig55_H_nonisol.wav | 55 | Gunfire | 50 | Head |
| 80 | Sig76_H_nonisol.wav | 76 | Recorded boom | 50 | Head |

Table E.2. Signals in the Purdue test, Part 2. HP - high-pass filter.

| **Sound number (Purdue test)** | **Sound name (Purdue test)** | **Sound number (NASA test)** | **Sound type** | **HP cutoff frequency (Hz)** | **Recording method** |
|---|---|---|---|---|---|
| 1 | Sig_M_isol_01.wav | 1 | Car door slam | 6 | Microphone |
| 2 | Sig_M_isol_02.wav | 2 | Synthetic boom | 6 | Microphone |
| 3 | Sig_M_isol_03.wav | 3 | Gunfire | 25 | Microphone |
| 4 | Sig_M_isol_04.wav | 4 | Blast | 6 | Microphone |
| 5 | Sig_M_isol_05.wav | 5 | Blast | 6 | Microphone |
| 6 | Sig_M_isol_06.wav | 6 | Synthetic boom | 6 | Microphone |
| 7 | Sig_M_isol_08.wav | 8 | Car door slam | 6 | Microphone |
| 8 | Sig_M_isol_09.wav | 9 | Synthetic boom | 6 | Microphone |
| 9 | Sig_M_isol_10.wav | 10 | Gunfire | 25 | Microphone |
| 10 | Sig_M_isol_11.wav | 11 | Blast | 6 | Microphone |
| 11 | Sig_M_isol_12.wav | 12 | Blast | 6 | Microphone |
| 12 | Sig_M_isol_13.wav | 13 | Synthetic boom | 6 | Microphone |
| 13 | Sig_M_isol_15.wav | 15 | Recorded boom | 6 | Microphone |
| 14 | Sig_M_isol_16.wav | 16 | Car door slam | 6 | Microphone |
| 15 | Sig_M_isol_17.wav | 17 | Car door slam | 6 | Microphone |
| 16 | Sig_M_isol_18.wav | 18 | Gunfire | 25 | Microphone |
| 17 | Sig_M_isol_19.wav | 19 | Synthetic boom | 6 | Microphone |
| 18 | Sig_M_isol_20.wav | 20 | Synthetic boom | 6 | Microphone |
| 19 | Sig_M_isol_21.wav | 21 | Synthetic boom | 6 | Microphone |
| 20 | Sig_M_isol_22.wav | 22 | Recorded boom | 6 | Microphone |
| 21 | Sig_M_isol_23.wav | 23 | Recorded boom | 6 | Microphone |
| 22 | Sig_M_isol_24.wav | 24 | Recorded boom | 6 | Microphone |

Table E.2. Continued from previous page.

| **Sound number (Purdue test)** | **Sound name (Purdue test)** | **Sound number (NASA test)** | **Sound type** | **HP cutoff frequency (Hz)** | **Recording method** |
|---|---|---|---|---|---|
| 23 | Sig_M_isol_26.wav | 26 | Synthetic boom | 0 | Microphone |
| 24 | Sig_M_isol_27.wav | 27 | Synthetic boom | 0 | Microphone |
| 25 | Sig_M_isol_28.wav | 28 | Synthetic boom | 0 | Microphone |
| 26 | Sig_M_isol_29.wav | 29 | Synthetic boom | 0 | Microphone |
| 27 | Sig_M_isol_30.wav | 30 | Synthetic boom | 0 | Microphone |
| 28 | Sig_M_isol_31.wav | 31 | Synthetic boom | 0 | Microphone |
| 29 | Sig_M_isol_32.wav | 32 | Synthetic boom | 0 | Microphone |
| 30 | Sig_M_isol_33.wav | 33 | Synthetic boom | 0 | Microphone |
| 31 | Sig_M_isol_34.wav | 34 | Synthetic boom | 0 | Microphone |
| 32 | Sig_M_isol_36.wav | 36 | Synthetic boom | 0 | Microphone |
| 33 | Sig_M_isol_37.wav | 37 | Synthetic boom | 0 | Microphone |
| 34 | Sig_M_isol_38.wav | 38 | Synthetic boom | 0 | Microphone |
| 35 | Sig_M_isol_39.wav | 39 | Synthetic boom | 0 | Microphone |
| 36 | Sig_M_isol_40.wav | 40 | Synthetic boom | 0 | Microphone |
| 37 | Sig_M_isol_41.wav | 41 | Synthetic boom | 0 | Microphone |
| 38 | Sig_M_isol_42.wav | 42 | Synthetic boom | 0 | Microphone |
| 39 | Sig_M_isol_43.wav | 43 | Synthetic boom | 0 | Microphone |
| 40 | Sig_M_isol_44.wav | 44 | Synthetic boom | 0 | Microphone |

Table E.2. Continued from previous page.

| Sound number (Purdue test) | Sound name (Purdue test) | Sound number (NASA test) | Sound type | HP cutoff frequency (Hz) | Recording method |
|---|---|---|---|---|---|
| 41 | Sig_M_isol_46.wav | 46 | Synthetic boom | 4 | Microphone |
| 42 | Sig_M_isol_47.wav | 47 | Synthetic boom | 4 | Microphone |
| 43 | Sig_M_isol_48.wav | 48 | Synthetic boom | 4 | Microphone |
| 44 | Sig_M_isol_49.wav | 49 | Car door slam | 50 | Microphone |
| 45 | Sig_M_isol_50.wav | 50 | Gunfire | 50 | Microphone |
| 46 | Sig_M_isol_52.wav | 52 | Gunfire | 50 | Microphone |
| 47 | Sig_M_isol_53.wav | 53 | Blast | 50 | Microphone |
| 48 | Sig_M_isol_54.wav | 54 | Car door slam | 50 | Microphone |
| 49 | Sig_M_isol_55.wav | 55 | Gunfire | 50 | Microphone |
| 50 | Sig_M_isol_56.wav | 56 | Recorded boom | 50 | Microphone |
| 51 | Sig_M_isol_57.wav | 57 | Synthetic boom | 50 | Microphone |
| 52 | Sig_M_isol_59.wav | 59 | Synthetic boom | 50 | Microphone |
| 53 | Sig_M_isol_60.wav | 60 | Synthetic boom | 50 | Microphone |
| 54 | Sig_M_isol_61.wav | 61 | Synthetic boom | 50 | Microphone |
| 55 | Sig_M_isol_62.wav | 62 | Synthetic boom | 50 | Microphone |
| 56 | Sig_M_isol_63.wav | 63 | Synthetic boom | 50 | Microphone |
| 57 | Sig_M_isol_65.wav | 65 | Synthetic boom | 50 | Microphone |
| 58 | Sig_M_isol_66.wav | 66 | Synthetic boom | 50 | Microphone |
| 59 | Sig_M_isol_67.wav | 67 | Synthetic boom | 50 | Microphone |
| 60 | Sig_M_isol_68.wav | 68 | Synthetic boom | 50 | Microphone |

Table E.2. Continued from previous page.

| **Sound number (Purdue test)** | **Sound name (Purdue test)** | **Sound number (NASA test)** | **Sound type** | **HP cutoff frequency (Hz)** | **Recording method** |
|---|---|---|---|---|---|
| 61 | Sig_M_isol_69.wav | 69 | Synthetic boom | 50 | Microphone |
| 62 | Sig_M_isol_71.wav | 71 | Synthetic boom | 50 | Microphone |
| 63 | Sig_M_isol_72.wav | 72 | Synthetic boom | 50 | Microphone |
| 64 | Sig_M_isol_73.wav | 73 | Synthetic boom | 50 | Microphone |
| 65 | Sig_M_isol_74.wav | 74 | Synthetic boom | 50 | Microphone |
| 66 | Sig_M_isol_75.wav | 75 | Synthetic boom | 50 | Microphone |
| 67 | Sig_M_isol_76.wav | 76 | Synthetic boom | 50 | Microphone |
| 68 | Sig_M_isol_78.wav | 78 | Synthetic boom | 50 | Microphone |
| 69 | Sig_M_isol_79.wav | 79 | Synthetic boom | 50 | Microphone |
| 70 | Sig_M_isol_80.wav | 80 | Synthetic boom | 50 | Microphone |
| 71 | Sig05_H_isol.wav | 5 | Blast | 6 | Head |
| 72 | Sig05_isol_hcon1_HPff_wind.wav | 5 | Blast | 6 | Simulated |
| 73 | Sig17_H_isol.wav | 17 | Car door slam | 6 | Head |
| 74 | Sig17_isol_hcon1_HPff_wind.wav | 17 | Car door slam | 6 | Simulated |
| 75 | Sig32_H_isol_trail.wav | 32 | Synthetic boom | 0 | Head |
| 76 | Sig32_isol_hcon1_HPff_wind_rerun.wav | 32 | Synthetic boom | 0 | Simulated |
| 77 | Sig55_H_isol.wav | 55 | Gunfire | 50 | Head |
| 78 | Sig55_isol_hcon1_HPff_wind.wav | 55 | Gunfire | 50 | Simulated |
| 79 | Sig76_H_isol.wav | 76 | Synthetic boom | 50 | Head |
| 80 | Sig76_isol_hcon1_HPff_wind.wav | 76 | Synthetic boom | 50 | Simulated |

Table E.3. Windowing on signals in the Purdue test, Part 1.

| | Leading edge of window | | Trailing edge of window | | Linear prediction |
|---|---|---|---|---|---|
| **Sound number** | **Threshold (Pa)** | **Duration (s)** | **Threshold (Pa)** | **Duration (s)** | |
| 1 | 0.05 | 0.02 | 0.032 | 0.3 | No |
| 2 | 0.05 | 0.02 | 0.03 | 0.3 | No |
| 3 | 0.05 | 0.02 | 0.035 | 0.5 | No |
| 4 | 0.05 | 0.02 | 0.02 | 0.5 | No |
| 5 | 0.05 | 0.02 | 0.02 | 0.7 | No |
| 6 | 0.05 | 0.02 | 0.009 | 0.1 | No |
| 7 | 0.05 | 0.02 | 0.025 | 0.045 | No |
| 8 | 0.05 | 0.02 | 0.03 | 0.4 | No |
| 9 | 0.00001 | 0.02 | 0.00001 | 0.2 | Yes |
| 10 | 0.05 | 0.02 | 0.02 | 0.5 | No |
| 11 | 0.05 | 0.02 | 0.02 | 0.5 | No |
| 12 | 0.05 | 0.02 | 0.017 | 0.2 | No |
| 13 | 0.05 | 0.02 | 0.01 | 0.15 | No |
| 14 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 15 | 0.05 | 0.02 | 0.015 | 0.2 | No |
| 16 | 0.05 | 0.02 | 0.015 | 0.15 | No |
| 17 | 0.05 | 0.02 | 0.04 | 0.4 | No |
| 18 | 0.00001 | 0.02 | 0.00001 | 0.2 | Yes |
| 19 | 0.00001 | 0.02 | 0.00001 | 0.2 | Yes |
| 20 | 0.05 | 0.02 | 0.03 | 0.27 | No |

Table E.3. Continued from previous page.

| | Leading edge of window | | Trailing edge of window | | Linear prediction |
|---|---|---|---|---|---|
| **Sound number** | **Threshold (Pa)** | **Duration (s)** | **Threshold (Pa)** | **Duration (s)** | |
| 21 | 0.05 | 0.02 | 0.016 | 0.1 | No |
| 22 | 0.05 | 0.02 | 0.00001 | 0.2 | Yes |
| 23 | 0.05 | 0.02 | 0.5 | 0.84 | No |
| 24 | 0.05 | 0.02 | 0.012 | 0.15 | No |
| 25 | 0.05 | 0.02 | 0.012 | 0.1 | No |
| 26 | 0.05 | 0.02 | 0.018 | 0.13 | No |
| 27 | 0.05 | 0.02 | 0.03 | 0.3 | No |
| 28 | 0.05 | 0.02 | 0.022 | 0.2 | No |
| 29 | 0.05 | 0.02 | 0.03 | 0.2 | No |
| 30 | 0.05 | 0.02 | 0.02 | 0.02 | No |
| 31 | 0.05 | 0.02 | 0.022 | 0.02 | No |
| 32 | 0.05 | 0.02 | 0.018 | 0.02 | No |
| 33 | 0.05 | 0.02 | 0.012 | 0.12 | No |
| 34 | 0.05 | 0.02 | 0.02 | 0.2 | No |
| 35 | 0.05 | 0.02 | 0.03 | 0.2 | No |
| 36 | 0.05 | 0.02 | 0.021 | 0.2 | No |
| 37 | 0.05 | 0.02 | 0.025 | 0.22 | No |
| 38 | 0.05 | 0.02 | 0.022 | 0.18 | No |
| 39 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 40 | 0.05 | 0.02 | 0.05 | 0.4 | No |

Table E.3. Continued from previous page.

| | **Leading edge of window** | | **Trailing edge of window** | | **Linear prediction** |
|---|---|---|---|---|---|
| **Sound number** | **Threshold (Pa)** | **Duration (s)** | **Threshold (Pa)** | **Duration (s)** | |
| 41 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 42 | 0.00001 | 0.02 | 0.00001 | 0.2 | Yes |
| 43 | 0.05 | 0.02 | 0.015 | 0.1 | No |
| 44 | 0.05 | 0.02 | 0.027 | 0.25 | No |
| 45 | 0.05 | 0.02 | 0.025 | 0.27 | No |
| 46 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 47 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 48 | 0.05 | 0.02 | 0.02 | 0.7 | No |
| 49 | 0.05 | 0.02 | 0.02 | 0.75 | No |
| 50 | 0.05 | 0.02 | 0.01 | 0.7 | No |
| 51 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 52 | 0.00001 | 0.02 | 0.00001 | 0.2 | Yes |
| 53 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 54 | 0.05 | 0.02 | 0.01 | 0.3 | No |
| 55 | 0.05 | 0.02 | 0.01 | 0.15 | No |
| 56 | 0.05 | 0.02 | 0.01 | 0.22 | No |
| 57 | 0.05 | 0.02 | 0.04 | 0.1 | No |
| 58 | 0.05 | 0.02 | 0.04 | 0.1 | No |
| 59 | 0.05 | 0.02 | 0.022 | 0.12 | No |
| 60 | 0.05 | 0.02 | 0.022 | 0.2 | No |

Table E.3. Continued from previous page.

| | Leading edge of window | | Trailing edge of window | | Linear prediction |
|---|---|---|---|---|---|
| Sound number | Threshold (Pa) | Duration (s) | Threshold (Pa) | Duration (s) | |
| 61 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 62 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 63 | 0.05 | 0.02 | 0.03 | 0.32 | No |
| 64 | 0.05 | 0.02 | 0.018 | 0.08 | No |
| 65 | 0.05 | 0.02 | 0.018 | 0.2 | No |
| 66 | 0.05 | 0.02 | 0.03 | 0.28 | No |
| 67 | 0.05 | 0.02 | 0.014 | 0.03 | No |
| 68 | 0.05 | 0.02 | 0.025 | 0.4 | No |
| 69 | 0.00001 | 0.02 | 0.00001 | 0.2 | Yes |
| 70 | 0.05 | 0.02 | 0.02 | 0.23 | No |
| 71 | 0.05 | 0.02 | 0.04 | 0.53 | No |
| 72 | 0.05 | 0.02 | 0.015 | 0.18 | No |
| 73 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 74 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 75 | 0.05 | 0.02 | 0.0095 | 0.2 | No |
| 76 | 0.00001 | 0.02 | 0.00001 | 0.2 | Yes |
| 77 | 0.00001 | 0.02 | 0.00001 | 0.2 | Yes |
| 78 | 0.00001 | 0.02 | 0.00001 | 0.2 | Yes |
| 79 | 0.00001 | 0.02 | 0.00001 | 0.2 | Yes |
| 80 | 0.00001 | 0.02 | 0.5 | 0.4 | Yes |

Table E.4. Windowing on signals in the Purdue test, Part 2. Tops of windows defined by pressure.

| | **Leading edge of window** | | **Trailing edge of window** | | **Linear prediction** |
|---|---|---|---|---|---|
| **Sound number** | **Threshold (Pa)** | **Duration (s)** | **Threshold (Pa)** | **Duration (s)** | |
| 1 | 0.05 | 0.02 | 0.034 | 0.32 | No |
| 2 | 0.05 | 0.02 | 0.031 | 0.09 | No |
| 3 | 0.05 | 0.02 | 0.035 | 0.45 | No |
| 4 | 0.05 | 0.02 | 0.02 | 0.7 | No |
| 5 | 0.05 | 0.02 | 0.02 | 0.5 | No |
| 6 | 0.05 | 0.02 | 0.009 | 0.09 | No |
| 7 | 0.05 | 0.02 | 0.025 | 0.45 | No |
| 8 | 0.05 | 0.02 | 0.0295 | 0.25 | No |
| 9 | 0.00001 | 0.02 | 0.00001 | 0.2 | Yes |
| 10 | 0.05 | 0.02 | 0.02 | 0.5 | No |
| 11 | 0.05 | 0.02 | 0.02 | 0.5 | No |
| 12 | 0.05 | 0.02 | 0.02 | 0.15 | No |
| 13 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 14 | 0.05 | 0.02 | 0.015 | 0.2 | No |
| 15 | 0.05 | 0.02 | 0.015 | 0.18 | No |
| 16 | 0.05 | 0.02 | 0.04 | 0.4 | No |
| 17 | 0.05 | 0.02 | 0.015 | 0.18 | No |
| 18 | 0.00001 | 0.02 | 0.00001 | 0.2 | Yes |
| 19 | 0.05 | 0.02 | 0.0275 | 0.12 | No |
| 20 | 0.05 | 0.02 | 0.022 | 0.11 | No |

Table E.4. Continued from previous page.

| | Leading edge of window | | Trailing edge of window | | Linear prediction |
|---|---|---|---|---|---|
| **Sound number** | **Threshold (Pa)** | **Duration (s)** | **Threshold (Pa)** | **Duration (s)** | |
| 21 | 0.05 | 0.02 | 0.00001 | 0.2 | Yes |
| 22 | 0.05 | 0.02 | 0.5 | 0.84 | No |
| 23 | 0.05 | 0.02 | 0.015 | 0.12 | No |
| 24 | 0.05 | 0.02 | 0.018 | 0.15 | No |
| 25 | 0.05 | 0.02 | 0.03 | 0.3 | No |
| 26 | 0.05 | 0.02 | 0.03 | 0.2 | No |
| 27 | 0.05 | 0.02 | 0.03 | 0.2 | No |
| 28 | 0.05 | 0.02 | 0.02 | 0.02 | No |
| 29 | 0.05 | 0.02 | 0.022 | 0.02 | No |
| 30 | 0.05 | 0.02 | 0.016 | 0.03 | No |
| 31 | 0.05 | 0.02 | 0.012 | 0.12 | No |
| 32 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 33 | 0.05 | 0.02 | 0.025 | 0.2 | No |
| 34 | 0.05 | 0.02 | 0.021 | 0.17 | No |
| 35 | 0.05 | 0.02 | 0.025 | 0.22 | No |
| 36 | 0.05 | 0.02 | 0.022 | 0.13 | No |
| 37 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 38 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 39 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 40 | 0.05 | 0.02 | 0.05 | 0.4 | No |

Table E.4. Continued from previous page.

| Sound number | Leading edge of window | | Trailing edge of window | | Linear prediction |
|---|---|---|---|---|---|
| | **Threshold (Pa)** | **Duration (s)** | **Threshold (Pa)** | **Duration (s)** | |
| 41 | 0.05 | 0.02 | 0.02 | 0.22 | No |
| 42 | 0.05 | 0.02 | 0.027 | 0.25 | No |
| 43 | 0.05 | 0.02 | 0.025 | 0.27 | No |
| 44 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 45 | 0.05 | 0.02 | 0.03 | 0.55 | No |
| 46 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 47 | 0.05 | 0.02 | 0.01 | 0.7 | No |
| 48 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 49 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 50 | 0.05 | 0.02 | 0.02 | 0.3 | No |
| 51 | 0.05 | 0.02 | 0.015 | 0.3 | No |
| 52 | 0.05 | 0.02 | 0.01 | 0.15 | No |
| 53 | 0.05 | 0.02 | 0.01 | 0.22 | No |
| 54 | 0.05 | 0.02 | 0.02 | 0.12 | No |
| 55 | 0.05 | 0.02 | 0.02 | 0.12 | No |
| 56 | 0.05 | 0.02 | 0.025 | 0.12 | No |
| 57 | 0.05 | 0.02 | 0.02 | 0.2 | No |
| 58 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 59 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 60 | 0.05 | 0.02 | 0.035 | 0.3 | No |

Table E.4. Continued from previous page.

| Sound number | Leading edge of window | | Trailing edge of window | | Linear prediction |
|---|---|---|---|---|---|
| | **Threshold (Pa)** | **Duration (s)** | **Threshold (Pa)** | **Duration (s)** | |
| 61 | 0.05 | 0.02 | 0.03 | 0.05 | No |
| 62 | 0.05 | 0.02 | 0.03 | 0.28 | No |
| 63 | 0.05 | 0.02 | 0.012 | 0.25 | No |
| 64 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 65 | 0.05 | 0.02 | 0.02 | 0.3 | No |
| 66 | 0.05 | 0.02 | 0.013 | 0.3 | No |
| 67 | 0.05 | 0.02 | 0.04 | 0.52 | No |
| 68 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 69 | 0.05 | 0.02 | 0.05 | 0.4 | No |
| 70 | 0.05 | 0.02 | 0.01 | 0.2 | No |
| 71 | 0.00001 | 0.02 | 0.00001 | 0.2 | Yes |
| 73 | 0.00001 | 0.02 | 0.00001 | 0.2 | Yes |
| 77 | 0.00001 | 0.02 | 0.00001 | 0.2 | Yes |
| 79 | 0.00001 | 0.02 | 0.00001 | 0.2 | Yes |

Table E.5. Windowing on signals in the Purdue test, Part 2. Tops of windows defined by time.

| Sound number | Leading edge of window | | Trailing edge of window | | Linear prediction |
|---|---|---|---|---|---|
| | **Time at top (s)** | **Duration (s)** | **Time at top (s)** | **Duration (s)** | |
| 72 | 0.2 | 0.02 | 1.2 | 0.2 | No |
| 74 | 0.2 | 0.02 | 1.06 | 0.2 | No |
| 75 | 3.635 | 0.02 | 4.5 | 0.3 | No |
| 76 | 0.193 | 0.02 | 0.8 | 0.2 | No |
| 78 | 0.58 | 0.02 | 1.4 | 0.2 | No |
| 80 | 0.204 | 0.02 | 1.15 | 0.2 | No |

Table E.6. Linear predictions on leading edges of signals in the Purdue test, Part 1. Quantities are the same for each ear unless otherwise specified.

| | Prediction | | | Transition | | |
|---|---|---|---|---|---|---|
| **Sound number** | **Start time (s)** | **Order** | **Length (s)** | **Nominal length (s)** | **Margin (s)** | **MA points (one-sided)** |
| 9 | 1.829 | 100 | 0.02 | 0.02 | 0.001 | 48 |
| 18 | 1.94 | 100 | 0.02 | 0.02 | 0.001 | 48 |
| 19 | 1.443 | 100 | 0.02 | 0.02 | 0.001 | 48 |
| 42 | 2.226 | 100 | 0.02 | 0.02 | 0.001 | 48 |
| 52 | 1.8285 | 100 | 0.02 | 0.02 | 0.001 | 48 |
| 69 | 2.227 | 100 | 0.02 | 0.02 | 0.001 | 48 |
| 76 | 2.185 (L), 2.179 (R) | 200 | 0.04 | 0.04 | 0.001 | 48 |
| 77 | 2.18 | 200 | 0.04 | 0.04 | 0.001 | 48 |
| 78 | 2.23 (L), 2.235 (R) | 200 | 0.04 | 0.04 | 0.001 | 48 |
| 79 | 1.835 | 200 | 0.04 | 0.04 | 0.001 | 48 |
| 80 | 2.226 (L), 2.227 (R) | 200 | 0.04 | 0.02 | 0.001 | 48 |

Table E.7. Linear predictions on trailing edges of signals in the Purdue test, Part 1. Quantities are the same for each ear unless otherwise specified.

| | **Prediction** | | | **Transition** | | |
|---|---|---|---|---|---|---|
| **Sound number** | **Start time (s)** | **Order** | **Length (s)** | **Nominal length (s)** | **Margin (s)** | **MA points (one-sided)** |
| 9 | 4.4 | 540 | 0.12 | 0.18 | 0.01 | 480 |
| 18 | 4.85 | 540 | 0.12 | 0.18 | 0.01 | 480 |
| 19 | 4.9 | 540 | 0.12 | 0.25 | 0.01 | 480 |
| 22 | 4.2 | 540 | 0.12 | 0.1 | 0 | 10 |
| 42 | 4.25 | 540 | 0.12 | 0.4 | 0.01 | 480 |
| 52 | 4.45 | 540 | 0.12 | 0.21 | 0.01 | 480 |
| 69 | 4.32 | 540 | 0.12 | 0.2 | 0.01 | 480 |
| 76 | 4.1 | 540 | 0.12 | 0.4 | 0.01 | 480 |
| 77 | 4.14 | 540 | 0.12 | 0.2 | 0.01 | 480 |
| 78 | 4.4 | 540 | 0.12 | 0.24 | 0.01 | 480 |
| 79 | 4.45 | 540 | 0.12 | 0.21 | 0.01 | 480 |
| 80 | 4.21 | 540 | 0.12 | 0.2 | 0.01 | 480 |

Table E.8. Linear predictions on leading edges of signals in the Purdue test, Part 2. Quantities are the same for each ear unless otherwise specified.

| | **Prediction** | | | **Transition** | | |
|---|---|---|---|---|---|---|
| **Sound number** | **Start time (s)** | **Order** | **Length (s)** | **Nominal length (s)** | **Margin (s)** | **MA points (one-sided)** |
| 9 | 1.829 | 100 | 0.02 | 0.02 | 0.001 | 48 |
| 18 | 1.444 | 100 | 0.02 | 0.02 | 0.001 | 48 |
| 71 | 2.185 | 200 | 0.04 | 0.02 | 0.001 | 48 |
| 73 | 2.18 | 200 | 0.04 | 0.02 | 0.001 | 48 |
| 77 | 1.835 | 200 | 0.04 | 0.02 | 0.001 | 48 |
| 79 | 2.226 (L), 2.227 (R) | 200 | 0.04 | 0.02 | 0.001 | 48 |

Table E.9. Linear predictions on trailing edges of signals in the Purdue test, Part 2. Quantities are the same for each ear unless otherwise specified.

| | Prediction | | | Transition | | |
|---|---|---|---|---|---|---|
| **Sound number** | **Start time (s)** | **Order** | **Length (s)** | **Nominal length (s)** | **Margin (s)** | **MA points (one-sided)** |
| 9 | 4.415 | 540 | 0.12 | 0.17 | 0.01 | 480 |
| 18 | 4.9 | 540 | 0.12 | 0.25 | 0.01 | 480 |
| 21 | 4.2 | 540 | 0.12 | 0.1 | 0 | 10 |
| 71 | 4.1 | 540 | 0.12 | 0.4 | 0.01 | 480 |
| 73 | 4.14 | 540 | 0.12 | 0.2 | 0.01 | 480 |
| 77 | 4.45 | 540 | 0.12 | 0.21 | 0.01 | 480 |
| 79 | 4.24 | 540 | 0.12 | 0.2 | 0.01 | 480 |

## E.2 Average and Raw Annoyance Ratings

Tables E.10-E.15 contain the annoyance ratings given during the Purdue test. Tables E.10 and E.11 contains the averaged annoyance ratings across all thirty-five subjects, with separate averaged values for Parts 1 plain and isolated chairs. Tables E.12 and E.13 contain the ratings given by the first eighteen and last seventeen subjects, respectively, during Part 1. Tables E.14 and E.15 contain the ratings given by the first eighteen and last seventeen subjects, respectively, during Part 2.

Table E.10. Annoyance ratings for Purdue test, Part 1, averaged across all thirty-five subjects.

| **Signal** | ***Ann*** | **Signal** | ***Ann*** | **Signal** | ***Ann*** | **Signal** | ***Ann*** |
|---|---|---|---|---|---|---|---|
| **1** | 3.219 | **21** | 5.896 | **41** | 5.368 | **61** | 2.707 |
| **2** | 3.798 | **22** | 4.810 | **42** | 5.967 | **62** | 2.945 |
| **3** | 2.959 | **23** | 5.425 | **43** | 4.008 | **63** | 3.386 |
| **4** | 3.226 | **24** | 3.361 | **44** | 4.376 | **64** | 3.386 |
| **5** | 3.194 | **25** | 3.512 | **45** | 5.096 | **65** | 3.576 |
| **6** | 2.822 | **26** | 3.958 | **46** | 3.208 | **66** | 4.088 |
| **7** | 4.179 | **27** | 4.605 | **47** | 3.222 | **67** | 4.877 |
| **8** | 4.824 | **28** | 4.109 | **48** | 3.295 | **68** | 4.307 |
| **9** | 4.182 | **29** | 4.922 | **49** | 4.408 | **69** | 4.760 |
| **10** | 4.122 | **30** | 5.770 | **50** | 3.809 | **70** | 5.281 |
| **11** | 4.365 | **31** | 6.344 | **51** | 4.323 | **71** | 5.939 |
| **12** | 4.735 | **32** | 2.961 | **52** | 5.144 | **72** | 3.286 |
| **13** | 4.056 | **33** | 3.064 | **53** | 5.032 | **73** | 3.421 |
| **14** | 4.387 | **34** | 4.822 | **54** | 2.845 | **74** | 3.640 |
| **15** | 4.739 | **35** | 3.869 | **55** | 3.594 | **75** | 4.191 |
| **16** | 4.819 | **36** | 4.218 | **56** | 4.154 | **76** | 3.578 |
| **17** | 5.315 | **37** | 5.135 | **57** | 3.069 | **77** | 5.247 |
| **18** | 5.226 | **38** | 5.681 | **58** | 2.915 | **78** | 7.288 |
| **19** | 4.591 | **39** | 4.463 | **59** | 3.279 | **79** | 5.960 |
| **20** | 5.203 | **40** | 4.477 | **60** | 2.760 | **80** | 6.525 |

Table E.11. Annoyance ratings for Purdue test, Part 2, averaged across all thirty-five subjects.

| **Signal** | ***Ann*** | **Signal** | ***Ann*** | **Signal** | ***Ann*** | **Signal** | ***Ann*** |
|---|---|---|---|---|---|---|---|
| **1** | 3.306 | **21** | 4.289 | **41** | 4.257 | **61** | 3.217 |
| **2** | 3.921 | **22** | 5.695 | **42** | 4.936 | **62** | 4.081 |
| **3** | 3.226 | **23** | 3.745 | **43** | 5.153 | **63** | 4.915 |
| **4** | 3.286 | **24** | 3.946 | **44** | 3.121 | **64** | 4.470 |
| **5** | 3.299 | **25** | 4.643 | **45** | 3.208 | **65** | 4.895 |
| **6** | 2.966 | **26** | 4.086 | **46** | 4.470 | **66** | 5.203 |
| **7** | 4.067 | **27** | 5.034 | **47** | 4.273 | **67** | 5.974 |
| **8** | 5.046 | **28** | 5.610 | **48** | 4.696 | **68** | 3.309 |
| **9** | 4.479 | **29** | 6.646 | **49** | 5.469 | **69** | 3.747 |
| **10** | 4.305 | **30** | 3.281 | **50** | 5.279 | **70** | 4.296 |
| **11** | 4.403 | **31** | 3.283 | **51** | 3.030 | **71** | 3.923 |
| **12** | 4.701 | **32** | 4.947 | **52** | 3.569 | **72** | 3.295 |
| **13** | 4.225 | **33** | 3.923 | **53** | 3.889 | **73** | 5.229 |
| **14** | 4.826 | **34** | 4.422 | **54** | 2.664 | **74** | 5.233 |
| **15** | 4.927 | **35** | 5.537 | **55** | 3.089 | **75** | 7.208 |
| **16** | 5.331 | **36** | 5.734 | **56** | 3.448 | **76** | 3.560 |
| **17** | 5.379 | **37** | 4.641 | **57** | 2.593 | **77** | 5.967 |
| **18** | 4.609 | **38** | 4.607 | **58** | 3.021 | **78** | 5.651 |
| **19** | 5.379 | **39** | 5.718 | **59** | 3.261 | **79** | 6.705 |
| **20** | 5.905 | **40** | 6.426 | **60** | 3.359 | **80** | 6.346 |

Table E.12. Annoyance ratings in the Purdue test, Part 1, subjects 1-18.

| **Sound** | **Subjects** | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** |
| **1** | 3.48 | 2.84 | 3.32 | 2.04 | 2.44 | 3.40 | 4.60 | 3.40 | 3.56 | 4.20 | 3.48 | 2.44 | 4.44 | 2.76 | 2.44 | 3.80 | 4.68 | 2.84 |
| **2** | 3.88 | 6.12 | 4.60 | 2.52 | 3.96 | 1.80 | 3.08 | 3.40 | 3.96 | 3.32 | 4.28 | 2.84 | 4.36 | 3.96 | 3.40 | 5.96 | 3.72 | 4.84 |
| **3** | 3.48 | 2.12 | 2.52 | 2.52 | 3.16 | 1.80 | 1.96 | 3.40 | 2.60 | 3.80 | 2.52 | 2.36 | 2.60 | 1.24 | 1.80 | 3.56 | 3.88 | 2.68 |
| **4** | 3.00 | 4.44 | 5.48 | 2.36 | 3.88 | 1.88 | 2.28 | 3.40 | 2.84 | 4.52 | 3.08 | 2.20 | 4.12 | 2.28 | 2.12 | 2.84 | 1.96 | 3.32 |
| **5** | 3.56 | 3.16 | 3.56 | 2.12 | 2.52 | 1.16 | 3.16 | 3.40 | 2.28 | 3.72 | 5.16 | 2.44 | 3.40 | 3.08 | 3.32 | 2.52 | 2.20 | 3.16 |
| **6** | 2.84 | 2.04 | 3.56 | 1.96 | 2.04 | 2.12 | 2.92 | 3.40 | 3.24 | 2.68 | 3.48 | 2.28 | 2.36 | 1.80 | 2.44 | 3.88 | 3.64 | 3.08 |
| **7** | 6.60 | 2.92 | 4.92 | 4.60 | 5.96 | 4.28 | 4.20 | 5.00 | 3.00 | 5.56 | 3.72 | 3.08 | 3.32 | 3.24 | 3.00 | 4.84 | 4.36 | 5.16 |
| **8** | 7.32 | 3.96 | 5.40 | 5.08 | 4.28 | 5.00 | 5.24 | 3.40 | 3.72 | 6.44 | 3.48 | 2.36 | 2.60 | 5.64 | 2.60 | 5.64 | 5.24 | 6.44 |
| **9** | 4.84 | 3.32 | 5.00 | 5.08 | 7.16 | 5.08 | 4.28 | 3.40 | 4.12 | 4.84 | 3.24 | 3.08 | 5.00 | 2.44 | 2.76 | 2.04 | 5.48 | 4.84 |
| **10** | 6.84 | 4.20 | 5.80 | 2.76 | 5.00 | 5.00 | 3.56 | 3.40 | 3.16 | 5.72 | 3.24 | 3.00 | 2.36 | 3.64 | 2.84 | 5.24 | 3.88 | 3.48 |
| **11** | 6.20 | 4.60 | 4.36 | 3.00 | 5.00 | 3.40 | 4.20 | 3.40 | 3.64 | 3.08 | 5.80 | 2.68 | 7.40 | 4.84 | 3.48 | 3.08 | 4.20 | 5.00 |
| **12** | 6.92 | 2.68 | 4.36 | 5.16 | 3.00 | 3.48 | 5.24 | 5.00 | 4.84 | 6.28 | 2.52 | 3.32 | 5.64 | 7.08 | 2.68 | 5.64 | 3.48 | 3.40 |
| **13** | 7.00 | 3.40 | 4.92 | 3.24 | 2.84 | 1.80 | 4.68 | 3.40 | 2.44 | 5.16 | 4.84 | 2.76 | 3.24 | 5.16 | 2.52 | 5.56 | 4.52 | 3.40 |
| **14** | 6.52 | 3.08 | 5.48 | 5.08 | 5.00 | 4.28 | 3.16 | 3.40 | 4.44 | 4.68 | 7.08 | 3.40 | 2.36 | 2.76 | 2.60 | 4.68 | 2.44 | 5.08 |
| **15** | 7.16 | 3.88 | 4.92 | 5.16 | 5.00 | 5.00 | 5.24 | 5.00 | 3.80 | 5.24 | 4.68 | 3.40 | 5.48 | 5.00 | 3.80 | 5.72 | 5.24 | 4.04 |
| **16** | 7.16 | 3.16 | 5.16 | 6.12 | 6.04 | 5.00 | 6.52 | 5.00 | 4.28 | 5.56 | 6.04 | 3.64 | 3.32 | 5.24 | 2.68 | 4.12 | 4.20 | 3.16 |
| **17** | 7.16 | 5.00 | 6.12 | 5.72 | 7.24 | 6.36 | 6.20 | 5.00 | 4.68 | 6.52 | 5.32 | 3.48 | 8.04 | 5.08 | 2.92 | 3.48 | 5.64 | 4.28 |
| **18** | 7.00 | 4.44 | 5.88 | 4.28 | 5.24 | 5.00 | 2.52 | 5.00 | 4.52 | 7.08 | 7.08 | 3.88 | 4.20 | 7.24 | 3.56 | 3.16 | 6.28 | 5.00 |
| **19** | 6.84 | 3.32 | 5.88 | 3.72 | 6.04 | 5.00 | 6.92 | 5.00 | 4.36 | 5.88 | 3.72 | 2.44 | 4.60 | 4.68 | 2.60 | 2.84 | 3.40 | 3.96 |
| **20** | 7.72 | 2.92 | 5.48 | 5.96 | 6.52 | 6.76 | 2.28 | 5.00 | 4.28 | 6.28 | 7.24 | 3.72 | 2.44 | 4.68 | 4.04 | 3.00 | 5.88 | 5.56 |

Table E.12. Continued from previous page.

| **Sound** | **Subjects** | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** |
| **21** | 7.24 | 3.64 | 5.24 | 6.20 | 7.24 | 6.60 | 5.08 | 5.00 | 4.60 | 7.00 | 6.76 | 4.04 | 4.60 | 7.72 | 3.64 | 7.48 | 5.48 | 5.48 |
| **22** | 6.84 | 2.52 | 6.52 | 2.28 | 5.56 | 5.16 | 1.96 | 5.00 | 3.32 | 6.68 | 6.52 | 3.24 | 5.00 | 6.28 | 3.48 | 4.04 | 5.00 | 4.04 |
| **23** | 7.96 | 3.24 | 6.12 | 5.32 | 5.32 | 5.56 | 5.80 | 5.00 | 3.96 | 7.16 | 6.20 | 2.92 | 7.40 | 6.84 | 3.88 | 3.48 | 5.08 | 5.16 |
| **24** | 6.68 | 2.68 | 3.16 | 3.72 | 3.88 | 1.80 | 4.28 | 3.40 | 2.20 | 3.32 | 4.84 | 2.60 | 7.16 | 1.88 | 2.28 | 5.64 | 2.76 | 3.24 |
| **25** | 6.92 | 3.32 | 5.48 | 3.56 | 2.44 | 3.40 | 3.88 | 3.40 | 2.04 | 3.80 | 4.84 | 2.36 | 4.92 | 3.08 | 2.36 | 3.40 | 2.44 | 4.04 |
| **26** | 6.84 | 3.72 | 4.76 | 2.20 | 3.32 | 2.04 | 4.28 | 3.40 | 3.96 | 3.96 | 6.60 | 3.00 | 5.56 | 2.36 | 2.44 | 6.12 | 2.76 | 3.40 |
| **27** | 7.56 | 5.00 | 4.36 | 3.00 | 5.88 | 5.32 | 3.56 | 5.00 | 3.88 | 5.00 | 4.12 | 3.24 | 4.68 | 5.00 | 2.84 | 4.12 | 2.92 | 3.72 |
| **28** | 3.64 | 3.48 | 3.88 | 5.00 | 5.08 | 3.40 | 4.44 | 3.40 | 4.20 | 6.68 | 2.84 | 3.00 | 3.40 | 5.88 | 2.68 | 3.80 | 3.08 | 5.72 |
| **29** | 4.04 | 3.88 | 5.56 | 2.76 | 5.56 | 3.40 | 6.76 | 5.00 | 3.48 | 7.32 | 5.72 | 2.84 | 5.08 | 7.80 | 3.00 | 6.60 | 4.68 | 6.12 |
| **30** | 7.40 | 5.88 | 5.24 | 3.72 | 5.96 | 6.60 | 7.00 | 6.60 | 3.56 | 7.00 | 6.52 | 3.88 | 4.92 | 8.44 | 3.64 | 5.00 | 3.64 | 6.76 |
| **31** | 7.64 | 5.24 | 5.48 | 4.44 | 7.72 | 6.60 | 9.00 | 5.00 | 4.84 | 9.00 | 5.80 | 3.96 | 6.52 | 8.52 | 4.12 | 8.04 | 5.80 | 5.08 |
| **32** | 2.52 | 2.92 | 3.48 | 2.12 | 2.60 | 1.80 | 1.32 | 3.40 | 3.48 | 3.40 | 3.40 | 2.36 | 5.00 | 3.88 | 3.16 | 6.04 | 2.52 | 3.16 |
| **33** | 3.64 | 2.36 | 4.28 | 3.08 | 2.52 | 2.12 | 2.44 | 3.40 | 2.12 | 4.44 | 3.40 | 2.28 | 1.88 | 3.40 | 2.92 | 5.88 | 3.08 | 4.44 |
| **34** | 7.72 | 3.16 | 3.80 | 4.68 | 5.88 | 4.20 | 3.56 | 5.00 | 3.48 | 7.16 | 3.96 | 3.08 | 6.60 | 6.76 | 3.96 | 4.76 | 1.96 | 5.16 |
| **35** | 6.52 | 6.44 | 5.08 | 2.52 | 4.68 | 1.80 | 5.24 | 3.40 | 3.88 | 4.20 | 2.52 | 2.84 | 3.08 | 5.00 | 3.00 | 6.12 | 2.76 | 4.60 |
| **36** | 6.52 | 3.40 | 5.08 | 3.24 | 5.40 | 2.12 | 7.40 | 3.40 | 3.32 | 6.28 | 4.44 | 3.00 | 3.96 | 5.72 | 2.76 | 7.48 | 2.68 | 4.68 |
| **37** | 7.56 | 3.56 | 5.00 | 5.16 | 6.84 | 6.76 | 5.48 | 5.00 | 4.44 | 6.60 | 6.52 | 3.64 | 3.32 | 7.48 | 2.28 | 6.28 | 2.52 | 5.80 |
| **38** | 7.80 | 5.72 | 6.20 | 6.44 | 5.32 | 5.00 | 6.20 | 5.00 | 4.28 | 6.76 | 6.84 | 3.56 | 3.24 | 8.36 | 2.60 | 7.32 | 6.12 | 7.24 |
| **39** | 5.96 | 3.48 | 5.24 | 3.40 | 5.48 | 4.28 | 4.52 | 5.00 | 4.44 | 5.00 | 5.64 | 3.00 | 4.20 | 4.76 | 3.00 | 4.76 | 3.80 | 4.68 |
| **40** | 4.68 | 3.16 | 5.00 | 4.20 | 3.72 | 5.00 | 3.56 | 5.00 | 3.88 | 4.20 | 6.12 | 3.16 | 4.20 | 5.24 | 3.96 | 3.48 | 1.96 | 5.08 |

Table E.12. Continued from previous page.

| **Sound** | **Subjects** | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** |
| **41** | 7.64 | 4.52 | 6.36 | 6.52 | 5.48 | 6.68 | 7.24 | 5.00 | 4.44 | 6.68 | 7.24 | 3.80 | 2.84 | 7.16 | 3.88 | 3.56 | 4.36 | 3.64 |
| **42** | 7.24 | 3.32 | 6.44 | 6.12 | 6.76 | 7.16 | 6.52 | 6.60 | 5.00 | 7.32 | 7.40 | 3.80 | 6.60 | 7.00 | 3.40 | 5.88 | 4.36 | 5.32 |
| **43** | 4.52 | 2.84 | 4.68 | 4.20 | 3.16 | 2.04 | 5.24 | 3.40 | 4.04 | 6.12 | 5.88 | 2.36 | 3.64 | 4.76 | 3.48 | 4.12 | 3.48 | 2.52 |
| **44** | 5.40 | 3.72 | 4.84 | 4.60 | 4.36 | 4.84 | 4.68 | 3.40 | 3.80 | 6.28 | 4.12 | 2.92 | 2.84 | 5.00 | 2.68 | 3.48 | 5.08 | 4.76 |
| **45** | 7.16 | 4.28 | 4.92 | 6.04 | 4.68 | 5.08 | 5.80 | 3.40 | 4.28 | 7.64 | 5.40 | 3.48 | 5.00 | 7.88 | 3.64 | 5.96 | 3.48 | 5.24 |
| **46** | 3.80 | 2.84 | 3.56 | 2.20 | 4.20 | 3.56 | 3.08 | 3.40 | 2.36 | 3.88 | 3.08 | 2.20 | 2.60 | 1.80 | 2.44 | 3.96 | 4.20 | 3.72 |
| **47** | 3.56 | 2.04 | 3.48 | 2.44 | 2.44 | 3.56 | 2.20 | 3.40 | 2.52 | 4.92 | 5.16 | 2.36 | 3.24 | 1.80 | 2.44 | 3.56 | 2.68 | 3.96 |
| **48** | 5.16 | 2.04 | 3.56 | 2.20 | 2.12 | 1.80 | 2.60 | 3.40 | 3.16 | 3.56 | 5.96 | 2.44 | 3.40 | 2.44 | 2.84 | 2.44 | 3.64 | 2.76 |
| **49** | 5.72 | 2.20 | 5.00 | 3.72 | 3.72 | 5.00 | 3.72 | 5.00 | 4.20 | 4.68 | 5.56 | 2.36 | 5.64 | 3.40 | 2.76 | 2.36 | 5.24 | 3.64 |
| **50** | 5.00 | 3.16 | 5.80 | 3.08 | 3.96 | 2.60 | 3.64 | 3.40 | 4.12 | 4.68 | 3.32 | 2.60 | 5.48 | 2.36 | 3.40 | 3.32 | 4.12 | 4.04 |
| **51** | 5.88 | 3.48 | 5.00 | 3.80 | 3.48 | 3.40 | 4.84 | 5.00 | 3.72 | 4.20 | 4.12 | 3.08 | 3.40 | 3.16 | 2.92 | 4.44 | 5.64 | 3.48 |
| **52** | 6.20 | 5.00 | 4.44 | 6.28 | 6.52 | 6.60 | 6.28 | 5.00 | 4.20 | 6.44 | 6.84 | 3.32 | 6.04 | 5.48 | 2.28 | 2.20 | 3.24 | 4.12 |
| **53** | 6.84 | 4.04 | 4.36 | 6.68 | 6.60 | 7.08 | 4.04 | 5.00 | 4.28 | 6.76 | 3.72 | 3.24 | 4.92 | 2.60 | 3.48 | 5.88 | 4.12 | 4.36 |
| **54** | 4.20 | 2.52 | 3.72 | 2.52 | 1.96 | 2.04 | 2.68 | 3.40 | 2.20 | 3.48 | 3.24 | 2.20 | 4.60 | 1.32 | 2.28 | 3.56 | 2.04 | 2.60 |
| **55** | 6.68 | 3.40 | 5.56 | 2.76 | 4.04 | 3.56 | 3.00 | 3.40 | 2.44 | 3.64 | 2.84 | 2.68 | 3.24 | 3.16 | 2.20 | 6.52 | 4.12 | 3.48 |
| **56** | 5.32 | 5.00 | 5.96 | 4.52 | 4.92 | 1.88 | 6.84 | 3.40 | 4.52 | 4.52 | 4.76 | 2.84 | 2.60 | 2.84 | 3.40 | 3.32 | 2.20 | 3.40 |
| **57** | 2.60 | 3.56 | 2.04 | 1.40 | 2.28 | 1.64 | 4.60 | 3.40 | 2.04 | 1.80 | 5.40 | 2.60 | 5.56 | 2.28 | 2.12 | 7.72 | 1.80 | 4.68 |
| **58** | 2.52 | 2.04 | 4.60 | 2.04 | 4.04 | 1.80 | 3.96 | 3.40 | 2.20 | 4.04 | 3.24 | 2.52 | 2.84 | 2.28 | 1.88 | 6.20 | 1.80 | 2.84 |
| **59** | 3.48 | 5.40 | 3.56 | 3.40 | 3.16 | 1.64 | 4.28 | 3.40 | 2.28 | 3.56 | 3.48 | 2.36 | 4.36 | 4.68 | 2.76 | 6.20 | 1.96 | 3.56 |
| **60** | 5.00 | 4.92 | 1.96 | 1.24 | 1.80 | 1.00 | 4.68 | 3.40 | 2.04 | 1.96 | 3.16 | 2.28 | 3.96 | 3.32 | 2.04 | 3.88 | 2.04 | 3.00 |

Table E.12. Continued from previous page.

| Sound | Subjects | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** |
| **61** | 3.48 | 3.56 | 2.20 | 1.40 | 2.84 | 2.92 | 1.96 | 3.40 | 2.12 | 2.12 | 3.08 | 2.20 | 5.08 | 1.40 | 2.20 | 4.76 | 2.60 | 3.16 |
| **62** | 4.52 | 3.40 | 3.56 | 3.16 | 2.68 | 2.04 | 2.28 | 3.40 | 2.36 | 2.68 | 2.84 | 2.44 | 4.68 | 1.72 | 3.48 | 5.48 | 2.52 | 2.04 |
| **63** | 5.00 | 2.28 | 5.64 | 2.20 | 3.96 | 1.80 | 2.20 | 3.40 | 2.52 | 3.48 | 3.24 | 2.28 | 4.60 | 3.72 | 2.28 | 5.00 | 4.84 | 3.72 |
| **64** | 3.72 | 2.04 | 3.72 | 3.72 | 3.56 | 1.80 | 4.52 | 3.40 | 2.52 | 3.64 | 5.16 | 2.84 | 3.32 | 4.76 | 2.68 | 5.48 | 3.80 | 4.28 |
| **65** | 3.80 | 6.04 | 3.72 | 3.00 | 3.00 | 1.80 | 4.12 | 3.40 | 2.36 | 3.48 | 3.80 | 2.52 | 4.28 | 5.24 | 3.64 | 6.04 | 2.20 | 4.04 |
| **66** | 5.16 | 6.28 | 3.72 | 4.36 | 6.28 | 3.56 | 5.24 | 3.40 | 2.76 | 4.68 | 4.60 | 2.92 | 2.36 | 5.32 | 2.84 | 5.32 | 3.40 | 4.68 |
| **67** | 5.16 | 7.08 | 5.00 | 2.52 | 7.08 | 5.88 | 5.24 | 3.40 | 4.20 | 6.44 | 6.36 | 3.00 | 5.48 | 5.88 | 2.84 | 2.84 | 5.64 | 5.56 |
| **68** | 7.08 | 4.76 | 5.00 | 3.56 | 4.44 | 4.44 | 2.12 | 3.40 | 4.12 | 3.88 | 5.24 | 3.32 | 3.32 | 4.60 | 2.84 | 3.40 | 3.80 | 4.76 |
| **69** | 7.32 | 5.16 | 5.00 | 6.20 | 4.44 | 3.40 | 6.12 | 5.00 | 2.92 | 6.36 | 5.40 | 3.24 | 4.92 | 4.44 | 3.24 | 3.16 | 4.52 | 5.64 |
| **70** | 7.24 | 4.52 | 5.72 | 5.08 | 6.12 | 3.48 | 7.08 | 5.00 | 4.36 | 6.44 | 6.60 | 3.16 | 5.00 | 6.12 | 3.56 | 5.00 | 5.00 | 5.00 |
| **71** | 7.56 | 3.32 | 5.96 | 3.88 | 7.56 | 7.40 | 9.00 | 5.00 | 4.84 | 6.76 | 7.08 | 4.20 | 6.04 | 7.64 | 3.40 | 6.60 | 4.12 | 5.96 |
| **72** | 6.28 | 3.32 | 3.96 | 3.64 | 2.04 | 1.80 | 4.28 | 3.40 | 3.48 | 4.20 | 4.28 | 2.20 | 4.68 | 1.80 | 2.20 | 5.40 | 1.96 | 1.72 |
| **73** | 5.00 | 4.36 | 3.80 | 2.68 | 3.72 | 1.64 | 4.84 | 3.40 | 2.04 | 3.88 | 3.80 | 2.44 | 2.84 | 3.72 | 2.60 | 2.52 | 3.80 | 2.84 |
| **74** | 6.36 | 3.16 | 4.36 | 3.00 | 3.08 | 3.40 | 6.04 | 3.40 | 3.72 | 4.36 | 5.32 | 3.24 | 5.08 | 4.36 | 2.44 | 3.48 | 3.64 | 3.48 |
| **75** | 6.52 | 4.12 | 5.08 | 3.56 | 2.60 | 4.20 | 3.40 | 3.40 | 4.04 | 4.36 | 5.88 | 2.68 | 4.92 | 4.44 | 3.00 | 4.68 | 2.68 | 4.04 |
| **76** | 6.52 | 2.04 | 3.64 | 4.12 | 6.12 | 1.80 | 7.00 | 3.40 | 3.88 | 4.52 | 2.60 | 2.36 | 2.60 | 2.36 | 3.08 | 2.92 | 5.80 | 5.40 |
| **77** | 7.24 | 4.44 | 5.64 | 6.28 | 7.32 | 6.60 | 5.56 | 5.00 | 4.92 | 5.32 | 7.48 | 3.48 | 7.40 | 4.68 | 3.24 | 3.16 | 5.64 | 2.52 |
| **78** | 7.96 | 5.72 | 6.44 | 7.40 | 8.12 | 7.80 | 9.00 | 8.20 | 5.24 | 9.00 | 7.88 | 4.68 | 7.80 | 8.28 | 4.68 | 7.72 | 8.04 | 8.04 |
| **79** | 6.52 | 5.24 | 5.08 | 5.80 | 7.48 | 6.60 | 5.80 | 6.60 | 5.00 | 6.60 | 7.64 | 4.20 | 6.76 | 7.80 | 3.40 | 4.68 | 6.12 | 4.92 |
| **80** | 7.96 | 7.16 | 6.44 | 6.52 | 7.24 | 7.80 | 7.08 | 6.60 | 5.00 | 9.00 | 7.96 | 4.12 | 9.00 | 7.32 | 3.48 | 7.16 | 6.44 | 5.16 |

Table E.13. Annoyance ratings in the Purdue test, Part 1, subjects 19-35.

| **Sound** | **Subjects** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** | **35** |
| **1** | 2.20 | 4.20 | 4.84 | 4.28 | 1.80 | 2.68 | 2.36 | 5.16 | 3.64 | 2.44 | 1.80 | 2.92 | 3.32 | 2.52 | 2.76 | 2.52 | 3.08 |
| **2** | 2.92 | 5.96 | 2.68 | 4.12 | 3.96 | 5.48 | 3.48 | 6.28 | 3.96 | 2.76 | 1.00 | 2.44 | 5.32 | 2.20 | 3.40 | 3.00 | 3.96 |
| **3** | 3.40 | 3.48 | 3.64 | 3.72 | 2.60 | 3.40 | 3.08 | 5.96 | 3.48 | 2.92 | 1.00 | 3.32 | 3.24 | 3.08 | 3.48 | 2.12 | 3.64 |
| **4** | 2.04 | 4.92 | 4.44 | 3.96 | 4.52 | 1.64 | 3.48 | 6.20 | 5.08 | 2.52 | 1.00 | 2.36 | 3.80 | 2.84 | 2.84 | 2.60 | 2.68 |
| **5** | 2.20 | 5.16 | 2.52 | 6.20 | 3.72 | 1.96 | 3.24 | 6.52 | 5.16 | 2.44 | 1.00 | 4.28 | 2.04 | 3.32 | 2.92 | 2.60 | 2.60 |
| **6** | 2.12 | 4.12 | 2.84 | 5.32 | 2.60 | 1.80 | 2.36 | 5.88 | 3.88 | 2.04 | 1.00 | 1.80 | 2.68 | 2.36 | 2.68 | 2.28 | 3.24 |
| **7** | 2.60 | 4.04 | 3.88 | 3.72 | 4.84 | 3.56 | 5.72 | 5.32 | 5.56 | 2.68 | 3.00 | 2.04 | 4.28 | 3.24 | 5.24 | 4.04 | 4.76 |
| **8** | 2.68 | 6.68 | 6.52 | 6.84 | 4.20 | 3.32 | 5.56 | 5.56 | 6.52 | 3.64 | 3.32 | 6.84 | 5.40 | 3.48 | 5.40 | 5.24 | 3.80 |
| **9** | 2.12 | 6.92 | 2.52 | 5.24 | 5.32 | 2.04 | 5.40 | 5.08 | 6.12 | 3.00 | 2.76 | 5.56 | 2.12 | 3.32 | 4.20 | 3.32 | 5.32 |
| **10** | 2.28 | 4.28 | 3.40 | 6.20 | 2.60 | 1.64 | 6.44 | 5.56 | 6.44 | 3.80 | 1.88 | 3.08 | 6.44 | 4.12 | 5.00 | 4.12 | 3.88 |
| **11** | 2.44 | 5.88 | 6.68 | 4.28 | 2.60 | 2.68 | 4.04 | 6.28 | 5.08 | 3.40 | 2.84 | 4.60 | 4.28 | 5.32 | 5.00 | 3.80 | 6.20 |
| **12** | 3.40 | 5.88 | 3.96 | 6.76 | 5.56 | 3.96 | 5.32 | 6.12 | 6.12 | 3.80 | 3.56 | 5.16 | 6.04 | 3.24 | 5.56 | 4.36 | 6.20 |
| **13** | 2.28 | 5.64 | 6.04 | 5.56 | 3.64 | 2.12 | 5.32 | 5.24 | 3.48 | 2.52 | 2.52 | 4.76 | 5.56 | 3.48 | 4.60 | 3.96 | 4.36 |
| **14** | 2.12 | 4.68 | 4.20 | 5.72 | 5.00 | 2.12 | 4.92 | 6.36 | 6.68 | 2.60 | 2.12 | 5.40 | 6.28 | 4.60 | 5.00 | 4.68 | 5.56 |
| **15** | 2.68 | 6.76 | 2.76 | 5.88 | 5.80 | 1.64 | 5.00 | 6.60 | 5.40 | 3.16 | 3.16 | 5.88 | 4.12 | 5.08 | 5.24 | 2.92 | 6.04 |
| **16** | 2.92 | 4.60 | 3.96 | 4.84 | 7.40 | 2.04 | 6.60 | 7.32 | 6.60 | 3.00 | 2.84 | 5.56 | 5.40 | 3.56 | 5.00 | 5.00 | 5.64 |
| **17** | 2.04 | 5.00 | 6.44 | 7.16 | 5.88 | 5.48 | 6.28 | 6.84 | 6.76 | 3.24 | 2.52 | 6.36 | 3.80 | 5.00 | 4.68 | 6.04 | 4.28 |
| **18** | 3.00 | 4.04 | 4.52 | 6.28 | 5.80 | 6.04 | 6.60 | 6.60 | 6.20 | 4.36 | 3.40 | 5.64 | 5.08 | 4.84 | 5.56 | 6.36 | 7.24 |
| **19** | 3.08 | 5.88 | 4.92 | 5.24 | 7.32 | 2.60 | 5.00 | 5.32 | 6.12 | 3.88 | 1.88 | 2.52 | 5.16 | 3.88 | 5.40 | 5.72 | 5.56 |
| **20** | 2.92 | 6.68 | 3.64 | 6.20 | 8.12 | 3.24 | 7.72 | 6.52 | 7.40 | 3.48 | 3.24 | 5.40 | 6.36 | 5.00 | 5.08 | 5.80 | 5.56 |

Table E.13. Continued from previous page.

| Sound | Subjects | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** | **35** |
| **21** | 2.28 | 5.64 | 6.52 | 8.28 | 9.00 | 5.32 | 8.76 | 6.28 | 7.32 | 4.20 | 4.92 | 4.12 | 6.36 | 5.24 | 5.64 | 6.76 | 6.68 |
| **22** | 2.44 | 6.76 | 5.96 | 7.72 | 4.20 | 4.36 | 5.88 | 6.20 | 6.52 | 2.60 | 2.68 | 5.88 | 4.76 | 4.92 | 4.20 | 5.08 | 4.76 |
| **23** | 2.04 | 6.76 | 6.20 | 5.96 | 7.32 | 3.72 | 5.80 | 6.68 | 6.68 | 3.64 | 3.32 | 6.44 | 6.44 | 4.84 | 5.80 | 5.16 | 6.68 |
| **24** | 2.20 | 5.80 | 3.32 | 5.32 | 2.60 | 2.12 | 2.28 | 5.24 | 4.28 | 2.20 | 1.00 | 1.88 | 3.16 | 2.12 | 3.00 | 3.40 | 2.20 |
| **25** | 2.04 | 4.52 | 3.00 | 4.12 | 4.76 | 2.04 | 3.88 | 4.92 | 5.32 | 2.20 | 2.60 | 2.28 | 3.72 | 2.28 | 3.48 | 3.24 | 2.84 |
| **26** | 2.28 | 5.96 | 3.40 | 4.52 | 5.40 | 2.12 | 5.00 | 6.28 | 3.88 | 2.68 | 3.32 | 3.24 | 3.08 | 3.88 | 4.44 | 3.16 | 5.16 |
| **27** | 3.16 | 8.52 | 5.24 | 5.32 | 5.72 | 4.04 | 5.24 | 6.68 | 6.28 | 3.24 | 1.88 | 5.00 | 5.48 | 3.40 | 5.00 | 2.36 | 5.40 |
| **28** | 1.80 | 6.60 | 3.32 | 4.04 | 4.20 | 2.84 | 5.32 | 5.00 | 6.44 | 2.76 | 1.56 | 6.12 | 6.36 | 3.88 | 3.48 | 3.16 | 3.32 |
| **29** | 1.64 | 7.96 | 4.28 | 6.28 | 4.04 | 5.32 | 5.96 | 6.28 | 7.24 | 3.08 | 2.20 | 6.12 | 6.44 | 3.32 | 5.00 | 2.84 | 4.68 |
| **30** | 2.76 | 8.12 | 4.20 | 6.28 | 9.00 | 6.60 | 6.60 | 5.64 | 6.68 | 3.56 | 2.44 | 7.88 | 6.36 | 6.44 | 5.64 | 7.40 | 4.60 |
| **31** | 2.76 | 8.76 | 5.96 | 7.96 | 9.00 | 5.24 | 8.36 | 6.52 | 7.16 | 3.56 | 5.00 | 7.88 | 6.92 | 5.72 | 6.28 | 5.56 | 6.60 |
| **32** | 1.96 | 4.44 | 2.52 | 3.64 | 3.08 | 1.96 | 2.28 | 5.32 | 3.56 | 2.52 | 1.00 | 2.52 | 2.60 | 1.24 | 2.76 | 3.08 | 2.60 |
| **33** | 2.36 | 4.60 | 3.24 | 4.04 | 2.68 | 1.72 | 2.60 | 5.08 | 3.96 | 2.20 | 1.00 | 2.28 | 1.96 | 3.00 | 3.48 | 2.52 | 2.84 |
| **34** | 3.08 | 7.00 | 4.84 | 6.28 | 5.40 | 3.16 | 5.56 | 6.52 | 6.12 | 4.44 | 2.12 | 3.08 | 4.52 | 5.00 | 5.16 | 5.56 | 6.04 |
| **35** | 1.72 | 5.96 | 6.12 | 4.44 | 3.00 | 3.56 | 3.08 | 4.92 | 6.20 | 2.28 | 2.68 | 4.12 | 2.92 | 2.12 | 3.08 | 2.84 | 2.68 |
| **36** | 2.68 | 5.72 | 3.64 | 3.88 | 4.20 | 3.16 | 5.00 | 5.56 | 5.00 | 2.84 | 2.68 | 6.36 | 4.28 | 2.20 | 3.40 | 3.56 | 2.60 |
| **37** | 2.36 | 7.72 | 6.36 | 5.24 | 4.84 | 4.36 | 6.52 | 6.28 | 6.68 | 3.08 | 2.60 | 6.12 | 4.52 | 4.92 | 5.00 | 4.12 | 4.76 |
| **38** | 2.36 | 7.72 | 2.92 | 7.08 | 6.20 | 5.08 | 6.92 | 7.16 | 7.00 | 3.72 | 3.56 | 6.68 | 6.44 | 5.16 | 5.08 | 6.28 | 5.48 |
| **39** | 2.04 | 5.88 | 2.92 | 5.24 | 7.56 | 3.64 | 6.68 | 6.36 | 5.08 | 2.68 | 1.32 | 2.20 | 4.68 | 5.08 | 5.00 | 4.20 | 5.00 |
| **40** | 2.60 | 8.04 | 3.48 | 5.80 | 6.60 | 2.68 | 7.08 | 5.96 | 5.00 | 2.92 | 3.24 | 4.04 | 4.68 | 2.92 | 5.48 | 5.72 | 4.84 |

Table E.13. Continued from previous page.

| **Sound** | **Subjects** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** | **35** |
| **41** | 2.28 | 4.28 | 3.16 | 6.20 | 6.60 | 5.40 | 6.68 | 7.08 | 5.24 | 3.56 | 3.56 | 7.16 | 6.36 | 4.60 | 5.80 | 5.72 | 7.16 |
| **42** | 2.04 | 7.80 | 3.64 | 7.32 | 9.00 | 5.48 | 7.96 | 6.60 | 7.48 | 3.08 | 4.20 | 6.60 | 6.28 | 5.32 | 5.88 | 6.68 | 7.24 |
| **43** | 2.20 | 6.36 | 5.72 | 4.84 | 4.52 | 4.52 | 3.88 | 5.00 | 6.04 | 3.24 | 2.84 | 2.92 | 2.68 | 2.84 | 3.96 | 3.88 | 4.36 |
| **44** | 2.52 | 5.56 | 2.04 | 4.68 | 4.60 | 3.08 | 5.56 | 6.52 | 6.20 | 3.32 | 3.16 | 5.72 | 4.68 | 4.68 | 5.00 | 5.40 | 3.64 |
| **45** | 3.72 | 7.80 | 3.40 | 6.28 | 7.72 | 3.56 | 7.24 | 5.24 | 5.24 | 3.24 | 3.24 | 5.80 | 5.00 | 3.32 | 4.28 | 5.24 | 4.68 |
| **46** | 2.20 | 3.40 | 3.00 | 4.60 | 4.12 | 2.60 | 2.76 | 6.04 | 5.88 | 2.36 | 2.44 | 1.32 | 3.32 | 2.52 | 2.68 | 3.08 | 3.08 |
| **47** | 2.12 | 3.72 | 4.84 | 3.80 | 5.72 | 2.60 | 2.36 | 5.40 | 5.80 | 2.52 | 1.32 | 2.20 | 3.24 | 3.08 | 2.92 | 2.52 | 2.84 |
| **48** | 2.12 | 5.40 | 2.04 | 4.60 | 3.40 | 1.64 | 2.60 | 6.36 | 3.72 | 2.76 | 3.00 | 4.52 | 3.00 | 3.16 | 3.96 | 4.36 | 3.16 |
| **49** | 2.44 | 5.16 | 3.56 | 5.16 | 4.68 | 1.88 | 5.56 | 6.36 | 7.16 | 3.24 | 4.04 | 5.40 | 5.64 | 5.16 | 5.24 | 3.32 | 6.36 |
| **50** | 2.28 | 6.28 | 3.16 | 6.28 | 2.60 | 2.60 | 4.20 | 6.36 | 4.28 | 3.24 | 2.36 | 4.44 | 3.64 | 3.40 | 3.48 | 2.36 | 4.28 |
| **51** | 1.64 | 6.36 | 3.96 | 6.68 | 4.20 | 1.88 | 5.64 | 5.24 | 6.52 | 3.08 | 2.36 | 4.44 | 5.24 | 4.28 | 5.00 | 6.84 | 4.92 |
| **52** | 2.28 | 3.88 | 6.28 | 7.00 | 3.40 | 5.32 | 5.96 | 7.16 | 6.84 | 3.64 | 4.92 | 6.52 | 5.64 | 4.68 | 5.48 | 4.84 | 5.72 |
| **53** | 2.12 | 6.92 | 5.96 | 8.36 | 6.44 | 3.40 | 6.52 | 6.12 | 5.80 | 3.24 | 3.40 | 3.40 | 4.76 | 4.44 | 4.44 | 6.04 | 6.76 |
| **54** | 2.84 | 5.56 | 2.12 | 3.08 | 2.60 | 1.88 | 2.36 | 4.60 | 3.56 | 2.20 | 2.44 | 3.32 | 1.96 | 2.28 | 3.08 | 2.44 | 2.68 |
| **55** | 2.12 | 5.08 | 2.20 | 4.52 | 4.12 | 2.36 | 4.28 | 6.44 | 5.24 | 2.28 | 1.00 | 3.00 | 3.80 | 2.36 | 3.48 | 3.00 | 3.80 |
| **56** | 2.12 | 6.04 | 3.40 | 4.68 | 7.40 | 3.00 | 5.16 | 5.48 | 5.56 | 3.32 | 2.28 | 4.20 | 4.68 | 4.68 | 4.36 | 3.72 | 3.08 |
| **57** | 1.96 | 5.40 | 3.56 | 4.36 | 1.00 | 2.60 | 1.08 | 6.12 | 3.40 | 2.12 | 1.00 | 6.20 | 2.12 | 1.80 | 2.60 | 2.04 | 2.52 |
| **58** | 2.28 | 5.88 | 2.68 | 4.12 | 2.60 | 2.04 | 1.08 | 5.16 | 3.08 | 2.52 | 1.00 | 2.76 | 2.60 | 1.80 | 2.68 | 2.20 | 3.32 |
| **59** | 1.96 | 5.64 | 3.96 | 5.24 | 3.00 | 2.92 | 2.36 | 5.88 | 2.76 | 2.12 | 1.00 | 2.04 | 3.16 | 2.12 | 2.36 | 2.20 | 2.52 |
| **60** | 1.80 | 5.08 | 2.20 | 3.80 | 2.60 | 2.04 | 2.28 | 5.40 | 2.52 | 2.04 | 1.00 | 1.56 | 2.68 | 1.96 | 2.84 | 3.08 | 2.04 |

Table E.13. Continued from previous page.

| Sound | Subjects | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** | **35** |
| **61** | 2.52 | 2.76 | 2.12 | 3.96 | 2.84 | 2.04 | 2.20 | 5.40 | 3.64 | 2.20 | 1.00 | 1.48 | 1.88 | 1.96 | 2.92 | 2.44 | 2.92 |
| **62** | 3.00 | 4.76 | 2.60 | 3.64 | 1.64 | 1.80 | 2.28 | 6.12 | 3.40 | 2.28 | 1.00 | 2.04 | 2.68 | 1.24 | 3.40 | 2.60 | 3.32 |
| **63** | 2.04 | 5.24 | 2.04 | 5.96 | 2.60 | 1.96 | 3.56 | 6.28 | 5.08 | 2.60 | 1.00 | 2.04 | 2.76 | 2.68 | 4.36 | 3.08 | 3.08 |
| **64** | 1.64 | 5.64 | 4.04 | 4.68 | 3.24 | 1.88 | 3.32 | 6.20 | 3.40 | 2.28 | 2.60 | 1.96 | 2.60 | 2.28 | 3.00 | 2.68 | 2.12 |
| **65** | 2.04 | 5.40 | 2.92 | 5.40 | 3.00 | 3.32 | 4.68 | 5.24 | 5.08 | 2.60 | 1.00 | 2.84 | 3.88 | 3.00 | 2.76 | 2.84 | 2.68 |
| **66** | 2.36 | 5.72 | 3.88 | 4.92 | 4.60 | 2.28 | 4.60 | 4.44 | 4.52 | 2.44 | 2.36 | 5.08 | 4.76 | 3.08 | 4.60 | 2.92 | 3.64 |
| **67** | 2.20 | 8.20 | 6.52 | 4.52 | 5.80 | 3.08 | 5.24 | 4.92 | 6.84 | 2.84 | 3.08 | 5.24 | 5.32 | 2.68 | 5.00 | 5.72 | 3.88 |
| **68** | 2.76 | 6.28 | 5.00 | 6.36 | 4.84 | 1.40 | 5.56 | 5.80 | 7.24 | 3.40 | 2.44 | 4.04 | 3.88 | 3.24 | 4.68 | 4.84 | 4.92 |
| **69** | 2.20 | 5.64 | 5.56 | 5.16 | 7.40 | 3.48 | 7.72 | 5.96 | 6.28 | 3.64 | 2.52 | 3.64 | 2.92 | 4.04 | 4.68 | 4.12 | 5.16 |
| **70** | 2.20 | 6.04 | 3.48 | 5.88 | 9.00 | 4.52 | 6.52 | 7.00 | 6.52 | 4.04 | 3.16 | 7.24 | 6.36 | 3.88 | 5.56 | 4.12 | 4.84 |
| **71** | 2.60 | 7.48 | 4.36 | 7.64 | 9.00 | 6.84 | 6.12 | 7.16 | 6.84 | 3.96 | 2.52 | 6.68 | 6.52 | 5.00 | 5.48 | 6.60 | 6.76 |
| **72** | 1.88 | 5.08 | 2.60 | 5.56 | 3.96 | 1.96 | 3.32 | 4.76 | 5.00 | 2.36 | 1.88 | 2.28 | 1.96 | 2.44 | 2.68 | 3.80 | 2.84 |
| **73** | 2.20 | 4.84 | 3.16 | 5.24 | 4.36 | 2.04 | 2.44 | 5.72 | 5.00 | 2.60 | 1.00 | 3.72 | 3.80 | 3.48 | 4.68 | 2.76 | 2.76 |
| **74** | 1.72 | 5.56 | 3.16 | 5.32 | 3.08 | 1.48 | 2.60 | 6.04 | 5.00 | 2.20 | 1.00 | 2.44 | 1.00 | 3.16 | 4.68 | 3.08 | 3.96 |
| **75** | 2.44 | 6.68 | 2.04 | 5.56 | 3.24 | 5.08 | 5.32 | 5.72 | 7.08 | 2.52 | 1.80 | 4.44 | 4.20 | 4.44 | 3.88 | 3.56 | 5.08 |
| **76** | 2.68 | 5.00 | 2.04 | 4.20 | 2.60 | 3.40 | 2.60 | 4.84 | 3.00 | 3.40 | 1.00 | 3.32 | 4.28 | 3.72 | 2.84 | 3.48 | 2.68 |
| **77** | 2.44 | 6.92 | 6.28 | 6.92 | 4.20 | 4.28 | 6.76 | 7.40 | 7.32 | 4.04 | 1.56 | 4.12 | 6.04 | 4.60 | 5.40 | 3.80 | 5.64 |
| **78** | 3.80 | 8.44 | 8.52 | 9.00 | 9.00 | 6.44 | 8.84 | 8.04 | 8.04 | 3.72 | 5.00 | 7.88 | 7.72 | 7.48 | 6.52 | 7.16 | 7.48 |
| **79** | 2.76 | 7.64 | 6.44 | 7.64 | 9.00 | 5.32 | 5.72 | 7.08 | 6.60 | 2.84 | 2.28 | 7.24 | 6.52 | 6.12 | 5.88 | 7.64 | 5.64 |
| **80** | 2.36 | 7.80 | 7.00 | 7.00 | 8.92 | 5.00 | 8.12 | 5.56 | 7.80 | 4.28 | 3.00 | 8.12 | 6.52 | 4.76 | 6.20 | 7.88 | 6.60 |

Table E.14. Annoyance ratings in the Purdue test, Part 2, subjects 1-18.

| **Sound** | **Subjects** | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** |
| **1** | 4.60 | 5.16 | 3.48 | 2.76 | 2.04 | 1.48 | 2.52 | 3.40 | 2.36 | 3.32 | 3.00 | 2.52 | 3.40 | 1.40 | 3.40 | 5.08 | 2.20 | 3.24 |
| **2** | 5.00 | 5.08 | 5.08 | 3.08 | 1.96 | 2.76 | 4.36 | 3.40 | 3.56 | 5.56 | 2.68 | 2.60 | 2.52 | 4.20 | 3.40 | 5.80 | 4.20 | 3.88 |
| **3** | 5.32 | 3.32 | 2.12 | 2.52 | 4.60 | 2.04 | 2.44 | 3.40 | 2.76 | 3.72 | 2.76 | 2.44 | 3.40 | 1.32 | 2.76 | 4.60 | 2.36 | 2.76 |
| **4** | 3.56 | 3.48 | 2.36 | 2.28 | 3.24 | 1.40 | 5.80 | 3.40 | 2.52 | 3.80 | 4.20 | 2.36 | 4.92 | 3.24 | 2.36 | 5.32 | 2.28 | 4.52 |
| **5** | 3.96 | 2.12 | 2.28 | 3.48 | 3.48 | 1.88 | 3.32 | 3.40 | 3.80 | 3.64 | 2.68 | 2.44 | 3.40 | 3.72 | 2.52 | 3.96 | 3.48 | 3.72 |
| **6** | 3.48 | 2.28 | 2.04 | 2.04 | 2.04 | 1.88 | 4.20 | 3.40 | 3.24 | 4.12 | 2.68 | 2.12 | 2.36 | 1.56 | 2.36 | 3.40 | 2.60 | 3.32 |
| **7** | 5.00 | 3.80 | 4.36 | 2.44 | 3.16 | 5.00 | 2.36 | 3.40 | 3.64 | 4.76 | 3.32 | 3.08 | 2.76 | 4.04 | 3.00 | 3.96 | 5.00 | 4.68 |
| **8** | 6.20 | 5.64 | 4.04 | 2.60 | 5.88 | 3.88 | 4.52 | 5.00 | 4.28 | 5.16 | 3.88 | 3.48 | 6.60 | 6.20 | 2.44 | 5.80 | 3.72 | 5.16 |
| **9** | 5.48 | 3.72 | 2.84 | 2.68 | 5.48 | 3.56 | 6.84 | 3.40 | 4.84 | 5.88 | 4.28 | 2.84 | 2.76 | 2.12 | 3.48 | 4.84 | 5.16 | 4.44 |
| **10** | 6.60 | 3.48 | 5.00 | 3.64 | 5.32 | 2.12 | 6.60 | 3.40 | 2.12 | 4.52 | 4.20 | 2.92 | 3.00 | 3.88 | 2.84 | 4.60 | 3.48 | 2.92 |
| **11** | 5.00 | 4.12 | 3.72 | 2.04 | 5.96 | 2.44 | 3.96 | 3.40 | 4.12 | 3.80 | 2.92 | 2.68 | 6.60 | 4.92 | 3.08 | 5.64 | 3.32 | 3.72 |
| **12** | 5.00 | 4.60 | 3.32 | 4.76 | 4.20 | 3.48 | 5.64 | 5.00 | 4.76 | 5.88 | 2.52 | 2.60 | 6.28 | 5.88 | 2.84 | 4.28 | 2.36 | 5.24 |
| **13** | 4.28 | 2.92 | 3.32 | 4.68 | 3.24 | 5.40 | 3.96 | 3.40 | 3.96 | 4.76 | 5.32 | 2.76 | 3.00 | 5.32 | 3.16 | 3.48 | 4.44 | 3.00 |
| **14** | 5.32 | 3.96 | 4.68 | 4.76 | 5.48 | 6.20 | 3.80 | 5.00 | 3.32 | 5.80 | 3.40 | 3.08 | 4.60 | 5.96 | 3.00 | 5.24 | 3.96 | 2.84 |
| **15** | 6.36 | 3.32 | 5.16 | 4.12 | 5.24 | 5.24 | 6.12 | 5.00 | 3.40 | 5.80 | 4.84 | 3.32 | 6.44 | 5.96 | 2.36 | 5.08 | 4.84 | 4.20 |
| **16** | 7.48 | 5.00 | 3.56 | 6.52 | 6.52 | 7.16 | 5.40 | 5.00 | 4.68 | 6.04 | 7.56 | 3.96 | 2.52 | 3.96 | 3.80 | 4.60 | 5.24 | 4.28 |
| **17** | 5.00 | 3.56 | 4.36 | 4.92 | 3.56 | 6.36 | 6.28 | 3.40 | 4.92 | 6.84 | 7.16 | 3.48 | 6.60 | 5.96 | 3.00 | 6.04 | 6.28 | 4.28 |
| **18** | 5.00 | 3.40 | 4.92 | 5.16 | 5.08 | 6.52 | 5.00 | 5.00 | 4.20 | 4.44 | 2.76 | 2.84 | 3.00 | 5.32 | 3.40 | 6.20 | 6.04 | 3.08 |
| **19** | 6.12 | 3.32 | 5.40 | 4.36 | 3.48 | 7.32 | 2.60 | 5.00 | 4.44 | 6.28 | 7.08 | 3.48 | 6.60 | 5.64 | 3.32 | 4.68 | 7.64 | 4.92 |
| **20** | 5.96 | 5.64 | 5.64 | 5.72 | 6.76 | 7.80 | 6.60 | 5.00 | 4.68 | 6.28 | 7.72 | 3.56 | 6.68 | 6.84 | 3.24 | 6.52 | 5.72 | 4.92 |

Table E.14. Continued from previous page.

| **Sound** | **Subjects** | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** |
| **21** | 5.00 | 3.08 | 4.28 | 4.12 | 3.40 | 5.96 | 3.48 | 5.00 | 3.48 | 5.80 | 3.88 | 3.16 | 4.92 | 4.52 | 2.44 | 4.12 | 3.64 | 3.32 |
| **22** | 6.52 | 3.48 | 4.28 | 6.36 | 6.84 | 7.24 | 5.24 | 5.00 | 5.08 | 5.32 | 7.88 | 3.24 | 7.32 | 7.56 | 4.28 | 7.32 | 6.12 | 4.84 |
| **23** | 3.88 | 3.40 | 2.52 | 3.96 | 3.16 | 2.36 | 4.20 | 3.40 | 3.24 | 3.56 | 5.48 | 2.68 | 6.60 | 2.92 | 3.56 | 4.76 | 2.84 | 3.08 |
| **24** | 5.00 | 3.24 | 3.88 | 3.00 | 3.48 | 4.36 | 2.28 | 3.40 | 2.52 | 4.20 | 5.48 | 2.52 | 2.20 | 4.36 | 3.96 | 4.84 | 3.72 | 4.04 |
| **25** | 5.08 | 3.08 | 4.12 | 5.72 | 4.04 | 5.16 | 5.00 | 5.00 | 3.64 | 5.40 | 2.92 | 2.44 | 7.00 | 4.68 | 3.48 | 4.84 | 3.64 | 3.80 |
| **26** | 6.04 | 3.32 | 3.56 | 4.28 | 5.72 | 2.44 | 2.60 | 3.40 | 4.76 | 5.00 | 2.52 | 2.84 | 2.12 | 5.32 | 3.16 | 7.00 | 1.88 | 4.12 |
| **27** | 5.16 | 6.60 | 5.40 | 3.32 | 5.32 | 3.88 | 5.80 | 5.00 | 4.28 | 6.60 | 4.36 | 3.16 | 5.00 | 5.64 | 3.80 | 6.04 | 2.68 | 5.56 |
| **28** | 6.44 | 4.20 | 6.04 | 4.68 | 7.64 | 3.64 | 9.00 | 6.60 | 4.68 | 7.08 | 5.64 | 3.32 | 6.52 | 5.80 | 3.00 | 5.32 | 5.72 | 5.48 |
| **29** | 7.32 | 6.44 | 6.04 | 5.32 | 7.64 | 6.76 | 9.00 | 6.60 | 5.00 | 9.00 | 7.80 | 3.80 | 6.60 | 8.68 | 4.36 | 7.48 | 7.00 | 6.36 |
| **30** | 3.56 | 3.08 | 4.28 | 2.44 | 2.60 | 2.12 | 3.40 | 1.80 | 3.16 | 4.04 | 3.32 | 2.44 | 2.84 | 4.36 | 2.12 | 4.52 | 4.20 | 2.68 |
| **31** | 3.88 | 3.16 | 3.48 | 2.12 | 1.88 | 2.04 | 1.80 | 3.40 | 2.52 | 4.20 | 3.32 | 2.52 | 3.88 | 2.60 | 3.16 | 4.12 | 2.36 | 2.28 |
| **32** | 6.20 | 4.36 | 5.32 | 4.36 | 4.76 | 4.12 | 7.40 | 5.00 | 3.80 | 6.52 | 3.88 | 3.40 | 5.32 | 5.40 | 3.16 | 5.64 | 5.08 | 5.40 |
| **33** | 4.20 | 3.80 | 3.32 | 2.52 | 5.56 | 1.96 | 4.20 | 3.40 | 3.96 | 5.00 | 4.76 | 2.52 | 5.08 | 5.96 | 3.24 | 5.00 | 3.72 | 4.92 |
| **34** | 5.00 | 5.00 | 2.68 | 3.88 | 5.16 | 3.00 | 4.20 | 5.00 | 3.88 | 5.72 | 4.60 | 3.32 | 6.52 | 5.64 | 3.64 | 5.24 | 3.72 | 3.88 |
| **35** | 5.00 | 6.52 | 5.40 | 4.92 | 5.80 | 7.64 | 7.40 | 5.00 | 4.92 | 5.96 | 6.44 | 3.56 | 6.28 | 7.40 | 3.48 | 5.88 | 5.64 | 5.32 |
| **36** | 6.52 | 4.68 | 5.40 | 5.88 | 6.60 | 6.28 | 6.68 | 5.00 | 4.76 | 5.24 | 6.52 | 3.96 | 6.68 | 6.92 | 3.32 | 5.48 | 6.28 | 6.12 |
| **37** | 5.48 | 3.88 | 3.96 | 3.40 | 5.00 | 5.16 | 5.64 | 3.40 | 4.44 | 5.48 | 5.56 | 2.76 | 6.60 | 4.28 | 3.56 | 4.84 | 3.96 | 4.28 |
| **38** | 6.28 | 3.16 | 4.12 | 5.16 | 5.56 | 5.00 | 3.00 | 5.00 | 4.60 | 6.04 | 5.56 | 3.08 | 3.00 | 4.76 | 3.16 | 3.00 | 5.08 | 3.88 |
| **39** | 6.52 | 3.40 | 6.20 | 4.36 | 5.16 | 6.84 | 7.40 | 5.00 | 4.28 | 6.92 | 5.72 | 3.24 | 6.68 | 5.40 | 2.76 | 6.76 | 5.56 | 5.16 |
| **40** | 6.84 | 4.76 | 6.44 | 6.52 | 6.60 | 8.04 | 8.36 | 5.00 | 5.00 | 9.00 | 6.36 | 4.28 | 8.60 | 6.76 | 4.36 | 5.96 | 7.64 | 4.52 |

Table E.14. Continued from previous page.

| **Sound** | **Subjects** | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** |
| **41** | 5.16 | 2.12 | 4.92 | 4.12 | 3.80 | 2.44 | 4.20 | 3.40 | 3.96 | 4.04 | 6.44 | 2.52 | 3.32 | 4.84 | 3.80 | 5.96 | 2.20 | 3.64 |
| **42** | 6.20 | 4.28 | 5.32 | 2.76 | 5.32 | 6.68 | 5.56 | 5.00 | 4.36 | 6.20 | 3.32 | 2.84 | 6.60 | 4.76 | 3.40 | 5.32 | 5.24 | 4.12 |
| **43** | 5.96 | 5.32 | 5.88 | 5.16 | 4.04 | 7.24 | 7.08 | 5.00 | 4.12 | 6.20 | 4.84 | 3.08 | 7.08 | 6.28 | 4.52 | 4.60 | 5.08 | 5.32 |
| **44** | 4.60 | 2.36 | 2.04 | 1.96 | 2.04 | 3.64 | 1.80 | 3.40 | 3.08 | 3.64 | 3.00 | 2.20 | 2.84 | 1.40 | 2.12 | 4.68 | 2.04 | 2.68 |
| **45** | 5.24 | 2.12 | 2.20 | 2.76 | 3.40 | 2.44 | 3.80 | 3.40 | 2.52 | 3.88 | 3.80 | 2.36 | 3.16 | 2.76 | 2.36 | 5.00 | 1.88 | 3.00 |
| **46** | 5.08 | 2.76 | 3.64 | 3.08 | 4.12 | 5.00 | 5.24 | 3.40 | 3.72 | 3.96 | 4.68 | 2.76 | 8.04 | 3.80 | 2.84 | 5.00 | 6.44 | 4.36 |
| **47** | 5.16 | 2.44 | 5.72 | 3.72 | 6.04 | 6.52 | 5.24 | 3.40 | 3.72 | 3.72 | 3.88 | 2.76 | 6.92 | 2.20 | 3.24 | 3.88 | 4.92 | 3.08 |
| **48** | 5.64 | 2.84 | 3.88 | 3.24 | 5.32 | 5.32 | 5.72 | 3.40 | 3.96 | 3.96 | 5.96 | 3.32 | 5.08 | 4.36 | 2.68 | 4.92 | 5.24 | 4.84 |
| **49** | 6.52 | 2.36 | 3.64 | 5.16 | 5.96 | 6.44 | 6.60 | 5.00 | 4.84 | 5.16 | 5.96 | 3.64 | 7.80 | 5.00 | 3.00 | 5.40 | 6.44 | 5.00 |
| **50** | 5.08 | 5.32 | 4.92 | 4.60 | 6.68 | 6.52 | 4.60 | 5.00 | 4.28 | 5.72 | 5.16 | 3.00 | 7.32 | 4.76 | 2.68 | 6.04 | 5.80 | 5.40 |
| **51** | 3.64 | 2.04 | 2.04 | 2.04 | 3.00 | 2.20 | 1.00 | 3.40 | 3.80 | 3.40 | 2.68 | 2.36 | 3.80 | 2.36 | 2.28 | 5.40 | 2.84 | 2.28 |
| **52** | 5.96 | 2.92 | 2.92 | 3.80 | 3.64 | 3.56 | 3.16 | 3.40 | 3.16 | 3.80 | 4.52 | 2.44 | 2.28 | 3.64 | 3.32 | 5.96 | 2.28 | 2.68 |
| **53** | 5.00 | 3.48 | 3.16 | 3.32 | 2.68 | 5.32 | 3.40 | 3.40 | 2.44 | 5.08 | 4.36 | 2.60 | 3.56 | 4.60 | 2.36 | 5.00 | 2.20 | 3.00 |
| **54** | 3.40 | 2.28 | 2.04 | 3.48 | 5.24 | 1.72 | 1.00 | 3.40 | 2.20 | 3.00 | 3.00 | 2.36 | 1.80 | 3.56 | 2.12 | 3.96 | 2.12 | 1.96 |
| **55** | 3.48 | 3.48 | 4.52 | 2.20 | 3.08 | 1.88 | 1.00 | 3.40 | 2.84 | 3.56 | 4.76 | 2.36 | 2.36 | 3.72 | 1.56 | 6.28 | 2.84 | 4.12 |
| **56** | 3.72 | 5.00 | 3.64 | 2.68 | 2.36 | 1.32 | 2.60 | 3.40 | 2.12 | 2.84 | 3.24 | 2.44 | 2.20 | 4.68 | 2.44 | 5.88 | 2.12 | 2.76 |
| **57** | 3.56 | 2.04 | 2.04 | 3.80 | 2.04 | 1.00 | 3.56 | 1.80 | 3.24 | 3.40 | 2.52 | 2.28 | 2.28 | 1.08 | 1.80 | 5.24 | 1.88 | 2.04 |
| **58** | 3.56 | 2.52 | 2.28 | 2.12 | 3.48 | 1.88 | 2.52 | 3.40 | 2.20 | 3.64 | 3.00 | 2.52 | 5.32 | 2.92 | 3.08 | 3.64 | 3.48 | 2.20 |
| **59** | 4.12 | 5.56 | 3.00 | 2.76 | 3.24 | 1.80 | 2.60 | 3.40 | 4.20 | 3.48 | 3.32 | 2.36 | 6.52 | 3.72 | 2.36 | 3.96 | 2.44 | 3.32 |
| **60** | 5.00 | 3.08 | 3.24 | 2.28 | 2.36 | 3.16 | 2.60 | 3.40 | 4.04 | 4.20 | 2.68 | 2.60 | 2.28 | 3.88 | 2.60 | 3.56 | 2.28 | 2.84 |

Table E.14. Continued from previous page.

| **Sound** | **Subjects** | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** |
| **61** | 3.96 | 2.04 | 4.28 | 2.52 | 3.08 | 2.04 | 1.00 | 3.40 | 4.04 | 3.80 | 4.28 | 2.52 | 2.28 | 3.88 | 3.16 | 3.80 | 2.84 | 2.36 |
| **62** | 6.52 | 2.12 | 3.32 | 2.28 | 5.08 | 3.48 | 3.80 | 3.40 | 2.36 | 4.44 | 3.08 | 2.68 | 7.32 | 5.56 | 3.40 | 6.04 | 2.68 | 4.92 |
| **63** | 6.52 | 6.52 | 5.32 | 5.24 | 4.76 | 5.64 | 4.36 | 5.00 | 4.68 | 5.48 | 4.60 | 3.24 | 4.92 | 5.96 | 4.44 | 5.24 | 4.60 | 5.32 |
| **64** | 5.80 | 2.60 | 4.68 | 4.12 | 4.44 | 4.20 | 4.20 | 5.00 | 4.12 | 5.00 | 6.44 | 3.00 | 2.28 | 4.28 | 3.16 | 4.60 | 4.52 | 4.36 |
| **65** | 5.64 | 3.96 | 4.84 | 4.20 | 4.28 | 3.72 | 3.96 | 5.00 | 4.04 | 5.56 | 5.88 | 3.08 | 6.44 | 5.40 | 2.36 | 5.16 | 5.64 | 2.60 |
| **66** | 6.12 | 3.72 | 6.20 | 6.52 | 5.00 | 6.44 | 6.60 | 5.00 | 4.44 | 5.32 | 6.44 | 3.80 | 2.12 | 6.20 | 3.24 | 4.52 | 5.40 | 5.00 |
| **67** | 6.84 | 5.24 | 4.36 | 6.36 | 6.44 | 7.64 | 5.40 | 5.00 | 5.00 | 6.52 | 7.56 | 3.00 | 8.04 | 7.80 | 4.04 | 6.60 | 5.00 | 5.32 |
| **68** | 5.40 | 2.92 | 2.28 | 2.36 | 3.56 | 2.36 | 3.64 | 3.40 | 2.12 | 4.28 | 3.56 | 2.60 | 2.76 | 3.08 | 3.08 | 4.12 | 2.12 | 2.20 |
| **69** | 5.56 | 3.88 | 3.72 | 3.24 | 3.64 | 4.76 | 4.04 | 3.40 | 2.20 | 4.36 | 5.32 | 2.44 | 3.88 | 4.60 | 2.68 | 4.44 | 2.20 | 4.12 |
| **70** | 5.96 | 3.40 | 2.36 | 5.00 | 4.04 | 4.44 | 3.40 | 3.40 | 3.72 | 4.92 | 6.28 | 2.52 | 2.44 | 4.44 | 3.48 | 5.32 | 4.44 | 4.12 |
| **71** | 5.64 | 2.52 | 3.40 | 2.84 | 5.16 | 2.68 | 2.92 | 5.00 | 2.60 | 5.40 | 3.16 | 2.52 | 7.32 | 1.80 | 2.52 | 5.48 | 5.08 | 5.40 |
| **72** | 5.00 | 6.12 | 2.60 | 1.24 | 2.04 | 1.88 | 3.88 | 3.40 | 2.36 | 3.64 | 2.60 | 2.60 | 2.52 | 3.80 | 2.28 | 5.24 | 2.12 | 3.24 |
| **73** | 5.40 | 3.00 | 4.52 | 3.40 | 5.72 | 2.52 | 5.80 | 3.40 | 5.00 | 5.72 | 3.80 | 3.80 | 6.60 | 6.36 | 3.40 | 6.36 | 6.28 | 5.32 |
| **74** | 6.76 | 5.00 | 3.32 | 3.96 | 6.60 | 6.44 | 5.40 | 3.40 | 4.84 | 3.96 | 7.32 | 3.16 | 7.00 | 3.16 | 2.68 | 5.56 | 5.56 | 4.92 |
| **75** | 6.92 | 6.76 | 7.00 | 7.88 | 7.96 | 8.44 | 9.00 | 6.60 | 5.24 | 8.92 | 7.72 | 4.28 | 7.48 | 8.68 | 4.20 | 7.56 | 6.60 | 7.56 |
| **76** | 4.04 | 2.04 | 5.40 | 1.80 | 2.68 | 2.28 | 7.16 | 3.40 | 3.64 | 3.48 | 4.12 | 2.52 | 1.56 | 4.12 | 2.92 | 6.28 | 3.56 | 4.84 |
| **77** | 6.52 | 4.84 | 4.28 | 6.20 | 6.28 | 6.84 | 6.84 | 5.00 | 5.08 | 6.84 | 7.80 | 3.56 | 6.60 | 5.00 | 2.44 | 5.96 | 6.60 | 5.72 |
| **78** | 7.08 | 3.48 | 5.00 | 4.28 | 7.48 | 3.80 | 6.84 | 3.40 | 5.00 | 7.16 | 6.52 | 3.48 | 8.60 | 3.96 | 3.16 | 5.80 | 6.60 | 5.08 |
| **79** | 7.16 | 6.60 | 6.44 | 6.36 | 7.40 | 7.64 | 9.00 | 5.00 | 5.08 | 8.04 | 7.48 | 3.80 | 7.80 | 7.48 | 4.36 | 6.76 | 6.20 | 6.12 |
| **80** | 7.48 | 6.84 | 5.00 | 6.12 | 7.64 | 7.80 | 6.76 | 5.00 | 5.00 | 7.32 | 7.16 | 4.60 | 7.00 | 7.08 | 4.12 | 5.56 | 6.60 | 5.80 |

Table E.15. Annoyance ratings in the Purdue test, Part 2, subjects 19-35.

| **Order** | **Subjects** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **played** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** | **35** |
| **1** | 2.60 | 3.32 | 2.52 | 4.76 | 4.20 | 1.64 | 3.40 | 3.48 | 5.24 | 2.68 | 3.00 | 2.36 | 3.96 | 5.00 | 3.64 | 3.32 | 5.24 |
| **2** | 3.24 | 4.68 | 6.04 | 4.76 | 4.60 | 1.80 | 4.84 | 5.56 | 3.96 | 3.00 | 3.32 | 3.40 | 4.60 | 2.44 | 3.56 | 3.88 | 4.44 |
| **3** | 2.92 | 4.84 | 4.52 | 5.16 | 3.56 | 1.64 | 3.08 | 4.12 | 5.72 | 2.20 | 1.00 | 2.28 | 2.60 | 3.24 | 3.48 | 3.72 | 4.20 |
| **4** | 1.80 | 3.64 | 6.12 | 5.08 | 3.08 | 2.04 | 3.24 | 4.28 | 2.52 | 2.20 | 1.00 | 3.88 | 2.52 | 2.36 | 3.64 | 3.56 | 3.00 |
| **5** | 2.12 | 2.68 | 6.84 | 6.36 | 2.60 | 1.96 | 2.36 | 4.68 | 6.60 | 2.20 | 1.00 | 3.88 | 2.68 | 2.20 | 3.00 | 3.00 | 4.04 |
| **6** | 3.88 | 5.72 | 2.28 | 5.96 | 3.32 | 1.64 | 1.72 | 4.04 | 3.16 | 2.12 | 1.00 | 3.72 | 2.92 | 4.20 | 3.40 | 2.44 | 3.16 |
| **7** | 2.12 | 4.68 | 4.60 | 5.96 | 3.96 | 3.16 | 4.52 | 6.12 | 6.04 | 3.08 | 3.40 | 4.36 | 5.00 | 5.00 | 3.96 | 3.08 | 5.56 |
| **8** | 2.68 | 6.52 | 7.96 | 5.88 | 6.44 | 3.08 | 6.20 | 5.88 | 6.84 | 4.12 | 2.92 | 6.76 | 5.00 | 6.44 | 5.08 | 4.28 | 6.04 |
| **9** | 2.60 | 7.24 | 6.12 | 6.68 | 5.56 | 3.16 | 3.48 | 5.48 | 7.24 | 2.84 | 3.32 | 5.24 | 4.28 | 5.16 | 4.04 | 3.72 | 5.96 |
| **10** | 3.08 | 6.92 | 6.36 | 6.92 | 2.52 | 1.96 | 5.00 | 6.12 | 6.84 | 2.52 | 3.48 | 3.56 | 4.20 | 5.08 | 4.76 | 4.84 | 5.88 |
| **11** | 2.76 | 7.24 | 6.36 | 6.04 | 4.60 | 3.00 | 5.40 | 6.52 | 6.92 | 2.92 | 2.60 | 5.08 | 3.40 | 3.96 | 4.92 | 4.20 | 6.76 |
| **12** | 4.36 | 7.72 | 6.20 | 7.00 | 3.96 | 4.44 | 5.00 | 5.72 | 6.52 | 3.64 | 2.36 | 3.16 | 4.60 | 6.36 | 5.80 | 4.44 | 4.60 |
| **13** | 1.80 | 6.92 | 6.20 | 5.40 | 3.16 | 1.96 | 5.80 | 6.12 | 5.32 | 3.32 | 2.28 | 2.92 | 4.76 | 5.24 | 4.68 | 4.76 | 6.84 |
| **14** | 4.12 | 6.68 | 5.48 | 5.56 | 9.00 | 3.24 | 5.40 | 5.64 | 7.56 | 3.24 | 2.68 | 5.24 | 3.88 | 5.88 | 5.32 | 4.68 | 4.92 |
| **15** | 3.56 | 5.32 | 6.44 | 5.48 | 3.96 | 4.60 | 3.80 | 6.84 | 6.76 | 3.48 | 2.76 | 5.40 | 4.52 | 5.00 | 5.64 | 4.92 | 7.16 |
| **16** | 2.84 | 7.88 | 5.72 | 6.12 | 7.64 | 4.92 | 6.28 | 6.28 | 8.04 | 3.08 | 3.48 | 5.48 | 4.60 | 4.92 | 5.56 | 6.36 | 4.12 |
| **17** | 5.08 | 5.80 | 5.24 | 7.32 | 7.00 | 4.20 | 6.52 | 5.72 | 7.88 | 4.04 | 3.16 | 4.28 | 4.76 | 5.48 | 5.24 | 7.64 | 6.92 |
| **18** | 4.36 | 5.56 | 5.40 | 5.00 | 7.16 | 1.64 | 5.00 | 4.60 | 6.04 | 2.76 | 2.44 | 3.56 | 4.36 | 5.32 | 5.24 | 6.36 | 5.16 |
| **19** | 3.24 | 5.56 | 6.20 | 6.28 | 8.76 | 3.16 | 5.16 | 6.76 | 6.60 | 4.28 | 3.96 | 6.28 | 5.80 | 6.12 | 5.56 | 6.12 | 6.76 |
| **20** | 3.72 | 7.16 | 6.84 | 6.92 | 7.88 | 3.88 | 6.20 | 7.00 | 8.04 | 4.12 | 3.64 | 4.76 | 5.48 | 6.60 | 6.20 | 6.52 | 6.44 |

Table E.15. Continued from previous page.

| **Order** | **Subjects** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **played** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** | **35** |
| **21** | 3.56 | 7.24 | 4.84 | 5.16 | 5.32 | 1.88 | 5.88 | 5.32 | 6.20 | 2.84 | 3.40 | 3.40 | 5.16 | 3.48 | 3.56 | 3.48 | 5.80 |
| **22** | 3.24 | 7.80 | 6.20 | 7.08 | 5.56 | 3.56 | 6.20 | 7.08 | 6.52 | 4.44 | 3.40 | 5.40 | 4.60 | 5.72 | 6.04 | 6.68 | 5.88 |
| **23** | 3.56 | 5.80 | 3.00 | 6.28 | 2.44 | 1.72 | 3.96 | 5.96 | 4.92 | 2.44 | 2.20 | 5.24 | 2.68 | 2.76 | 4.44 | 3.48 | 4.60 |
| **24** | 2.44 | 6.92 | 5.24 | 4.92 | 3.00 | 1.48 | 3.80 | 5.24 | 5.56 | 3.08 | 3.40 | 4.60 | 4.68 | 3.16 | 4.20 | 5.88 | 4.04 |
| **25** | 2.92 | 6.04 | 7.40 | 6.20 | 5.08 | 3.00 | 4.68 | 5.88 | 6.36 | 3.40 | 3.32 | 3.80 | 3.64 | 6.44 | 4.84 | 4.36 | 6.12 |
| **26** | 2.92 | 7.08 | 5.16 | 5.16 | 2.60 | 1.64 | 3.48 | 6.28 | 4.52 | 2.20 | 3.16 | 6.84 | 4.36 | 5.24 | 4.68 | 3.24 | 4.36 |
| **27** | 3.24 | 8.20 | 7.80 | 6.60 | 7.16 | 3.24 | 5.64 | 6.28 | 6.68 | 2.68 | 3.56 | 7.80 | 4.36 | 2.20 | 5.16 | 3.24 | 4.76 |
| **28** | 3.88 | 6.04 | 7.40 | 7.56 | 4.84 | 4.36 | 6.52 | 6.36 | 7.00 | 3.64 | 3.72 | 6.84 | 5.32 | 4.52 | 5.96 | 4.04 | 7.56 |
| **29** | 4.12 | 7.64 | 7.88 | 8.04 | 7.24 | 5.00 | 6.76 | 5.96 | 8.04 | 4.04 | 4.36 | 8.28 | 6.76 | 6.52 | 6.44 | 6.60 | 7.72 |
| **30** | 3.88 | 4.68 | 3.16 | 5.80 | 2.28 | 2.20 | 3.56 | 4.84 | 2.84 | 2.44 | 2.84 | 2.36 | 2.36 | 1.88 | 4.92 | 3.72 | 4.12 |
| **31** | 2.52 | 7.24 | 4.44 | 4.68 | 2.60 | 2.28 | 3.40 | 5.08 | 4.04 | 2.68 | 1.32 | 3.72 | 4.04 | 2.84 | 3.56 | 3.88 | 3.88 |
| **32** | 2.44 | 5.32 | 7.00 | 6.52 | 6.76 | 3.40 | 5.16 | 5.64 | 6.04 | 3.48 | 3.40 | 3.16 | 4.20 | 5.40 | 5.16 | 5.24 | 5.72 |
| **33** | 2.44 | 6.20 | 7.80 | 5.16 | 3.00 | 2.68 | 4.52 | 4.68 | 4.12 | 2.20 | 1.64 | 4.28 | 4.04 | 2.20 | 3.80 | 2.52 | 2.92 |
| **34** | 3.32 | 5.88 | 8.04 | 6.68 | 3.08 | 2.84 | 6.12 | 4.76 | 4.68 | 2.60 | 2.68 | 4.04 | 4.52 | 3.88 | 3.56 | 4.12 | 3.88 |
| **35** | 3.72 | 7.56 | 7.48 | 6.04 | 2.36 | 4.84 | 6.20 | 6.52 | 7.72 | 3.16 | 3.48 | 5.96 | 5.16 | 5.40 | 5.00 | 3.72 | 6.92 |
| **36** | 3.24 | 7.56 | 7.88 | 6.52 | 5.16 | 4.68 | 6.76 | 6.60 | 7.80 | 3.40 | 3.00 | 5.64 | 5.96 | 6.84 | 5.80 | 4.76 | 6.76 |
| **37** | 2.52 | 6.36 | 2.84 | 6.28 | 5.40 | 4.20 | 5.40 | 5.80 | 5.16 | 2.92 | 3.16 | 5.96 | 4.52 | 3.72 | 4.52 | 5.96 | 6.04 |
| **38** | 3.80 | 5.96 | 6.04 | 6.68 | 5.24 | 2.68 | 5.32 | 5.96 | 6.60 | 3.32 | 3.72 | 4.20 | 4.36 | 3.64 | 4.44 | 4.60 | 5.24 |
| **39** | 3.88 | 7.80 | 6.84 | 7.00 | 9.00 | 5.40 | 5.48 | 5.56 | 7.24 | 3.96 | 3.24 | 4.76 | 6.36 | 5.56 | 5.72 | 7.56 | 7.40 |
| **40** | 5.08 | 7.72 | 7.32 | 7.00 | 9.00 | 5.48 | 7.00 | 6.44 | 7.24 | 4.44 | 3.88 | 6.28 | 6.20 | 6.44 | 5.40 | 8.04 | 6.92 |

Table E.15. Continued from previous page.

| Order | Subjects | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **played** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** | **35** |
| **41** | 3.24 | 7.08 | 6.20 | 4.84 | 3.80 | 4.36 | 3.64 | 5.80 | 5.32 | 2.68 | 3.16 | 4.76 | 5.16 | 5.32 | 4.68 | 3.72 | 4.36 |
| **42** | 2.76 | 5.80 | 7.40 | 6.28 | 3.00 | 5.16 | 5.88 | 5.64 | 5.88 | 3.40 | 3.40 | 5.00 | 5.00 | 4.44 | 5.24 | 5.88 | 5.32 |
| **43** | 3.08 | 6.36 | 5.00 | 7.16 | 4.92 | 4.12 | 6.76 | 6.28 | 6.52 | 3.08 | 3.16 | 3.16 | 5.16 | 5.48 | 4.28 | 3.40 | 5.64 |
| **44** | 3.00 | 4.20 | 3.64 | 3.88 | 3.48 | 2.36 | 3.56 | 4.84 | 5.80 | 2.20 | 1.00 | 4.84 | 3.56 | 3.24 | 3.56 | 3.56 | 3.00 |
| **45** | 4.36 | 2.68 | 3.00 | 4.68 | 2.44 | 1.80 | 3.48 | 4.76 | 5.48 | 2.52 | 1.88 | 2.60 | 2.60 | 3.88 | 2.44 | 3.08 | 4.52 |
| **46** | 2.84 | 6.92 | 5.00 | 5.32 | 6.12 | 3.48 | 3.56 | 4.52 | 7.00 | 3.32 | 2.76 | 6.28 | 3.64 | 3.00 | 3.88 | 6.20 | 4.68 |
| **47** | 3.08 | 4.20 | 5.72 | 6.36 | 7.24 | 1.88 | 4.44 | 5.88 | 4.20 | 3.16 | 2.68 | 3.40 | 4.68 | 3.72 | 3.56 | 4.92 | 3.88 |
| **48** | 2.84 | 6.28 | 5.24 | 6.04 | 8.36 | 1.48 | 6.12 | 6.28 | 8.12 | 2.92 | 2.76 | 5.88 | 4.04 | 3.88 | 5.16 | 4.84 | 4.44 |
| **49** | 3.72 | 7.24 | 6.44 | 6.28 | 6.28 | 3.56 | 5.56 | 6.84 | 7.08 | 3.88 | 3.88 | 6.44 | 4.76 | 6.28 | 5.64 | 6.04 | 7.56 |
| **50** | 4.04 | 7.32 | 6.60 | 6.68 | 7.80 | 3.96 | 5.88 | 6.84 | 5.88 | 3.40 | 2.76 | 3.88 | 5.64 | 4.36 | 5.24 | 6.28 | 5.32 |
| **51** | 2.68 | 5.40 | 3.96 | 4.68 | 2.52 | 1.96 | 3.24 | 4.68 | 3.56 | 2.12 | 1.64 | 2.52 | 2.76 | 2.60 | 2.68 | 3.80 | 4.68 |
| **52** | 3.56 | 7.32 | 2.28 | 5.64 | 2.52 | 2.68 | 3.72 | 4.84 | 4.36 | 2.20 | 2.12 | 2.12 | 3.80 | 3.24 | 2.92 | 4.04 | 4.12 |
| **53** | 2.68 | 5.56 | 2.20 | 5.40 | 4.76 | 2.60 | 4.84 | 5.64 | 5.56 | 2.28 | 3.40 | 3.40 | 4.04 | 4.68 | 4.68 | 3.96 | 5.48 |
| **54** | 1.88 | 5.48 | 3.72 | 4.68 | 1.64 | 1.80 | 1.24 | 3.88 | 2.68 | 2.12 | 1.00 | 2.92 | 2.36 | 1.88 | 2.44 | 2.52 | 2.36 |
| **55** | 3.40 | 5.48 | 5.24 | 5.24 | 2.28 | 1.88 | 2.04 | 4.68 | 2.76 | 2.04 | 1.00 | 2.28 | 2.36 | 2.44 | 2.92 | 2.36 | 2.28 |
| **56** | 2.60 | 6.60 | 6.20 | 5.32 | 2.36 | 2.20 | 3.16 | 5.56 | 5.08 | 2.04 | 1.80 | 4.20 | 4.04 | 3.40 | 3.32 | 4.60 | 2.76 |
| **57** | 3.24 | 4.52 | 2.20 | 3.80 | 3.96 | 1.80 | 1.40 | 4.68 | 2.44 | 2.12 | 1.00 | 2.12 | 3.32 | 2.60 | 2.44 | 1.00 | 2.52 |
| **58** | 4.20 | 5.40 | 3.56 | 4.36 | 3.16 | 1.64 | 2.52 | 4.60 | 3.64 | 2.36 | 1.00 | 2.68 | 2.60 | 2.04 | 2.76 | 2.84 | 2.60 |
| **59** | 2.60 | 5.40 | 2.28 | 5.72 | 3.80 | 1.80 | 1.40 | 5.00 | 3.40 | 2.12 | 1.00 | 3.40 | 2.28 | 2.36 | 3.00 | 3.72 | 2.68 |
| **60** | 3.32 | 4.84 | 5.16 | 6.20 | 2.04 | 2.12 | 3.16 | 5.80 | 3.56 | 2.84 | 1.64 | 3.72 | 3.96 | 3.32 | 3.32 | 3.80 | 2.68 |

Table E.15. Continued from previous page.

| **Order** | **Subjects** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **played** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** | **35** |
| **61** | 3.80 | 5.96 | 6.84 | 4.36 | 1.00 | 1.88 | 3.08 | 4.44 | 5.16 | 2.12 | 1.00 | 2.04 | 2.52 | 1.96 | 3.32 | 4.04 | 3.80 |
| **62** | 3.32 | 6.52 | 5.24 | 5.80 | 2.60 | 1.64 | 5.00 | 5.96 | 5.16 | 2.60 | 3.80 | 3.64 | 4.36 | 3.56 | 3.72 | 3.24 | 4.20 |
| **63** | 3.24 | 7.00 | 6.04 | 5.32 | 4.44 | 5.00 | 4.12 | 5.96 | 7.16 | 3.00 | 3.64 | 3.80 | 4.76 | 3.24 | 4.52 | 3.32 | 5.64 |
| **64** | 2.20 | 5.80 | 5.40 | 5.80 | 3.48 | 2.36 | 5.32 | 4.68 | 7.40 | 2.36 | 3.48 | 5.40 | 4.60 | 5.56 | 5.40 | 4.68 | 5.72 |
| **65** | 3.24 | 5.96 | 5.24 | 5.16 | 8.04 | 4.84 | 5.96 | 5.48 | 6.84 | 3.24 | 3.56 | 6.04 | 4.44 | 5.16 | 5.16 | 5.16 | 6.04 |
| **66** | 3.56 | 5.80 | 4.04 | 6.84 | 6.44 | 3.56 | 5.40 | 6.44 | 7.40 | 4.04 | 3.32 | 6.20 | 5.56 | 5.24 | 5.72 | 4.28 | 6.20 |
| **67** | 4.52 | 7.56 | 6.20 | 6.68 | 7.48 | 4.76 | 6.52 | 6.20 | 6.92 | 4.60 | 3.48 | 6.92 | 6.12 | 5.16 | 5.40 | 6.76 | 7.64 |
| **68** | 2.60 | 5.56 | 5.08 | 4.76 | 3.16 | 2.12 | 3.16 | 4.52 | 5.08 | 2.20 | 1.00 | 2.20 | 3.00 | 4.76 | 3.24 | 2.76 | 4.76 |
| **69** | 3.88 | 5.48 | 2.68 | 5.32 | 4.04 | 1.80 | 3.48 | 5.56 | 3.88 | 2.20 | 2.28 | 4.12 | 3.56 | 2.60 | 3.16 | 3.24 | 5.40 |
| **70** | 1.88 | 4.84 | 4.60 | 5.72 | 4.44 | 5.32 | 3.96 | 6.44 | 6.28 | 3.32 | 2.76 | 2.52 | 4.76 | 4.44 | 4.36 | 5.40 | 5.64 |
| **71** | 1.88 | 7.24 | 4.04 | 5.00 | 2.92 | 2.92 | 3.72 | 6.28 | 4.76 | 4.12 | 1.00 | 4.76 | 2.04 | 5.08 | 3.24 | 2.68 | 4.20 |
| **72** | 2.44 | 7.00 | 6.44 | 6.44 | 1.00 | 1.48 | 2.04 | 4.12 | 4.84 | 2.12 | 1.24 | 2.12 | 2.68 | 3.32 | 4.12 | 4.84 | 2.52 |
| **73** | 3.40 | 7.80 | 6.76 | 6.84 | 5.80 | 5.56 | 5.96 | 6.28 | 7.96 | 3.48 | 3.48 | 3.48 | 5.00 | 6.92 | 5.80 | 6.84 | 5.24 |
| **74** | 3.24 | 8.20 | 7.40 | 7.00 | 4.68 | 5.64 | 5.72 | 5.72 | 8.12 | 3.72 | 1.00 | 4.84 | 3.00 | 6.84 | 5.56 | 7.48 | 5.96 |
| **75** | 4.76 | 8.28 | 8.60 | 8.20 | 9.00 | 6.60 | 7.88 | 6.04 | 8.44 | 5.00 | 5.00 | 8.44 | 7.40 | 7.96 | 6.52 | 7.48 | 7.88 |
| **76** | 3.00 | 5.88 | 7.80 | 6.68 | 2.36 | 1.72 | 2.36 | 5.00 | 4.20 | 2.12 | 1.00 | 2.84 | 3.56 | 2.36 | 3.08 | 2.44 | 2.36 |
| **77** | 3.72 | 7.80 | 7.40 | 7.32 | 8.44 | 4.92 | 5.40 | 6.60 | 7.64 | 4.04 | 4.28 | 8.04 | 3.88 | 6.44 | 6.12 | 7.64 | 6.76 |
| **78** | 3.00 | 7.72 | 5.96 | 7.16 | 5.64 | 5.48 | 6.60 | 7.40 | 7.96 | 3.48 | 3.72 | 5.64 | 4.20 | 7.48 | 5.16 | 7.48 | 7.00 |
| **79** | 1.80 | 8.28 | 7.56 | 7.64 | 9.00 | 6.60 | 7.72 | 8.04 | 7.88 | 5.00 | 3.96 | 7.72 | 5.88 | 7.64 | 6.60 | 7.32 | 7.32 |
| **80** | 3.80 | 8.76 | 6.92 | 7.48 | 7.24 | 5.24 | 6.76 | 7.08 | 7.80 | 3.96 | 4.28 | 5.80 | 6.04 | 6.52 | 5.72 | 7.80 | 8.04 |

## E.3 Playback Order

Tables E.16-E.19 contain the playback orders used in each run of the Purdue test. The Purdue test was conducted in thirty-five runs, with each run containing one subject. The column headings in the table correspond to the numbers of the subjects in the run. The row headings in the table correspond to the signals that were played first, second, etc., in the test run. Numbers in the body of the table correspond to the numbers of the sounds given in Tables E.1 and E.2.

Table E.16. Playback orders in the Purdue test, Part 1, subjects 1-18.

| **Order** | **Subjects** | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **played** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** |
| **1** | 6 | 25 | 16 | 80 | 10 | 69 | 48 | 67 | 22 | 2 | 9 | 8 | 9 | 53 | 38 | 68 | 40 | 62 |
| **2** | 17 | 39 | 31 | 31 | 76 | 74 | 79 | 63 | 51 | 59 | 72 | 33 | 5 | 14 | 55 | 25 | 34 | 16 |
| **3** | 16 | 74 | 2 | 1 | 9 | 18 | 27 | 57 | 40 | 11 | 57 | 61 | 51 | 62 | 37 | 52 | 43 | 52 |
| **4** | 63 | 26 | 45 | 58 | 22 | 72 | 22 | 56 | 52 | 40 | 76 | 49 | 45 | 72 | 26 | 24 | 45 | 72 |
| **5** | 66 | 35 | 26 | 68 | 71 | 79 | 3 | 17 | 75 | 35 | 60 | 40 | 42 | 26 | 14 | 40 | 70 | 76 |
| **6** | 67 | 2 | 44 | 70 | 68 | 19 | 34 | 23 | 17 | 16 | 21 | 15 | 34 | 11 | 59 | 55 | 65 | 7 |
| **7** | 70 | 11 | 67 | 55 | 31 | 35 | 10 | 62 | 56 | 33 | 71 | 78 | 28 | 64 | 36 | 36 | 71 | 44 |
| **8** | 59 | 69 | 32 | 18 | 5 | 21 | 21 | 64 | 4 | 32 | 48 | 63 | 48 | 27 | 10 | 54 | 75 | 20 |
| **9** | 46 | 67 | 48 | 50 | 35 | 8 | 18 | 71 | 53 | 26 | 5 | 6 | 22 | 60 | 68 | 47 | 41 | 30 |
| **10** | 28 | 32 | 52 | 78 | 66 | 77 | 65 | 53 | 14 | 44 | 64 | 51 | 65 | 78 | 66 | 48 | 19 | 8 |
| **11** | 33 | 75 | 57 | 28 | 37 | 52 | 49 | 52 | 61 | 28 | 63 | 68 | 79 | 47 | 48 | 43 | 42 | 24 |
| **12** | 77 | 17 | 20 | 59 | 58 | 11 | 19 | 21 | 65 | 68 | 34 | 73 | 19 | 71 | 44 | 71 | 66 | 75 |
| **13** | 65 | 29 | 47 | 10 | 56 | 38 | 54 | 66 | 77 | 56 | 66 | 80 | 21 | 50 | 8 | 57 | 26 | 70 |
| **14** | 39 | 78 | 54 | 32 | 52 | 63 | 80 | 58 | 2 | 24 | 50 | 44 | 58 | 51 | 17 | 31 | 35 | 57 |
| **15** | 21 | 6 | 37 | 29 | 34 | 51 | 20 | 39 | 46 | 51 | 43 | 5 | 71 | 20 | 6 | 74 | 12 | 34 |
| **16** | 41 | 13 | 27 | 54 | 60 | 29 | 37 | 74 | 18 | 42 | 75 | 76 | 44 | 59 | 49 | 9 | 16 | 64 |
| **17** | 51 | 73 | 14 | 35 | 54 | 15 | 62 | 13 | 78 | 45 | 42 | 62 | 73 | 76 | 57 | 17 | 47 | 33 |
| **18** | 71 | 27 | 64 | 66 | 75 | 16 | 70 | 55 | 30 | 20 | 14 | 22 | 41 | 23 | 28 | 60 | 36 | 35 |
| **19** | 31 | 70 | 8 | 64 | 12 | 49 | 69 | 65 | 27 | 55 | 80 | 20 | 1 | 63 | 67 | 23 | 23 | 37 |
| **20** | 8 | 38 | 51 | 45 | 17 | 32 | 50 | 75 | 8 | 62 | 26 | 35 | 80 | 77 | 25 | 69 | 73 | 5 |

Table E.16. Continued from previous page.

| **Order** | **Subjects** | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **played** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** |
| **21** | 49 | 58 | 39 | 24 | 73 | 65 | 2 | 18 | 13 | 74 | 70 | 64 | 77 | 73 | 39 | 39 | 59 | 47 |
| **22** | 57 | 22 | 35 | 16 | 44 | 58 | 46 | 29 | 71 | 53 | 74 | 69 | 56 | 4 | 77 | 10 | 57 | 17 |
| **23** | 42 | 12 | 29 | 69 | 25 | 64 | 17 | 41 | 15 | 65 | 46 | 10 | 3 | 46 | 42 | 79 | 39 | 60 |
| **24** | 43 | 7 | 9 | 60 | 57 | 28 | 40 | 42 | 34 | 22 | 61 | 47 | 18 | 19 | 13 | 2 | 9 | 15 |
| **25** | 9 | 77 | 75 | 27 | 23 | 76 | 55 | 14 | 11 | 36 | 28 | 59 | 39 | 66 | 80 | 50 | 10 | 79 |
| **26** | 54 | 21 | 80 | 61 | 16 | 1 | 33 | 68 | 36 | 64 | 53 | 60 | 40 | 7 | 69 | 51 | 3 | 46 |
| **27** | 40 | 48 | 59 | 20 | 3 | 25 | 51 | 16 | 23 | 29 | 44 | 19 | 76 | 65 | 58 | 13 | 17 | 67 |
| **28** | 32 | 36 | 6 | 9 | 47 | 10 | 29 | 47 | 66 | 31 | 40 | 54 | 8 | 49 | 74 | 37 | 69 | 58 |
| **29** | 50 | 50 | 15 | 51 | 6 | 31 | 4 | 3 | 73 | 3 | 23 | 53 | 46 | 45 | 30 | 33 | 13 | 73 |
| **30** | 79 | 61 | 33 | 63 | 72 | 67 | 45 | 1 | 5 | 66 | 51 | 4 | 23 | 13 | 24 | 65 | 76 | 56 |
| **31** | 76 | 54 | 74 | 40 | 41 | 61 | 36 | 59 | 69 | 12 | 19 | 72 | 11 | 34 | 61 | 78 | 31 | 32 |
| **32** | 4 | 3 | 11 | 49 | 26 | 70 | 23 | 32 | 7 | 78 | 6 | 28 | 57 | 12 | 72 | 45 | 1 | 50 |
| **33** | 2 | 63 | 40 | 44 | 48 | 45 | 57 | 46 | 31 | 80 | 68 | 57 | 10 | 18 | 51 | 4 | 29 | 21 |
| **34** | 56 | 59 | 13 | 21 | 79 | 2 | 61 | 72 | 20 | 58 | 62 | 38 | 14 | 79 | 46 | 41 | 67 | 25 |
| **35** | 53 | 60 | 1 | 57 | 33 | 13 | 42 | 4 | 70 | 15 | 54 | 37 | 66 | 36 | 12 | 77 | 51 | 59 |
| **36** | 38 | 68 | 60 | 26 | 29 | 40 | 64 | 24 | 41 | 52 | 10 | 14 | 26 | 39 | 71 | 19 | 77 | 29 |
| **37** | 27 | 56 | 78 | 17 | 78 | 42 | 6 | 79 | 38 | 46 | 13 | 2 | 25 | 6 | 9 | 73 | 44 | 11 |
| **38** | 75 | 65 | 5 | 48 | 19 | 50 | 11 | 38 | 25 | 70 | 29 | 17 | 13 | 2 | 35 | 30 | 48 | 23 |
| **39** | 68 | 66 | 66 | 34 | 63 | 43 | 16 | 27 | 10 | 60 | 38 | 79 | 47 | 70 | 75 | 16 | 22 | 39 |
| **40** | 80 | 62 | 28 | 23 | 61 | 73 | 44 | 12 | 57 | 67 | 52 | 27 | 38 | 30 | 79 | 20 | 11 | 9 |

Table E.16. Continued from previous page.

| **Order** | **Subjects** | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **played** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** |
| **41** | 1 | 5 | 65 | 65 | 43 | 36 | 13 | 36 | 33 | 10 | 47 | 11 | 55 | 74 | 21 | 44 | 46 | 40 |
| **42** | 23 | 19 | 71 | 79 | 45 | 59 | 24 | 44 | 60 | 38 | 39 | 32 | 69 | 5 | 1 | 11 | 80 | 45 |
| **43** | 47 | 1 | 17 | 38 | 28 | 75 | 26 | 70 | 29 | 72 | 15 | 23 | 53 | 43 | 16 | 49 | 63 | 14 |
| **44** | 5 | 24 | 24 | 4 | 42 | 46 | 72 | 80 | 58 | 39 | 2 | 24 | 16 | 1 | 63 | 67 | 8 | 1 |
| **45** | 3 | 30 | 34 | 39 | 39 | 30 | 68 | 10 | 79 | 4 | 56 | 65 | 7 | 21 | 52 | 5 | 68 | 13 |
| **46** | 52 | 80 | 77 | 11 | 21 | 62 | 71 | 73 | 35 | 25 | 73 | 3 | 37 | 29 | 18 | 27 | 64 | 27 |
| **47** | 29 | 18 | 10 | 3 | 24 | 57 | 1 | 25 | 64 | 18 | 59 | 25 | 52 | 41 | 56 | 63 | 49 | 74 |
| **48** | 7 | 57 | 50 | 2 | 11 | 26 | 5 | 49 | 47 | 49 | 45 | 9 | 12 | 32 | 22 | 53 | 74 | 55 |
| **49** | 44 | 15 | 55 | 67 | 8 | 44 | 78 | 54 | 3 | 43 | 65 | 12 | 49 | 33 | 50 | 62 | 62 | 65 |
| **50** | 62 | 44 | 63 | 42 | 4 | 20 | 76 | 51 | 63 | 73 | 32 | 16 | 20 | 75 | 2 | 22 | 53 | 53 |
| **51** | 58 | 10 | 41 | 37 | 40 | 53 | 30 | 19 | 55 | 9 | 49 | 74 | 54 | 25 | 45 | 59 | 55 | 48 |
| **52** | 61 | 31 | 25 | 71 | 15 | 55 | 52 | 77 | 62 | 48 | 16 | 18 | 63 | 55 | 23 | 58 | 32 | 42 |
| **53** | 18 | 41 | 4 | 75 | 2 | 39 | 39 | 45 | 59 | 61 | 24 | 30 | 78 | 48 | 31 | 12 | 50 | 69 |
| **54** | 72 | 14 | 18 | 13 | 74 | 23 | 41 | 76 | 54 | 41 | 25 | 71 | 33 | 38 | 73 | 46 | 18 | 28 |
| **55** | 10 | 8 | 19 | 36 | 1 | 4 | 14 | 40 | 24 | 57 | 30 | 48 | 70 | 22 | 7 | 56 | 28 | 71 |
| **56** | 55 | 45 | 46 | 47 | 20 | 56 | 35 | 8 | 1 | 17 | 37 | 34 | 32 | 37 | 70 | 42 | 54 | 68 |
| **57** | 24 | 76 | 73 | 74 | 67 | 37 | 66 | 61 | 67 | 1 | 11 | 58 | 62 | 31 | 41 | 61 | 30 | 2 |
| **58** | 35 | 9 | 70 | 46 | 7 | 27 | 15 | 9 | 68 | 21 | 18 | 41 | 2 | 68 | 47 | 3 | 15 | 66 |
| **59** | 69 | 20 | 42 | 52 | 46 | 3 | 77 | 26 | 28 | 19 | 33 | 50 | 27 | 56 | 19 | 18 | 6 | 80 |
| **60** | 36 | 40 | 56 | 53 | 70 | 48 | 58 | 15 | 80 | 6 | 27 | 7 | 35 | 58 | 78 | 28 | 78 | 3 |

Table E.16. Continued from previous page.

| **Order** | **Subjects** | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **played** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** |
| **61** | 13 | 71 | 22 | 15 | 77 | 24 | 28 | 5 | 19 | 77 | 77 | 66 | 43 | 9 | 76 | 34 | 27 | 10 |
| **62** | 26 | 47 | 68 | 33 | 50 | 68 | 75 | 28 | 49 | 50 | 78 | 42 | 6 | 10 | 60 | 72 | 60 | 4 |
| **63** | 78 | 49 | 58 | 19 | 69 | 47 | 9 | 37 | 42 | 79 | 67 | 77 | 31 | 40 | 32 | 70 | 37 | 22 |
| **64** | 12 | 28 | 30 | 30 | 55 | 71 | 67 | 11 | 12 | 5 | 58 | 39 | 64 | 67 | 11 | 75 | 20 | 38 |
| **65** | 20 | 53 | 38 | 5 | 80 | 60 | 38 | 50 | 74 | 75 | 20 | 13 | 68 | 28 | 54 | 15 | 61 | 18 |
| **66** | 25 | 52 | 7 | 22 | 32 | 78 | 43 | 2 | 44 | 76 | 41 | 46 | 4 | 24 | 33 | 6 | 72 | 6 |
| **67** | 64 | 4 | 72 | 6 | 38 | 54 | 73 | 6 | 37 | 7 | 79 | 43 | 72 | 8 | 53 | 14 | 4 | 36 |
| **68** | 11 | 46 | 23 | 77 | 14 | 80 | 60 | 35 | 39 | 63 | 4 | 36 | 15 | 52 | 27 | 32 | 79 | 26 |
| **69** | 73 | 16 | 69 | 73 | 30 | 41 | 8 | 22 | 43 | 13 | 31 | 26 | 50 | 35 | 4 | 64 | 38 | 61 |
| **70** | 48 | 43 | 49 | 12 | 64 | 9 | 12 | 30 | 26 | 23 | 69 | 56 | 67 | 80 | 3 | 26 | 33 | 78 |
| **71** | 19 | 23 | 36 | 72 | 62 | 6 | 56 | 20 | 32 | 34 | 12 | 1 | 74 | 69 | 29 | 29 | 25 | 63 |
| **72** | 22 | 79 | 62 | 41 | 51 | 17 | 74 | 7 | 9 | 69 | 36 | 31 | 61 | 17 | 64 | 21 | 14 | 43 |
| **73** | 15 | 64 | 53 | 14 | 49 | 5 | 59 | 60 | 72 | 37 | 7 | 45 | 29 | 16 | 15 | 38 | 58 | 19 |
| **74** | 45 | 51 | 61 | 76 | 36 | 12 | 31 | 43 | 45 | 47 | 8 | 21 | 59 | 15 | 5 | 35 | 7 | 51 |
| **75** | 37 | 42 | 21 | 7 | 53 | 34 | 7 | 78 | 50 | 71 | 1 | 55 | 30 | 61 | 43 | 7 | 24 | 54 |
| **76** | 30 | 34 | 76 | 25 | 27 | 33 | 53 | 34 | 48 | 8 | 17 | 75 | 75 | 3 | 20 | 8 | 52 | 12 |
| **77** | 34 | 55 | 3 | 43 | 59 | 14 | 25 | 33 | 21 | 54 | 55 | 70 | 17 | 54 | 65 | 80 | 2 | 49 |
| **78** | 74 | 72 | 12 | 8 | 65 | 7 | 32 | 48 | 76 | 14 | 22 | 67 | 24 | 42 | 62 | 1 | 5 | 77 |
| **79** | 14 | 33 | 79 | 62 | 13 | 22 | 47 | 69 | 6 | 30 | 3 | 29 | 60 | 57 | 40 | 76 | 56 | 41 |
| **80** | 60 | 37 | 43 | 56 | 18 | 66 | 63 | 31 | 16 | 27 | 35 | 52 | 36 | 44 | 34 | 66 | 21 | 31 |

Table E.17. Playback orders in the Purdue test, Part 1, subjects 19-35.

| **Order** | **Subjects** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **played** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** | **35** |
| **1** | 60 | 41 | 44 | 18 | 1 | 68 | 19 | 54 | 13 | 22 | 77 | 19 | 45 | 77 | 43 | 77 | 67 |
| **2** | 56 | 61 | 38 | 38 | 52 | 69 | 57 | 66 | 26 | 79 | 39 | 21 | 29 | 21 | 50 | 49 | 30 |
| **3** | 2 | 21 | 75 | 19 | 41 | 55 | 44 | 43 | 11 | 42 | 28 | 72 | 69 | 23 | 30 | 59 | 26 |
| **4** | 33 | 13 | 76 | 44 | 46 | 60 | 64 | 9 | 9 | 3 | 68 | 63 | 74 | 14 | 11 | 70 | 64 |
| **5** | 12 | 1 | 15 | 25 | 27 | 73 | 51 | 80 | 64 | 78 | 3 | 76 | 59 | 75 | 10 | 46 | 59 |
| **6** | 45 | 20 | 5 | 32 | 23 | 59 | 7 | 67 | 74 | 56 | 62 | 37 | 9 | 44 | 3 | 9 | 18 |
| **7** | 62 | 71 | 9 | 58 | 80 | 72 | 61 | 53 | 5 | 24 | 22 | 60 | 54 | 28 | 69 | 31 | 19 |
| **8** | 3 | 58 | 63 | 80 | 5 | 61 | 37 | 28 | 44 | 55 | 74 | 28 | 18 | 74 | 5 | 50 | 49 |
| **9** | 54 | 60 | 2 | 10 | 9 | 57 | 63 | 25 | 69 | 29 | 51 | 26 | 5 | 50 | 53 | 15 | 38 |
| **10** | 27 | 55 | 42 | 42 | 57 | 3 | 17 | 21 | 17 | 40 | 27 | 23 | 39 | 13 | 51 | 57 | 24 |
| **11** | 61 | 6 | 20 | 40 | 33 | 80 | 30 | 75 | 3 | 53 | 9 | 27 | 28 | 29 | 41 | 54 | 79 |
| **12** | 18 | 53 | 72 | 1 | 20 | 22 | 76 | 40 | 40 | 58 | 59 | 50 | 70 | 35 | 36 | 12 | 15 |
| **13** | 79 | 9 | 50 | 31 | 25 | 58 | 33 | 34 | 31 | 48 | 24 | 74 | 41 | 17 | 1 | 64 | 69 |
| **14** | 7 | 72 | 61 | 33 | 45 | 8 | 52 | 15 | 66 | 28 | 61 | 36 | 33 | 53 | 22 | 8 | 62 |
| **15** | 71 | 49 | 54 | 37 | 4 | 42 | 42 | 68 | 60 | 66 | 47 | 66 | 72 | 19 | 37 | 7 | 39 |
| **16** | 49 | 11 | 55 | 66 | 47 | 63 | 60 | 1 | 39 | 62 | 71 | 79 | 26 | 6 | 59 | 60 | 60 |
| **17** | 66 | 39 | 48 | 26 | 66 | 11 | 36 | 65 | 78 | 13 | 50 | 35 | 61 | 67 | 79 | 25 | 73 |
| **18** | 13 | 32 | 10 | 68 | 38 | 36 | 28 | 10 | 59 | 36 | 79 | 22 | 63 | 68 | 27 | 5 | 29 |
| **19** | 67 | 51 | 6 | 60 | 48 | 66 | 70 | 33 | 22 | 65 | 30 | 13 | 1 | 16 | 66 | 55 | 75 |
| **20** | 5 | 43 | 40 | 51 | 42 | 7 | 11 | 72 | 19 | 8 | 6 | 52 | 46 | 52 | 72 | 17 | 53 |

Table E.17. Continued from previous page.

| **Order** | **Subjects** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **played** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** | **35** |
| **21** | 37 | 42 | 70 | 67 | 72 | 6 | 50 | 11 | 70 | 12 | 19 | 16 | 60 | 2 | 33 | 16 | 68 |
| **22** | 44 | 4 | 39 | 2 | 11 | 62 | 26 | 42 | 18 | 68 | 76 | 12 | 44 | 61 | 78 | 44 | 37 |
| **23** | 8 | 68 | 49 | 23 | 43 | 39 | 66 | 63 | 36 | 71 | 33 | 77 | 24 | 80 | 16 | 18 | 23 |
| **24** | 76 | 63 | 41 | 46 | 39 | 76 | 22 | 4 | 45 | 70 | 58 | 53 | 76 | 9 | 23 | 13 | 54 |
| **25** | 11 | 30 | 51 | 11 | 21 | 32 | 62 | 71 | 73 | 61 | 75 | 59 | 8 | 57 | 35 | 48 | 41 |
| **26** | 77 | 46 | 3 | 70 | 19 | 34 | 4 | 59 | 79 | 51 | 17 | 46 | 13 | 7 | 21 | 42 | 5 |
| **27** | 43 | 75 | 74 | 7 | 31 | 23 | 45 | 23 | 76 | 17 | 37 | 30 | 2 | 47 | 6 | 61 | 74 |
| **28** | 17 | 29 | 46 | 56 | 26 | 12 | 72 | 52 | 21 | 20 | 63 | 8 | 71 | 10 | 52 | 37 | 34 |
| **29** | 63 | 67 | 36 | 12 | 55 | 41 | 39 | 16 | 27 | 50 | 69 | 73 | 79 | 54 | 14 | 47 | 58 |
| **30** | 4 | 31 | 12 | 39 | 32 | 78 | 40 | 26 | 2 | 9 | 80 | 47 | 49 | 8 | 25 | 1 | 71 |
| **31** | 69 | 27 | 29 | 17 | 49 | 48 | 20 | 77 | 41 | 30 | 14 | 49 | 20 | 18 | 57 | 20 | 4 |
| **32** | 78 | 16 | 59 | 36 | 70 | 15 | 69 | 38 | 56 | 69 | 34 | 32 | 19 | 37 | 39 | 32 | 50 |
| **33** | 19 | 33 | 26 | 74 | 69 | 4 | 32 | 48 | 48 | 6 | 7 | 18 | 16 | 71 | 65 | 43 | 3 |
| **34** | 36 | 7 | 45 | 47 | 17 | 10 | 58 | 62 | 53 | 14 | 57 | 80 | 25 | 33 | 9 | 36 | 42 |
| **35** | 50 | 18 | 65 | 20 | 68 | 51 | 13 | 18 | 50 | 39 | 10 | 70 | 57 | 59 | 80 | 39 | 12 |
| **36** | 25 | 65 | 58 | 14 | 63 | 67 | 29 | 5 | 23 | 2 | 38 | 65 | 55 | 1 | 28 | 76 | 63 |
| **37** | 42 | 57 | 16 | 52 | 73 | 74 | 65 | 41 | 37 | 75 | 18 | 62 | 23 | 63 | 46 | 4 | 25 |
| **38** | 65 | 12 | 73 | 49 | 64 | 28 | 31 | 14 | 67 | 16 | 41 | 42 | 43 | 31 | 44 | 41 | 21 |
| **39** | 24 | 17 | 71 | 4 | 62 | 45 | 10 | 46 | 68 | 60 | 2 | 24 | 15 | 78 | 19 | 78 | 66 |
| **40** | 73 | 50 | 14 | 54 | 34 | 27 | 16 | 73 | 75 | 7 | 56 | 29 | 31 | 72 | 26 | 67 | 9 |

Table E.17. Continued from previous page.

| **Order** | **Subjects** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **played** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** | **35** |
| **41** | 75 | 78 | 18 | 45 | 67 | 35 | 21 | 47 | 20 | 74 | 23 | 71 | 32 | 69 | 61 | 72 | 57 |
| **42** | 22 | 40 | 62 | 24 | 6 | 70 | 49 | 56 | 72 | 11 | 45 | 10 | 75 | 70 | 55 | 24 | 16 |
| **43** | 58 | 34 | 60 | 41 | 76 | 52 | 68 | 7 | 62 | 32 | 20 | 78 | 4 | 55 | 42 | 53 | 78 |
| **44** | 10 | 26 | 28 | 9 | 51 | 37 | 41 | 12 | 58 | 15 | 40 | 75 | 53 | 46 | 74 | 79 | 11 |
| **45** | 15 | 23 | 7 | 64 | 16 | 75 | 24 | 6 | 71 | 47 | 36 | 68 | 22 | 32 | 73 | 29 | 7 |
| **46** | 21 | 56 | 66 | 76 | 54 | 13 | 67 | 79 | 43 | 64 | 15 | 40 | 80 | 62 | 77 | 33 | 33 |
| **47** | 52 | 3 | 64 | 71 | 28 | 25 | 23 | 55 | 57 | 63 | 73 | 69 | 67 | 38 | 48 | 27 | 22 |
| **48** | 59 | 76 | 56 | 16 | 56 | 16 | 43 | 69 | 10 | 38 | 29 | 2 | 50 | 34 | 70 | 74 | 27 |
| **49** | 32 | 62 | 77 | 55 | 78 | 9 | 77 | 3 | 80 | 80 | 16 | 34 | 66 | 42 | 12 | 23 | 2 |
| **50** | 35 | 14 | 21 | 13 | 10 | 40 | 75 | 57 | 29 | 77 | 46 | 7 | 51 | 26 | 56 | 38 | 77 |
| **51** | 74 | 36 | 8 | 35 | 15 | 14 | 53 | 64 | 47 | 43 | 44 | 61 | 52 | 22 | 31 | 80 | 14 |
| **52** | 20 | 35 | 13 | 79 | 60 | 31 | 55 | 37 | 34 | 72 | 70 | 39 | 77 | 65 | 47 | 21 | 72 |
| **53** | 16 | 5 | 37 | 28 | 36 | 24 | 3 | 22 | 32 | 1 | 72 | 64 | 12 | 4 | 2 | 73 | 76 |
| **54** | 34 | 28 | 67 | 3 | 58 | 26 | 25 | 32 | 12 | 57 | 4 | 45 | 3 | 5 | 60 | 22 | 31 |
| **55** | 47 | 74 | 4 | 69 | 75 | 38 | 73 | 8 | 46 | 45 | 32 | 4 | 47 | 48 | 76 | 52 | 32 |
| **56** | 55 | 8 | 34 | 30 | 7 | 54 | 2 | 76 | 65 | 52 | 66 | 67 | 73 | 43 | 45 | 63 | 55 |
| **57** | 72 | 19 | 27 | 57 | 53 | 44 | 8 | 45 | 49 | 41 | 48 | 44 | 58 | 41 | 68 | 56 | 6 |
| **58** | 30 | 10 | 52 | 61 | 37 | 20 | 34 | 31 | 8 | 76 | 1 | 56 | 62 | 15 | 8 | 66 | 44 |
| **59** | 31 | 25 | 25 | 72 | 71 | 33 | 80 | 20 | 4 | 23 | 31 | 17 | 38 | 79 | 24 | 26 | 1 |
| **60** | 6 | 80 | 79 | 15 | 30 | 53 | 78 | 2 | 30 | 59 | 49 | 9 | 10 | 66 | 54 | 11 | 46 |

Table E.17. Continued from previous page.

| Order | Subjects | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **played** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** | **35** |
| **61** | 14 | 45 | 57 | 34 | 3 | 46 | 27 | 74 | 61 | 27 | 21 | 48 | 64 | 25 | 38 | 40 | 61 |
| **62** | 28 | 22 | 30 | 6 | 18 | 56 | 14 | 19 | 6 | 26 | 26 | 5 | 48 | 3 | 18 | 6 | 17 |
| **63** | 40 | 15 | 31 | 48 | 8 | 21 | 79 | 13 | 63 | 54 | 43 | 38 | 17 | 27 | 49 | 30 | 40 |
| **64** | 64 | 47 | 43 | 65 | 24 | 5 | 48 | 30 | 25 | 46 | 65 | 41 | 40 | 51 | 7 | 69 | 20 |
| **65** | 29 | 44 | 24 | 62 | 77 | 79 | 74 | 29 | 55 | 4 | 60 | 1 | 56 | 30 | 15 | 14 | 47 |
| **66** | 51 | 66 | 80 | 29 | 50 | 43 | 59 | 49 | 51 | 21 | 25 | 25 | 65 | 49 | 29 | 58 | 36 |
| **67** | 39 | 70 | 78 | 22 | 22 | 29 | 54 | 61 | 16 | 34 | 64 | 20 | 68 | 58 | 32 | 45 | 10 |
| **68** | 23 | 77 | 17 | 21 | 13 | 2 | 71 | 39 | 54 | 18 | 54 | 3 | 36 | 60 | 34 | 19 | 8 |
| **69** | 80 | 79 | 23 | 5 | 65 | 49 | 9 | 50 | 7 | 19 | 42 | 6 | 7 | 36 | 40 | 34 | 48 |
| **70** | 38 | 64 | 1 | 8 | 44 | 19 | 12 | 36 | 33 | 10 | 35 | 51 | 6 | 24 | 63 | 28 | 70 |
| **71** | 26 | 69 | 47 | 43 | 35 | 47 | 46 | 44 | 24 | 37 | 67 | 54 | 30 | 40 | 13 | 10 | 80 |
| **72** | 41 | 2 | 19 | 73 | 29 | 64 | 18 | 24 | 15 | 31 | 55 | 33 | 21 | 45 | 20 | 68 | 43 |
| **73** | 68 | 24 | 69 | 77 | 59 | 50 | 35 | 51 | 1 | 5 | 5 | 43 | 78 | 64 | 71 | 71 | 28 |
| **74** | 46 | 54 | 53 | 63 | 14 | 65 | 15 | 78 | 42 | 49 | 52 | 11 | 27 | 12 | 4 | 51 | 13 |
| **75** | 70 | 38 | 22 | 53 | 40 | 77 | 5 | 60 | 77 | 25 | 78 | 57 | 35 | 76 | 58 | 62 | 45 |
| **76** | 1 | 73 | 11 | 59 | 61 | 1 | 6 | 35 | 35 | 44 | 12 | 31 | 37 | 73 | 67 | 3 | 51 |
| **77** | 48 | 59 | 68 | 50 | 74 | 17 | 47 | 17 | 38 | 67 | 11 | 14 | 34 | 20 | 64 | 65 | 52 |
| **78** | 53 | 48 | 32 | 75 | 79 | 18 | 1 | 70 | 28 | 35 | 53 | 58 | 11 | 11 | 75 | 35 | 35 |
| **79** | 9 | 37 | 35 | 78 | 2 | 30 | 56 | 58 | 14 | 73 | 8 | 15 | 42 | 39 | 62 | 2 | 65 |
| **80** | 57 | 52 | 33 | 27 | 12 | 71 | 38 | 27 | 52 | 33 | 13 | 55 | 14 | 56 | 17 | 75 | 56 |

Table E.18. Playback orders in the Purdue test, Part 2, subjects 1-18.

| **Order** | **Subjects** | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **played** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** |
| **1** | 76 | 65 | 65 | 79 | 56 | 68 | 70 | 79 | 73 | 36 | 10 | 15 | 27 | 71 | 25 | 40 | 12 | 35 |
| **2** | 19 | 8 | 41 | 25 | 64 | 22 | 58 | 41 | 44 | 55 | 45 | 47 | 3 | 47 | 79 | 47 | 3 | 28 |
| **3** | 63 | 2 | 58 | 38 | 22 | 18 | 10 | 39 | 52 | 70 | 33 | 16 | 77 | 42 | 29 | 19 | 14 | 23 |
| **4** | 2 | 23 | 23 | 20 | 80 | 30 | 43 | 43 | 23 | 71 | 55 | 34 | 42 | 9 | 22 | 31 | 74 | 80 |
| **5** | 18 | 35 | 20 | 77 | 69 | 43 | 1 | 3 | 78 | 61 | 24 | 58 | 73 | 25 | 68 | 11 | 75 | 11 |
| **6** | 64 | 14 | 2 | 71 | 20 | 47 | 12 | 2 | 17 | 58 | 38 | 35 | 8 | 65 | 11 | 58 | 20 | 56 |
| **7** | 1 | 40 | 47 | 24 | 24 | 53 | 72 | 48 | 9 | 35 | 76 | 61 | 19 | 60 | 7 | 14 | 31 | 53 |
| **8** | 44 | 10 | 56 | 69 | 60 | 17 | 5 | 50 | 67 | 29 | 29 | 13 | 29 | 43 | 59 | 80 | 79 | 60 |
| **9** | 35 | 38 | 79 | 22 | 36 | 6 | 17 | 9 | 77 | 40 | 64 | 40 | 5 | 15 | 6 | 37 | 37 | 22 |
| **10** | 24 | 39 | 40 | 36 | 1 | 74 | 79 | 78 | 13 | 45 | 41 | 6 | 1 | 14 | 53 | 54 | 66 | 9 |
| **11** | 53 | 50 | 75 | 18 | 39 | 76 | 60 | 32 | 65 | 54 | 70 | 73 | 75 | 73 | 54 | 64 | 11 | 41 |
| **12** | 47 | 29 | 64 | 14 | 48 | 39 | 73 | 36 | 4 | 48 | 23 | 33 | 71 | 35 | 55 | 50 | 62 | 67 |
| **13** | 72 | 1 | 11 | 13 | 32 | 60 | 59 | 25 | 71 | 23 | 22 | 10 | 22 | 18 | 50 | 29 | 67 | 64 |
| **14** | 43 | 80 | 69 | 2 | 78 | 54 | 51 | 62 | 36 | 60 | 37 | 20 | 50 | 29 | 45 | 23 | 7 | 36 |
| **15** | 52 | 72 | 38 | 52 | 21 | 80 | 66 | 29 | 54 | 3 | 60 | 22 | 62 | 80 | 65 | 7 | 9 | 15 |
| **16** | 55 | 13 | 7 | 58 | 62 | 42 | 18 | 65 | 62 | 30 | 74 | 41 | 67 | 12 | 15 | 60 | 59 | 54 |
| **17** | 42 | 51 | 50 | 37 | 10 | 20 | 15 | 31 | 68 | 14 | 43 | 42 | 46 | 70 | 32 | 75 | 25 | 52 |
| **18** | 78 | 26 | 18 | 39 | 50 | 40 | 54 | 10 | 24 | 65 | 28 | 9 | 34 | 50 | 36 | 38 | 64 | 21 |
| **19** | 80 | 28 | 63 | 51 | 11 | 26 | 61 | 54 | 80 | 78 | 15 | 52 | 28 | 1 | 62 | 43 | 49 | 45 |
| **20** | 16 | 34 | 39 | 4 | 28 | 78 | 24 | 11 | 72 | 31 | 36 | 48 | 10 | 44 | 33 | 63 | 46 | 74 |

Table E.18. Continued from previous page.

| **Order** | **Subjects** | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **played** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** |
| **21** | 54 | 17 | 73 | 73 | 37 | 59 | 48 | 8 | 53 | 7 | 68 | 77 | 38 | 3 | 75 | 69 | 72 | 70 |
| **22** | 15 | 37 | 21 | 15 | 35 | 38 | 68 | 15 | 10 | 27 | 51 | 23 | 39 | 39 | 16 | 59 | 63 | 32 |
| **23** | 26 | 18 | 25 | 32 | 14 | 64 | 78 | 38 | 56 | 28 | 48 | 29 | 36 | 68 | 18 | 13 | 6 | 19 |
| **24** | 75 | 16 | 45 | 17 | 71 | 52 | 77 | 51 | 14 | 1 | 49 | 17 | 24 | 26 | 30 | 76 | 32 | 55 |
| **25** | 58 | 20 | 34 | 23 | 9 | 79 | 46 | 6 | 15 | 73 | 78 | 12 | 56 | 17 | 77 | 44 | 70 | 49 |
| **26** | 67 | 4 | 6 | 67 | 25 | 1 | 69 | 80 | 39 | 17 | 8 | 28 | 21 | 36 | 57 | 70 | 15 | 48 |
| **27** | 10 | 7 | 70 | 12 | 3 | 73 | 37 | 27 | 18 | 57 | 52 | 78 | 63 | 74 | 74 | 53 | 36 | 1 |
| **28** | 28 | 77 | 9 | 78 | 59 | 4 | 30 | 16 | 27 | 4 | 73 | 57 | 4 | 19 | 71 | 56 | 33 | 30 |
| **29** | 40 | 69 | 33 | 6 | 73 | 57 | 33 | 64 | 19 | 13 | 34 | 21 | 59 | 57 | 64 | 21 | 24 | 10 |
| **30** | 41 | 71 | 8 | 8 | 34 | 31 | 29 | 24 | 37 | 62 | 71 | 75 | 41 | 20 | 61 | 61 | 43 | 72 |
| **31** | 45 | 43 | 3 | 62 | 74 | 23 | 4 | 23 | 42 | 33 | 66 | 37 | 79 | 55 | 52 | 71 | 65 | 26 |
| **32** | 8 | 78 | 4 | 28 | 43 | 56 | 32 | 34 | 41 | 2 | 13 | 67 | 49 | 6 | 70 | 66 | 77 | 39 |
| **33** | 9 | 52 | 68 | 21 | 4 | 8 | 27 | 28 | 47 | 77 | 69 | 74 | 13 | 7 | 2 | 57 | 42 | 43 |
| **34** | 38 | 53 | 57 | 41 | 76 | 49 | 35 | 56 | 1 | 15 | 35 | 26 | 18 | 53 | 47 | 18 | 47 | 50 |
| **35** | 68 | 60 | 5 | 3 | 58 | 66 | 39 | 21 | 63 | 79 | 4 | 60 | 14 | 11 | 40 | 4 | 5 | 71 |
| **36** | 50 | 66 | 74 | 35 | 41 | 16 | 56 | 46 | 12 | 56 | 20 | 4 | 26 | 13 | 63 | 26 | 10 | 27 |
| **37** | 69 | 12 | 13 | 40 | 15 | 41 | 23 | 60 | 60 | 69 | 79 | 50 | 66 | 63 | 43 | 30 | 17 | 77 |
| **38** | 51 | 74 | 12 | 66 | 52 | 11 | 26 | 63 | 61 | 74 | 67 | 24 | 12 | 58 | 23 | 68 | 73 | 24 |
| **39** | 25 | 27 | 60 | 63 | 63 | 3 | 21 | 45 | 8 | 63 | 62 | 68 | 35 | 75 | 44 | 39 | 57 | 8 |
| **40** | 66 | 15 | 26 | 60 | 23 | 32 | 3 | 73 | 33 | 5 | 14 | 43 | 37 | 22 | 4 | 9 | 4 | 12 |

Table E.18. Continued from previous page.

| Order | Subjects | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **played** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** |
| **41** | 77 | 68 | 52 | 9 | 33 | 77 | 22 | 37 | 5 | 72 | 5 | 79 | 80 | 67 | 8 | 74 | 60 | 4 |
| **42** | 32 | 19 | 53 | 29 | 54 | 34 | 19 | 40 | 3 | 10 | 21 | 53 | 25 | 4 | 72 | 33 | 52 | 66 |
| **43** | 59 | 75 | 78 | 76 | 12 | 62 | 52 | 57 | 20 | 34 | 54 | 11 | 74 | 45 | 21 | 16 | 21 | 44 |
| **44** | 46 | 33 | 15 | 7 | 26 | 45 | 8 | 30 | 45 | 39 | 44 | 38 | 69 | 27 | 17 | 27 | 56 | 59 |
| **45** | 14 | 64 | 29 | 74 | 40 | 67 | 44 | 69 | 74 | 18 | 58 | 27 | 72 | 24 | 28 | 55 | 68 | 63 |
| **46** | 56 | 44 | 43 | 80 | 30 | 46 | 31 | 68 | 28 | 76 | 72 | 65 | 2 | 56 | 38 | 22 | 29 | 29 |
| **47** | 31 | 47 | 10 | 33 | 27 | 72 | 20 | 18 | 70 | 44 | 46 | 7 | 16 | 79 | 20 | 52 | 71 | 47 |
| **48** | 12 | 5 | 55 | 11 | 2 | 5 | 49 | 76 | 79 | 49 | 61 | 2 | 76 | 48 | 76 | 10 | 30 | 78 |
| **49** | 49 | 73 | 30 | 48 | 53 | 65 | 53 | 61 | 40 | 50 | 77 | 30 | 61 | 77 | 13 | 12 | 28 | 57 |
| **50** | 23 | 76 | 61 | 31 | 75 | 15 | 25 | 66 | 48 | 66 | 1 | 59 | 64 | 62 | 14 | 5 | 38 | 51 |
| **51** | 61 | 46 | 14 | 44 | 16 | 14 | 47 | 49 | 75 | 6 | 63 | 31 | 60 | 66 | 12 | 24 | 26 | 68 |
| **52** | 13 | 55 | 28 | 46 | 51 | 61 | 13 | 58 | 34 | 51 | 16 | 8 | 70 | 33 | 60 | 25 | 45 | 58 |
| **53** | 17 | 9 | 66 | 47 | 72 | 48 | 65 | 26 | 30 | 52 | 75 | 80 | 30 | 69 | 51 | 51 | 16 | 61 |
| **54** | 7 | 30 | 46 | 45 | 44 | 58 | 28 | 17 | 43 | 47 | 3 | 1 | 44 | 30 | 39 | 2 | 35 | 65 |
| **55** | 73 | 22 | 17 | 19 | 66 | 28 | 2 | 4 | 7 | 32 | 39 | 36 | 15 | 41 | 49 | 8 | 2 | 14 |
| **56** | 20 | 56 | 31 | 57 | 68 | 37 | 63 | 53 | 21 | 9 | 40 | 62 | 65 | 52 | 78 | 73 | 22 | 13 |
| **57** | 65 | 11 | 37 | 72 | 67 | 55 | 80 | 67 | 50 | 21 | 65 | 45 | 43 | 61 | 73 | 65 | 76 | 73 |
| **58** | 22 | 3 | 72 | 26 | 47 | 10 | 57 | 59 | 31 | 38 | 11 | 66 | 45 | 64 | 1 | 42 | 1 | 2 |
| **59** | 33 | 63 | 49 | 56 | 31 | 9 | 40 | 1 | 58 | 80 | 25 | 3 | 20 | 37 | 26 | 62 | 41 | 6 |
| **60** | 21 | 59 | 22 | 49 | 61 | 33 | 50 | 55 | 16 | 37 | 27 | 76 | 9 | 78 | 58 | 20 | 53 | 18 |

Table E.18. Continued from previous page.

| **Order** | **Subjects** | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **played** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** |
| **61** | 3 | 79 | 48 | 30 | 49 | 2 | 38 | 44 | 38 | 43 | 32 | 54 | 7 | 23 | 3 | 41 | 69 | 46 |
| **62** | 71 | 48 | 24 | 10 | 70 | 12 | 36 | 5 | 2 | 12 | 59 | 46 | 68 | 34 | 19 | 67 | 27 | 3 |
| **63** | 79 | 25 | 71 | 61 | 77 | 70 | 75 | 12 | 6 | 20 | 30 | 5 | 57 | 54 | 10 | 34 | 44 | 17 |
| **64** | 70 | 54 | 16 | 27 | 38 | 63 | 64 | 20 | 25 | 75 | 31 | 18 | 52 | 2 | 69 | 36 | 48 | 7 |
| **65** | 6 | 70 | 44 | 64 | 8 | 36 | 41 | 71 | 46 | 8 | 9 | 39 | 54 | 16 | 56 | 1 | 23 | 20 |
| **66** | 11 | 45 | 67 | 59 | 5 | 50 | 55 | 14 | 69 | 11 | 53 | 32 | 47 | 21 | 5 | 28 | 13 | 62 |
| **67** | 27 | 36 | 54 | 43 | 7 | 19 | 67 | 70 | 32 | 24 | 19 | 72 | 40 | 31 | 46 | 6 | 55 | 33 |
| **68** | 34 | 21 | 62 | 16 | 46 | 51 | 14 | 74 | 76 | 26 | 47 | 69 | 78 | 28 | 66 | 48 | 51 | 42 |
| **69** | 57 | 32 | 59 | 75 | 29 | 75 | 62 | 75 | 55 | 68 | 80 | 56 | 51 | 51 | 9 | 46 | 18 | 79 |
| **70** | 37 | 67 | 80 | 5 | 57 | 35 | 16 | 77 | 64 | 59 | 18 | 49 | 17 | 46 | 34 | 45 | 40 | 40 |
| **71** | 39 | 58 | 51 | 70 | 42 | 69 | 6 | 22 | 57 | 22 | 6 | 64 | 23 | 40 | 67 | 49 | 19 | 69 |
| **72** | 74 | 49 | 27 | 54 | 79 | 44 | 34 | 7 | 49 | 67 | 2 | 63 | 32 | 76 | 24 | 77 | 54 | 16 |
| **73** | 29 | 57 | 1 | 1 | 45 | 71 | 74 | 33 | 59 | 46 | 42 | 19 | 58 | 49 | 27 | 72 | 8 | 38 |
| **74** | 62 | 41 | 32 | 65 | 6 | 27 | 45 | 19 | 51 | 53 | 50 | 44 | 31 | 38 | 80 | 78 | 34 | 31 |
| **75** | 60 | 6 | 42 | 50 | 17 | 7 | 11 | 52 | 11 | 25 | 57 | 14 | 53 | 5 | 41 | 17 | 58 | 34 |
| **76** | 36 | 62 | 36 | 34 | 13 | 29 | 71 | 72 | 66 | 16 | 12 | 70 | 11 | 72 | 37 | 15 | 61 | 37 |
| **77** | 30 | 61 | 35 | 68 | 19 | 24 | 9 | 47 | 29 | 41 | 26 | 71 | 6 | 32 | 48 | 32 | 39 | 25 |
| **78** | 4 | 24 | 19 | 42 | 65 | 25 | 7 | 13 | 35 | 42 | 17 | 55 | 55 | 59 | 35 | 35 | 50 | 76 |
| **79** | 5 | 31 | 76 | 55 | 18 | 13 | 76 | 42 | 26 | 64 | 7 | 51 | 48 | 10 | 31 | 79 | 78 | 5 |
| **80** | 48 | 42 | 77 | 53 | 55 | 21 | 42 | 35 | 22 | 19 | 56 | 25 | 33 | 8 | 42 | 3 | 80 | 75 |

Table E.19. Playback orders in the Purdue test, Part 2, subjects 19-35.

| **Order** | **Subjects** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **played** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** | **35** |
| **1** | 13 | 76 | 21 | 35 | 23 | 71 | 17 | 75 | 37 | 57 | 51 | 30 | 53 | 22 | 70 | 62 | 7 |
| **2** | 79 | 33 | 71 | 37 | 24 | 44 | 43 | 77 | 22 | 23 | 73 | 24 | 50 | 75 | 58 | 21 | 30 |
| **3** | 4 | 35 | 55 | 8 | 7 | 15 | 76 | 44 | 55 | 45 | 52 | 23 | 71 | 12 | 76 | 53 | 19 |
| **4** | 70 | 54 | 16 | 36 | 38 | 9 | 26 | 31 | 34 | 41 | 35 | 46 | 65 | 37 | 32 | 35 | 2 |
| **5** | 64 | 75 | 60 | 1 | 73 | 4 | 63 | 27 | 33 | 42 | 56 | 33 | 72 | 33 | 37 | 52 | 78 |
| **6** | 16 | 12 | 18 | 21 | 21 | 49 | 80 | 60 | 1 | 28 | 27 | 8 | 49 | 40 | 77 | 32 | 18 |
| **7** | 48 | 71 | 38 | 13 | 43 | 35 | 40 | 10 | 57 | 56 | 32 | 77 | 79 | 45 | 66 | 76 | 43 |
| **8** | 23 | 10 | 29 | 52 | 17 | 52 | 5 | 41 | 40 | 19 | 64 | 59 | 16 | 16 | 17 | 63 | 58 |
| **9** | 15 | 50 | 13 | 65 | 5 | 20 | 9 | 17 | 21 | 6 | 45 | 60 | 73 | 15 | 42 | 36 | 55 |
| **10** | 47 | 72 | 73 | 27 | 61 | 42 | 61 | 80 | 72 | 53 | 25 | 65 | 7 | 2 | 14 | 19 | 44 |
| **11** | 61 | 52 | 12 | 30 | 72 | 56 | 24 | 53 | 53 | 4 | 29 | 29 | 44 | 30 | 11 | 55 | 10 |
| **12** | 28 | 61 | 63 | 45 | 26 | 33 | 52 | 16 | 36 | 17 | 65 | 27 | 52 | 28 | 24 | 43 | 28 |
| **13** | 18 | 6 | 47 | 76 | 76 | 59 | 29 | 22 | 11 | 68 | 21 | 37 | 15 | 42 | 39 | 66 | 68 |
| **14** | 12 | 37 | 30 | 78 | 40 | 54 | 37 | 79 | 63 | 48 | 5 | 5 | 67 | 29 | 64 | 14 | 69 |
| **15** | 6 | 53 | 59 | 66 | 62 | 7 | 22 | 19 | 15 | 36 | 22 | 2 | 78 | 17 | 16 | 28 | 61 |
| **16** | 49 | 40 | 66 | 77 | 1 | 69 | 8 | 28 | 6 | 12 | 55 | 4 | 32 | 32 | 54 | 15 | 36 |
| **17** | 21 | 59 | 7 | 29 | 3 | 34 | 14 | 57 | 47 | 78 | 72 | 66 | 63 | 26 | 15 | 54 | 31 |
| **18** | 52 | 43 | 11 | 9 | 36 | 31 | 64 | 46 | 28 | 77 | 13 | 26 | 20 | 10 | 20 | 41 | 80 |
| **19** | 50 | 18 | 4 | 75 | 2 | 28 | 20 | 25 | 23 | 61 | 8 | 31 | 59 | 24 | 41 | 49 | 64 |
| **20** | 69 | 42 | 79 | 56 | 33 | 70 | 35 | 61 | 71 | 64 | 26 | 19 | 23 | 63 | 49 | 59 | 3 |

Table E.19. Continued from previous page.

| **Order played** | **Subjects** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** | **35** |
| **21** | 80 | 25 | 6 | 26 | 11 | 39 | 34 | 72 | 46 | 52 | 19 | 44 | 54 | 27 | 31 | 3 | 14 |
| **22** | 38 | 36 | 37 | 80 | 59 | 41 | 67 | 73 | 39 | 72 | 59 | 67 | 30 | 72 | 13 | 25 | 60 |
| **23** | 77 | 30 | 22 | 12 | 37 | 40 | 69 | 78 | 76 | 21 | 31 | 64 | 1 | 44 | 50 | 34 | 48 |
| **24** | 20 | 7 | 27 | 43 | 71 | 45 | 77 | 14 | 2 | 35 | 78 | 48 | 60 | 56 | 23 | 69 | 71 |
| **25** | 35 | 2 | 25 | 28 | 56 | 2 | 44 | 20 | 62 | 40 | 38 | 34 | 47 | 77 | 72 | 78 | 77 |
| **26** | 14 | 48 | 34 | 57 | 18 | 57 | 19 | 74 | 73 | 33 | 41 | 73 | 24 | 64 | 19 | 42 | 29 |
| **27** | 45 | 49 | 54 | 33 | 9 | 53 | 60 | 67 | 9 | 46 | 43 | 32 | 80 | 80 | 56 | 61 | 45 |
| **28** | 67 | 9 | 80 | 69 | 27 | 21 | 15 | 47 | 12 | 43 | 30 | 12 | 41 | 20 | 5 | 1 | 25 |
| **29** | 58 | 21 | 3 | 79 | 57 | 8 | 66 | 12 | 70 | 51 | 53 | 10 | 29 | 49 | 71 | 30 | 63 |
| **30** | 30 | 24 | 65 | 60 | 15 | 16 | 57 | 50 | 54 | 75 | 76 | 76 | 26 | 36 | 27 | 8 | 39 |
| **31** | 76 | 26 | 56 | 47 | 19 | 24 | 59 | 23 | 27 | 66 | 7 | 72 | 27 | 59 | 65 | 2 | 13 |
| **32** | 1 | 46 | 68 | 40 | 35 | 19 | 32 | 51 | 5 | 58 | 77 | 47 | 8 | 21 | 48 | 4 | 56 |
| **33** | 39 | 13 | 76 | 49 | 44 | 36 | 39 | 65 | 74 | 29 | 49 | 15 | 19 | 38 | 30 | 29 | 62 |
| **34** | 26 | 34 | 33 | 17 | 68 | 23 | 50 | 30 | 68 | 76 | 2 | 79 | 61 | 50 | 12 | 50 | 37 |
| **35** | 72 | 20 | 51 | 10 | 25 | 76 | 2 | 8 | 52 | 16 | 1 | 69 | 39 | 35 | 22 | 37 | 53 |
| **36** | 24 | 67 | 32 | 62 | 66 | 22 | 27 | 7 | 42 | 32 | 48 | 62 | 46 | 13 | 3 | 51 | 76 |
| **37** | 3 | 23 | 42 | 67 | 34 | 50 | 18 | 55 | 78 | 44 | 46 | 51 | 3 | 39 | 74 | 26 | 11 |
| **38** | 10 | 58 | 14 | 51 | 20 | 55 | 72 | 68 | 61 | 10 | 20 | 80 | 58 | 69 | 51 | 75 | 67 |
| **39** | 34 | 51 | 58 | 61 | 39 | 61 | 7 | 76 | 45 | 3 | 28 | 21 | 77 | 4 | 73 | 46 | 70 |
| **40** | 62 | 14 | 31 | 41 | 48 | 47 | 30 | 52 | 67 | 27 | 16 | 52 | 14 | 5 | 28 | 80 | 8 |

Table E.19. Continued from previous page.

| **Order** | **Subjects** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **played** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** | **35** |
| **41** | 60 | 17 | 24 | 42 | 14 | 38 | 4 | 40 | 65 | 79 | 10 | 70 | 68 | 61 | 53 | 22 | 15 |
| **42** | 31 | 64 | 78 | 38 | 65 | 32 | 28 | 36 | 30 | 65 | 80 | 6 | 5 | 19 | 6 | 6 | 49 |
| **43** | 37 | 44 | 53 | 22 | 8 | 80 | 10 | 3 | 80 | 59 | 58 | 68 | 11 | 41 | 25 | 48 | 9 |
| **44** | 59 | 47 | 67 | 72 | 54 | 73 | 53 | 6 | 17 | 5 | 33 | 16 | 48 | 43 | 78 | 10 | 1 |
| **45** | 9 | 66 | 19 | 50 | 28 | 75 | 49 | 29 | 16 | 67 | 60 | 55 | 31 | 6 | 75 | 47 | 65 |
| **46** | 56 | 16 | 35 | 39 | 31 | 12 | 54 | 56 | 48 | 26 | 14 | 28 | 57 | 53 | 26 | 27 | 41 |
| **47** | 27 | 56 | 64 | 25 | 69 | 11 | 16 | 11 | 35 | 69 | 75 | 41 | 43 | 62 | 1 | 11 | 79 |
| **48** | 41 | 78 | 75 | 5 | 79 | 43 | 42 | 49 | 20 | 11 | 44 | 78 | 75 | 7 | 4 | 65 | 21 |
| **49** | 57 | 79 | 70 | 32 | 41 | 72 | 21 | 62 | 14 | 7 | 79 | 53 | 6 | 65 | 55 | 12 | 23 |
| **50** | 78 | 11 | 26 | 48 | 42 | 48 | 36 | 9 | 51 | 25 | 11 | 57 | 69 | 18 | 40 | 31 | 74 |
| **51** | 44 | 31 | 43 | 46 | 45 | 27 | 75 | 45 | 13 | 47 | 71 | 11 | 76 | 9 | 36 | 67 | 59 |
| **52** | 66 | 3 | 62 | 15 | 67 | 29 | 46 | 43 | 31 | 55 | 50 | 75 | 17 | 71 | 9 | 74 | 40 |
| **53** | 22 | 70 | 17 | 54 | 30 | 63 | 25 | 64 | 7 | 14 | 23 | 54 | 40 | 1 | 80 | 24 | 26 |
| **54** | 36 | 15 | 48 | 63 | 60 | 68 | 56 | 66 | 38 | 8 | 57 | 56 | 74 | 8 | 52 | 72 | 27 |
| **55** | 68 | 32 | 57 | 70 | 10 | 60 | 6 | 48 | 8 | 71 | 37 | 43 | 25 | 57 | 21 | 70 | 42 |
| **56** | 43 | 28 | 23 | 16 | 12 | 25 | 79 | 13 | 56 | 62 | 34 | 20 | 33 | 58 | 47 | 9 | 33 |
| **57** | 33 | 69 | 52 | 20 | 52 | 1 | 12 | 69 | 41 | 31 | 40 | 63 | 35 | 3 | 67 | 38 | 72 |
| **58** | 32 | 65 | 1 | 7 | 51 | 17 | 78 | 32 | 24 | 63 | 63 | 1 | 13 | 60 | 44 | 13 | 73 |
| **59** | 25 | 29 | 69 | 14 | 64 | 64 | 51 | 35 | 29 | 38 | 9 | 18 | 2 | 79 | 69 | 20 | 6 |
| **60** | 73 | 45 | 45 | 3 | 58 | 67 | 3 | 5 | 75 | 49 | 24 | 38 | 56 | 23 | 2 | 7 | 52 |

Table E.19. Continued from previous page.

| **Order** | **Subjects** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **played** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** | **35** |
| **61** | 40 | 5 | 40 | 2 | 55 | 78 | 41 | 34 | 64 | 20 | 18 | 50 | 18 | 67 | 79 | 71 | 46 |
| **62** | 17 | 77 | 8 | 71 | 70 | 18 | 70 | 18 | 3 | 22 | 15 | 3 | 28 | 34 | 10 | 45 | 20 |
| **63** | 54 | 41 | 72 | 55 | 16 | 58 | 23 | 42 | 32 | 37 | 17 | 61 | 64 | 74 | 43 | 73 | 32 |
| **64** | 71 | 68 | 15 | 31 | 50 | 6 | 47 | 39 | 58 | 50 | 47 | 36 | 12 | 76 | 59 | 39 | 51 |
| **65** | 7 | 80 | 28 | 58 | 75 | 62 | 58 | 33 | 43 | 34 | 42 | 14 | 66 | 73 | 34 | 40 | 17 |
| **66** | 5 | 74 | 77 | 18 | 47 | 66 | 33 | 54 | 59 | 54 | 3 | 39 | 34 | 54 | 63 | 17 | 35 |
| **67** | 46 | 27 | 74 | 68 | 4 | 10 | 62 | 1 | 69 | 73 | 4 | 58 | 37 | 46 | 7 | 18 | 24 |
| **68** | 42 | 1 | 5 | 44 | 63 | 5 | 71 | 21 | 77 | 74 | 69 | 25 | 42 | 47 | 38 | 77 | 57 |
| **69** | 11 | 62 | 61 | 24 | 80 | 13 | 31 | 4 | 26 | 80 | 67 | 13 | 55 | 11 | 35 | 33 | 16 |
| **70** | 75 | 8 | 9 | 53 | 49 | 51 | 1 | 63 | 49 | 15 | 70 | 22 | 38 | 66 | 68 | 57 | 4 |
| **71** | 2 | 63 | 44 | 64 | 13 | 79 | 68 | 2 | 10 | 70 | 6 | 7 | 62 | 68 | 46 | 68 | 50 |
| **72** | 74 | 55 | 20 | 11 | 78 | 65 | 74 | 26 | 66 | 13 | 54 | 40 | 10 | 14 | 57 | 44 | 22 |
| **73** | 51 | 39 | 39 | 4 | 74 | 46 | 73 | 70 | 79 | 60 | 62 | 49 | 70 | 55 | 45 | 64 | 75 |
| **74** | 8 | 57 | 46 | 19 | 22 | 30 | 65 | 71 | 25 | 18 | 74 | 71 | 51 | 48 | 62 | 5 | 5 |
| **75** | 53 | 38 | 41 | 34 | 6 | 3 | 48 | 37 | 4 | 2 | 12 | 42 | 36 | 31 | 61 | 23 | 54 |
| **76** | 65 | 60 | 10 | 23 | 53 | 26 | 11 | 15 | 50 | 1 | 39 | 17 | 45 | 78 | 60 | 60 | 47 |
| **77** | 19 | 73 | 50 | 6 | 29 | 14 | 13 | 59 | 18 | 30 | 66 | 74 | 22 | 25 | 8 | 79 | 12 |
| **78** | 63 | 22 | 2 | 59 | 77 | 77 | 38 | 24 | 60 | 39 | 61 | 45 | 21 | 51 | 33 | 16 | 34 |
| **79** | 29 | 4 | 36 | 73 | 46 | 74 | 55 | 58 | 19 | 24 | 68 | 35 | 4 | 70 | 29 | 56 | 38 |
| **80** | 55 | 19 | 49 | 74 | 32 | 37 | 45 | 38 | 44 | 9 | 36 | 9 | 9 | 52 | 18 | 58 | 66 |

## E.4 Metrics

Tables E.20 and E.21 contains all major metrics used in the Purdue test, for Part 1 and Part 2 sounds respectively.

Table E.22 contains correlation values between all major metrics used in the Purdue test. These correlations were calculated for entire groups of metrics, for both Part 1 and Part 2 sounds.

Table E.20. Metrics calculated for the Purdue test sounds played during Part 1 of the test. Metric acronyms are given in Table 4.1.

| **Sound** | **PL (dB)** | **ZN$_{max}$ (sone)** | **ASEL (dB)** | **SN$_{15}$ (sone)** | **LN$_{Et}$ (sone)** | **SN$_{max}$ (sone)** | **LN$_{max}$ (sone)** | **dZN$_{max}$ (sone/s)** | **dSN$_{max}$ (sone/s)** | **dLN$_{max}$ (sone/s)** | **Dur (s)** | **H (dB)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 61.5 | 7.62 | 47.2 | 7.19 | 4.77 | 9.23 | 6.39 | 177 | 255 | 60 | 0.632 | 18.8 |
| **2** | 60.6 | 5.84 | 46.0 | 4.81 | 3.36 | 5.54 | 4.49 | 169 | 178 | 37 | 0.819 | 30.0 |
| **3** | 61.3 | 7.10 | 47.1 | 7.47 | 4.73 | 8.63 | 6.33 | 236 | 267 | 58 | 0.583 | 14.7 |
| **4** | 61.1 | 6.41 | 46.6 | 4.80 | 3.90 | 7.52 | 5.18 | 248 | 283 | 58 | 0.779 | 21.5 |
| **5** | 60.9 | 6.47 | 46.2 | 4.01 | 3.57 | 6.90 | 4.71 | 205 | 227 | 48 | 0.889 | 23.7 |
| **6** | 61.7 | 6.60 | 47.1 | 5.01 | 3.37 | 6.75 | 4.53 | 199 | 216 | 49 | 0.657 | 22.4 |
| **7** | 71.1 | 15.10 | 57.2 | 11.20 | 8.95 | 17.02 | 11.93 | 337 | 471 | 111 | 0.891 | 19.0 |
| **8** | 69.1 | 10.76 | 53.9 | 8.23 | 5.83 | 9.46 | 7.77 | 294 | 295 | 64 | 0.923 | 30.3 |
| **9** | 70.9 | 14.62 | 57.6 | 14.14 | 9.22 | 16.54 | 12.30 | 460 | 492 | 112 | 0.648 | 14.7 |
| **10** | 70.2 | 12.41 | 56.0 | 7.46 | 7.21 | 13.65 | 9.49 | 467 | 506 | 105 | 1.068 | 21.8 |
| **11** | 70.2 | 12.69 | 55.5 | 6.65 | 6.56 | 12.50 | 8.58 | 385 | 404 | 88 | 1.041 | 23.9 |
| **12** | 68.9 | 10.78 | 54.0 | 6.33 | 5.64 | 11.01 | 7.54 | 227 | 297 | 80 | 0.879 | 29.9 |
| **13** | 71.0 | 11.99 | 57.1 | 8.61 | 6.39 | 10.23 | 8.52 | 270 | 338 | 73 | 1.127 | 21.0 |
| **14** | 69.8 | 11.92 | 56.6 | 9.78 | 7.25 | 11.08 | 9.51 | 407 | 405 | 77 | 1.072 | 18.9 |
| **15** | 75.4 | 19.47 | 61.3 | 12.90 | 10.92 | 22.12 | 14.51 | 572 | 627 | 152 | 0.901 | 20.2 |
| **16** | 74.9 | 19.56 | 61.1 | 13.74 | 11.35 | 21.54 | 15.12 | 428 | 587 | 140 | 0.944 | 19.1 |
| **17** | 78.9 | 25.41 | 65.8 | 21.40 | 15.08 | 26.73 | 20.03 | 756 | 757 | 179 | 0.800 | 14.7 |
| **18** | 78.6 | 22.41 | 66.3 | 16.88 | 13.10 | 21.36 | 17.38 | 857 | 777 | 153 | 1.223 | 16.8 |
| **19** | 78.9 | 21.47 | 63.1 | 12.04 | 9.50 | 18.80 | 12.68 | 577 | 596 | 135 | 0.805 | 22.8 |
| **20** | 78.7 | 22.45 | 66.3 | 17.45 | 13.21 | 21.57 | 17.53 | 917 | 828 | 155 | 1.047 | 16.7 |

Table E.20. Continued from previous page.

| **Sound** | **PL** (dB) | **ZN$_{max}$** (sone) | **ASEL** (dB) | **SN$_{15}$** (sone) | **LN$_{Et}$** (sone) | **SN$_{max}$** (sone) | **LN$_{max}$** (sone) | **dZN$_{max}$** (sone/s) | **dSN$_{max}$** (sone/s) | **dLN$_{max}$** (sone/s) | **Dur** (s) | **H** (dB) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **21** | 77.1 | 21.40 | 62.8 | 9.09 | 11.37 | 18.67 | 15.19 | 696 | 652 | 134 | 1.967 | 25.0 |
| **22** | 71.7 | 14.32 | 59.2 | 12.74 | 9.05 | 15.71 | 12.00 | 626 | 648 | 123 | 0.848 | 17.1 |
| **23** | 77.3 | 20.27 | 64.2 | 14.97 | 11.62 | 17.65 | 15.21 | 655 | 636 | 123 | 1.275 | 19.2 |
| **24** | 61.7 | 6.34 | 47.7 | 4.79 | 3.27 | 5.24 | 4.39 | 77 | 102 | 33 | 0.784 | 21.7 |
| **25** | 65.9 | 8.54 | 51.6 | 6.21 | 4.38 | 7.01 | 5.85 | 100 | 135 | 43 | 0.875 | 21.8 |
| **26** | 70.3 | 11.56 | 55.5 | 7.99 | 5.66 | 8.96 | 7.54 | 140 | 173 | 58 | 0.885 | 21.8 |
| **27** | 74.7 | 15.45 | 59.3 | 10.66 | 7.53 | 11.84 | 10.02 | 176 | 216 | 74 | 0.939 | 22.0 |
| **28** | 61.3 | 6.38 | 47.9 | 2.29 | 1.79 | 3.00 | 2.36 | 71 | 60 | 18 | 1.077 | 35.9 |
| **29** | 67.1 | 9.09 | 52.1 | 3.66 | 2.81 | 4.35 | 3.71 | 78 | 84 | 26 | 1.053 | 35.9 |
| **30** | 73.2 | 14.80 | 56.3 | 5.73 | 4.34 | 6.81 | 5.72 | 140 | 128 | 44 | 1.113 | 36.0 |
| **31** | 78.7 | 21.18 | 60.4 | 9.19 | 7.45 | 12.13 | 9.86 | 218 | 196 | 70 | 1.167 | 35.6 |
| **32** | 57.4 | 5.16 | 43.3 | 3.23 | 2.46 | 4.47 | 3.30 | 62 | 71 | 23 | 0.795 | 27.3 |
| **33** | 61.3 | 6.90 | 47.4 | 3.95 | 3.30 | 5.95 | 4.41 | 77 | 98 | 29 | 0.848 | 27.4 |
| **34** | 70.0 | 13.51 | 55.4 | 7.68 | 6.39 | 11.31 | 8.51 | 165 | 180 | 61 | 1.005 | 27.3 |
| **35** | 65.8 | 7.94 | 52.0 | 3.56 | 2.58 | 4.25 | 3.44 | 68 | 97 | 27 | 0.925 | 31.0 |
| **36** | 71.1 | 11.68 | 56.2 | 5.08 | 3.75 | 6.42 | 4.99 | 112 | 141 | 41 | 0.976 | 31.0 |
| **37** | 76.4 | 17.08 | 60.3 | 6.63 | 5.20 | 8.66 | 6.91 | 164 | 196 | 56 | 1.060 | 31.1 |
| **38** | 81.4 | 25.24 | 64.2 | 9.56 | 7.56 | 12.31 | 10.06 | 212 | 291 | 79 | 1.076 | 31.1 |
| **39** | 75.4 | 15.36 | 61.3 | 11.57 | 8.48 | 13.67 | 11.28 | 444 | 492 | 99 | 0.979 | 19.4 |
| **40** | 79.7 | 20.38 | 65.3 | 14.63 | 10.90 | 17.48 | 14.47 | 570 | 631 | 126 | 1.048 | 19.5 |

Table E.20. Continued from previous page.

| **Sound** | **PL (dB)** | **ZN$_{max}$ (sone)** | **ASEL (dB)** | **SN$_{15}$ (sone)** | **LN$_{Et}$ (sone)** | **SN$_{max}$ (sone)** | **LN$_{max}$ (sone)** | **dZN$_{max}$ (sone/s)** | **dSN$_{max}$ (sone/s)** | **dLN$_{max}$ (sone/s)** | **Dur (s)** | **H (dB)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **41** | 83.9 | 27.04 | 69.3 | 18.57 | 14.00 | 22.26 | 18.58 | 740 | 794 | 161 | 1.151 | 19.6 |
| **42** | 88.1 | 35.70 | 73.2 | 23.66 | 17.79 | 28.13 | 23.60 | 956 | 1011 | 202 | 1.120 | 19.8 |
| **43** | 66.1 | 8.93 | 52.2 | 5.72 | 4.53 | 7.61 | 6.03 | 141 | 182 | 43 | 0.911 | 26.3 |
| **44** | 70.4 | 12.55 | 56.2 | 7.51 | 6.22 | 10.39 | 8.28 | 191 | 226 | 56 | 0.987 | 26.4 |
| **45** | 74.5 | 16.20 | 60.1 | 10.22 | 7.96 | 12.93 | 10.52 | 275 | 291 | 79 | 1.196 | 26.7 |
| **46** | 61.1 | 7.47 | 47.1 | 7.28 | 4.72 | 9.14 | 6.33 | 180 | 257 | 59 | 0.577 | 15.9 |
| **47** | 61.2 | 7.03 | 47.1 | 7.51 | 4.69 | 8.58 | 6.29 | 233 | 278 | 58 | 0.564 | 14.5 |
| **48** | 60.3 | 6.11 | 46.8 | 5.28 | 3.84 | 6.01 | 5.06 | 209 | 225 | 41 | 0.899 | 15.5 |
| **49** | 70.8 | 14.52 | 57.5 | 13.28 | 9.21 | 16.46 | 12.27 | 452 | 490 | 111 | 0.747 | 14.4 |
| **50** | 69.5 | 12.32 | 55.9 | 7.34 | 7.15 | 13.37 | 9.42 | 474 | 511 | 103 | 1.097 | 16.7 |
| **51** | 74.6 | 19.08 | 61.0 | 14.43 | 10.79 | 21.78 | 14.36 | 581 | 622 | 150 | 0.771 | 15.6 |
| **52** | 78.8 | 25.31 | 65.8 | 22.00 | 15.04 | 26.67 | 19.99 | 782 | 771 | 179 | 0.768 | 14.4 |
| **53** | 76.0 | 19.80 | 62.5 | 9.39 | 11.09 | 18.06 | 14.79 | 668 | 647 | 129 | 1.989 | 18.4 |
| **54** | 61.4 | 6.35 | 47.7 | 4.73 | 3.25 | 5.22 | 4.35 | 82 | 111 | 32 | 0.731 | 20.1 |
| **55** | 70.3 | 11.88 | 55.8 | 8.09 | 5.65 | 9.00 | 7.54 | 133 | 172 | 55 | 0.807 | 20.2 |
| **56** | 74.8 | 16.07 | 59.8 | 10.30 | 7.34 | 11.61 | 9.78 | 173 | 220 | 71 | 0.897 | 20.2 |
| **57** | 49.6 | 2.25 | 37.6 | 0.95 | 0.67 | 1.18 | 0.91 | 20 | 23 | 6 | 0.853 | 34.2 |
| **58** | 53.7 | 3.48 | 41.7 | 1.34 | 0.95 | 1.64 | 1.27 | 40 | 31 | 9 | 0.868 | 34.2 |
| **59** | 58.2 | 5.11 | 45.9 | 1.80 | 1.37 | 2.32 | 1.83 | 49 | 47 | 14 | 0.929 | 34.2 |
| **60** | 56.2 | 4.86 | 42.5 | 3.23 | 2.27 | 4.14 | 3.06 | 59 | 69 | 20 | 0.617 | 19.9 |

Table E.20. Continued from previous page.

| **Sound** | **PL** (dB) | **ZN$_{max}$** (sone) | **ASEL** (dB) | **SN$_{15}$** (sone) | **LN$_{Et}$** (sone) | **SN$_{max}$** (sone) | **LN$_{max}$** (sone) | **dZN$_{max}$** (sone/s) | **dSN$_{max}$** (sone/s) | **dLN$_{max}$** (sone/s) | **Dur** (s) | **H** (dB) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **61** | 59.9 | 6.44 | 46.5 | 4.03 | 2.99 | 5.42 | 4.01 | 76 | 88 | 26 | 0.745 | 20.0 |
| **62** | 63.9 | 9.03 | 50.6 | 4.90 | 3.90 | 7.01 | 5.21 | 101 | 119 | 34 | 0.792 | 20.1 |
| **63** | 68.0 | 12.26 | 54.6 | 6.61 | 5.04 | 9.02 | 6.73 | 133 | 155 | 44 | 0.767 | 20.2 |
| **64** | 61.9 | 6.29 | 48.8 | 3.10 | 2.18 | 3.53 | 2.92 | 66 | 84 | 22 | 0.848 | 27.7 |
| **65** | 66.6 | 8.69 | 52.9 | 4.13 | 3.02 | 4.86 | 4.02 | 84 | 113 | 30 | 0.917 | 27.7 |
| **66** | 71.3 | 12.47 | 57.0 | 5.64 | 4.12 | 6.59 | 5.48 | 126 | 150 | 42 | 0.971 | 27.7 |
| **67** | 76.3 | 17.79 | 61.1 | 7.91 | 5.95 | 9.73 | 7.90 | 186 | 212 | 61 | 1.031 | 27.8 |
| **68** | 74.8 | 15.09 | 61.0 | 11.79 | 8.39 | 13.51 | 11.16 | 424 | 494 | 97 | 0.901 | 17.9 |
| **69** | 79.1 | 19.93 | 65.1 | 14.83 | 10.75 | 17.23 | 14.29 | 548 | 627 | 124 | 0.960 | 17.9 |
| **70** | 83.3 | 26.41 | 69.1 | 18.62 | 13.77 | 21.97 | 18.27 | 712 | 786 | 158 | 1.052 | 18.0 |
| **71** | 87.5 | 35.29 | 73.2 | 23.26 | 17.76 | 28.20 | 23.54 | 933 | 1003 | 203 | 1.129 | 18.0 |
| **72** | 60.7 | 6.27 | 47.3 | 4.13 | 3.25 | 5.57 | 4.36 | 99 | 131 | 30 | 0.809 | 19.5 |
| **73** | 64.7 | 8.31 | 51.4 | 5.36 | 4.23 | 7.19 | 5.66 | 130 | 169 | 39 | 0.817 | 19.6 |
| **74** | 68.7 | 11.20 | 55.4 | 6.90 | 5.46 | 9.22 | 7.28 | 172 | 216 | 51 | 0.904 | 19.7 |
| **75** | 72.9 | 15.02 | 59.5 | 8.76 | 7.02 | 11.78 | 9.34 | 221 | 277 | 66 | 1.085 | 19.8 |
| **76** | 61.0 | 6.53 | 46.4 | 4.54 | 3.82 | 7.48 | 5.03 | 179 | 216 | 50 | 0.853 | 23.2 |
| **77** | 75.2 | 20.98 | 61.9 | 14.31 | 12.05 | 23.72 | 16.06 | 397 | 556 | 147 | 0.889 | 18.0 |
| **78** | 79.6 | 23.81 | 60.7 | 14.40 | 11.17 | 16.67 | 14.55 | 355 | 366 | 106 | 1.335 | 34.9 |
| **79** | 78.9 | 26.88 | 66.5 | 23.01 | 15.89 | 28.58 | 21.09 | 732 | 771 | 203 | 0.756 | 13.0 |
| **80** | 86.7 | 34.65 | 73.1 | 26.18 | 18.53 | 28.81 | 24.59 | 888 | 940 | 203 | 0.921 | 17.1 |

Table E.21. Metrics calculated for the Purdue test sounds played during Part 2 of the test. Metric acronyms are given in Table 4.1.

| **Sound** | **PL (dB)** | **ZN$_{max}$ (sone)** | **ASEL (dB)** | **SN$_{15}$ (sone)** | **LN$_{Et}$ (sone)** | **SN$_{max}$ (sone)** | **LN$_{max}$ (sone)** | **dZN$_{max}$ (sone/s)** | **dSN$_{max}$ (sone/s)** | **dLN$_{max}$ (sone/s)** | **Dur (s)** | **H (dB)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 61.9 | 7.62 | 47.8 | 7.02 | 4.68 | 9.22 | 6.27 | 184 | 245 | 66 | 0.628 | 19.2 |
| **2** | 61.6 | 6.06 | 46.9 | 5.06 | 3.41 | 5.85 | 4.55 | 127 | 144 | 39 | 0.807 | 30.7 |
| **3** | 61.5 | 7.56 | 47.9 | 7.38 | 4.79 | 9.26 | 6.41 | 171 | 222 | 61 | 0.557 | 13.5 |
| **4** | 61.8 | 6.54 | 47.8 | 4.75 | 3.89 | 7.90 | 5.15 | 243 | 228 | 57 | 0.887 | 22.0 |
| **5** | 61.6 | 6.30 | 47.3 | 4.20 | 3.59 | 7.09 | 4.73 | 184 | 192 | 51 | 0.884 | 24.6 |
| **6** | 61.6 | 6.37 | 46.9 | 4.88 | 3.28 | 6.80 | 4.40 | 164 | 186 | 50 | 0.643 | 24.1 |
| **7** | 71.3 | 15.00 | 57.6 | 11.35 | 8.77 | 16.92 | 11.69 | 345 | 436 | 122 | 0.844 | 19.5 |
| **8** | 70.5 | 11.17 | 55.0 | 8.72 | 6.07 | 10.25 | 8.07 | 208 | 235 | 71 | 0.925 | 30.9 |
| **9** | 71.3 | 15.34 | 58.2 | 13.88 | 9.24 | 17.58 | 12.31 | 321 | 405 | 116 | 0.683 | 13.6 |
| **10** | 71.3 | 12.84 | 57.2 | 7.83 | 7.28 | 14.35 | 9.58 | 425 | 411 | 105 | 1.061 | 22.4 |
| **11** | 71.0 | 12.38 | 56.5 | 6.99 | 6.64 | 12.80 | 8.68 | 331 | 347 | 94 | 1.119 | 24.9 |
| **12** | 70.6 | 12.60 | 55.6 | 7.09 | 6.02 | 11.89 | 8.04 | 223 | 245 | 80 | 0.921 | 29.8 |
| **13** | 71.7 | 13.43 | 58.2 | 9.89 | 7.44 | 11.45 | 9.76 | 312 | 322 | 80 | 1.133 | 19.6 |
| **14** | 76.5 | 20.56 | 62.4 | 13.67 | 11.36 | 21.71 | 15.13 | 587 | 526 | 154 | 1.000 | 20.3 |
| **15** | 75.1 | 19.67 | 61.4 | 13.66 | 11.10 | 21.30 | 14.78 | 436 | 546 | 153 | 0.919 | 19.7 |
| **16** | 79.5 | 26.28 | 66.4 | 21.21 | 15.06 | 28.36 | 20.00 | 522 | 621 | 187 | 0.867 | 13.7 |
| **17** | 79.1 | 22.67 | 66.3 | 17.14 | 13.09 | 20.87 | 17.34 | 617 | 598 | 147 | 1.044 | 17.9 |
| **18** | 78.6 | 22.11 | 62.7 | 12.37 | 9.27 | 18.43 | 12.36 | 499 | 506 | 137 | 0.809 | 24.7 |
| **19** | 79.1 | 22.69 | 66.2 | 17.79 | 13.19 | 21.09 | 17.48 | 628 | 602 | 148 | 1.007 | 17.8 |
| **20** | 78.4 | 21.36 | 62.9 | 9.65 | 11.24 | 18.43 | 14.98 | 555 | 543 | 134 | 2.029 | 26.8 |

Table E.21. Continued from previous page.

| **Sound** | **PL** (dB) | **ZN$_{max}$** (sone) | **ASEL** (dB) | **SN$_{15}$** (sone) | **LN$_{Et}$** (sone) | **SN$_{max}$** (sone) | **LN$_{max}$** (sone) | **dZN$_{max}$** (sone/s) | **dSN$_{max}$** (sone/s) | **dLN$_{max}$** (sone/s) | **Dur** (s) | **H** (dB) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **21** | 71.8 | 14.18 | 58.9 | 12.42 | 8.85 | 15.71 | 11.69 | 478 | 497 | 118 | 0.908 | 18.7 |
| **22** | 79.7 | 23.18 | 65.8 | 15.70 | 12.04 | 18.50 | 15.75 | 525 | 508 | 128 | 1.349 | 19.8 |
| **23** | 65.3 | 8.65 | 51.4 | 5.93 | 4.37 | 7.41 | 5.83 | 97 | 122 | 42 | 0.836 | 22.5 |
| **24** | 69.8 | 11.47 | 55.3 | 7.67 | 5.65 | 9.36 | 7.53 | 139 | 156 | 56 | 0.849 | 22.6 |
| **25** | 74.3 | 15.44 | 59.3 | 10.08 | 7.52 | 12.35 | 10.01 | 174 | 202 | 72 | 0.939 | 22.8 |
| **26** | 62.4 | 6.89 | 48.8 | 2.43 | 1.86 | 3.02 | 2.46 | 65 | 61 | 17 | 1.068 | 36.2 |
| **27** | 68.4 | 9.63 | 53.0 | 3.95 | 3.07 | 4.76 | 4.06 | 81 | 96 | 27 | 1.188 | 36.2 |
| **28** | 74.4 | 15.89 | 57.2 | 6.11 | 4.59 | 7.15 | 6.04 | 155 | 146 | 47 | 1.133 | 36.2 |
| **29** | 80.1 | 22.16 | 61.6 | 9.89 | 7.89 | 12.80 | 10.42 | 210 | 253 | 77 | 1.233 | 35.5 |
| **30** | 58.0 | 5.17 | 44.2 | 2.99 | 2.54 | 4.88 | 3.41 | 67 | 71 | 25 | 0.753 | 28.2 |
| **31** | 61.9 | 6.86 | 48.2 | 3.73 | 3.37 | 6.41 | 4.52 | 84 | 92 | 33 | 0.831 | 28.3 |
| **32** | 70.7 | 13.21 | 56.3 | 7.36 | 6.53 | 12.23 | 8.71 | 249 | 222 | 61 | 1.040 | 28.5 |
| **33** | 68.5 | 10.89 | 54.7 | 3.88 | 2.92 | 5.05 | 3.88 | 129 | 128 | 36 | 1.019 | 30.7 |
| **34** | 74.0 | 16.11 | 58.8 | 5.41 | 4.24 | 7.42 | 5.61 | 178 | 188 | 54 | 1.139 | 30.7 |
| **35** | 78.9 | 22.57 | 62.7 | 7.35 | 5.96 | 10.28 | 7.91 | 242 | 280 | 76 | 1.121 | 30.7 |
| **36** | 83.8 | 31.06 | 66.5 | 10.83 | 8.67 | 14.58 | 11.50 | 384 | 399 | 109 | 1.176 | 30.5 |
| **37** | 75.1 | 15.47 | 61.2 | 11.31 | 8.38 | 13.42 | 11.12 | 349 | 397 | 95 | 0.959 | 20.4 |
| **38** | 79.4 | 20.59 | 65.3 | 14.55 | 10.82 | 17.27 | 14.34 | 475 | 509 | 121 | 1.020 | 20.5 |
| **39** | 83.8 | 27.41 | 69.4 | 18.54 | 13.98 | 22.15 | 18.51 | 643 | 649 | 155 | 1.093 | 20.7 |
| **40** | 88.1 | 36.63 | 73.3 | 23.24 | 17.88 | 28.08 | 23.65 | 819 | 833 | 194 | 1.161 | 20.8 |

Table E.21. Continued from previous page.

| Sound | PL (dB) | $ZN_{max}$ (sone) | ASEL (dB) | $SN_{15}$ (sone) | $LN_{Et}$ (sone) | $SN_{max}$ (sone) | $LN_{max}$ (sone) | $dZN_{max}$ (sone/s) | $dSN_{max}$ (sone/s) | $dLN_{max}$ (sone/s) | Dur (s) | H (dB) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **41** | 66.7 | 8.72 | 53.0 | 6.04 | 4.50 | 7.22 | 5.97 | 175 | 186 | 45 | 0.915 | 27.2 |
| **42** | 71.1 | 12.05 | 57.1 | 8.05 | 6.18 | 9.85 | 8.19 | 250 | 242 | 59 | 1.007 | 27.3 |
| **43** | 75.5 | 15.99 | 61.0 | 10.55 | 7.92 | 12.27 | 10.45 | 350 | 300 | 81 | 1.097 | 27.5 |
| **44** | 61.4 | 7.44 | 47.6 | 7.25 | 4.61 | 9.10 | 6.19 | 181 | 240 | 66 | 0.591 | 15.4 |
| **45** | 61.4 | 7.54 | 47.9 | 7.31 | 4.75 | 9.19 | 6.36 | 181 | 233 | 61 | 0.603 | 12.9 |
| **46** | 71.2 | 15.28 | 58.2 | 13.53 | 9.22 | 17.49 | 12.29 | 320 | 405 | 116 | 0.680 | 12.9 |
| **47** | 70.3 | 12.31 | 56.9 | 7.70 | 7.12 | 14.08 | 9.37 | 426 | 402 | 102 | 1.127 | 17.2 |
| **48** | 75.7 | 20.14 | 62.2 | 15.53 | 11.24 | 21.48 | 14.98 | 589 | 519 | 152 | 0.761 | 15.7 |
| **49** | 79.3 | 26.11 | 66.4 | 20.82 | 14.99 | 28.19 | 19.91 | 522 | 646 | 186 | 0.773 | 13.0 |
| **50** | 76.0 | 19.87 | 62.4 | 9.47 | 10.90 | 17.72 | 14.52 | 537 | 525 | 131 | 1.941 | 20.0 |
| **51** | 60.4 | 6.45 | 47.2 | 4.47 | 3.21 | 5.45 | 4.30 | 79 | 95 | 32 | 0.719 | 19.9 |
| **52** | 69.2 | 11.51 | 55.3 | 7.61 | 5.58 | 9.29 | 7.44 | 133 | 158 | 55 | 0.832 | 20.0 |
| **53** | 73.9 | 15.40 | 59.4 | 9.73 | 7.25 | 12.05 | 9.65 | 174 | 200 | 71 | 0.895 | 20.1 |
| **54** | 51.5 | 2.64 | 39.2 | 0.98 | 0.72 | 1.19 | 0.96 | 30 | 33 | 7 | 0.865 | 33.8 |
| **55** | 55.6 | 3.93 | 43.4 | 1.42 | 1.05 | 1.79 | 1.40 | 41 | 44 | 12 | 0.932 | 33.8 |
| **56** | 60.5 | 5.68 | 47.5 | 1.96 | 1.49 | 2.47 | 1.99 | 54 | 63 | 17 | 0.987 | 33.8 |
| **57** | 56.4 | 4.62 | 43.1 | 2.88 | 2.29 | 4.39 | 3.08 | 62 | 67 | 23 | 0.659 | 20.1 |
| **58** | 60.2 | 6.15 | 47.1 | 3.60 | 2.99 | 5.70 | 4.02 | 82 | 84 | 30 | 0.700 | 20.2 |
| **59** | 64.1 | 8.33 | 51.2 | 4.72 | 3.89 | 7.38 | 5.22 | 110 | 111 | 39 | 0.741 | 20.4 |
| **60** | 68.1 | 11.39 | 55.2 | 6.06 | 5.03 | 9.48 | 6.72 | 146 | 146 | 49 | 0.792 | 20.6 |

Table E.21. Continued from previous page.

| **Sound** | **PL** (dB) | **ZN$_{max}$** (sone) | **ASEL** (dB) | **SN$_{15}$** (sone) | **LN$_{Et}$** (sone) | **SN$_{max}$** (sone) | **LN$_{max}$** (sone) | **dZN$_{max}$** (sone/s) | **dSN$_{max}$** (sone/s) | **dLN$_{max}$** (sone/s) | **Dur** (s) | **H** (dB) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **61** | 64.6 | 8.02 | 51.3 | 3.39 | 2.37 | 3.95 | 3.15 | 93 | 86 | 27 | 0.892 | 28.5 |
| **62** | 74.6 | 17.02 | 59.6 | 6.09 | 4.62 | 7.58 | 6.12 | 193 | 179 | 54 | 1.000 | 28.5 |
| **63** | 78.9 | 24.33 | 63.5 | 8.33 | 6.65 | 10.89 | 8.81 | 257 | 267 | 78 | 1.161 | 28.5 |
| **64** | 74.4 | 15.07 | 60.9 | 11.26 | 8.20 | 13.00 | 10.88 | 347 | 400 | 91 | 0.921 | 18.2 |
| **65** | 78.7 | 19.96 | 65.0 | 14.42 | 10.56 | 16.69 | 13.99 | 459 | 510 | 116 | 0.972 | 18.2 |
| **66** | 82.9 | 26.35 | 69.0 | 18.00 | 13.60 | 21.41 | 18.01 | 614 | 650 | 147 | 1.109 | 18.3 |
| **67** | 87.2 | 35.01 | 73.1 | 23.16 | 17.55 | 27.39 | 23.21 | 783 | 837 | 188 | 1.104 | 18.4 |
| **68** | 64.9 | 7.84 | 52.0 | 5.59 | 4.07 | 6.47 | 5.42 | 171 | 176 | 41 | 0.825 | 20.1 |
| **69** | 69.0 | 10.40 | 56.0 | 7.22 | 5.28 | 8.33 | 7.02 | 225 | 224 | 54 | 0.919 | 20.2 |
| **70** | 73.2 | 14.22 | 60.0 | 9.23 | 6.79 | 10.69 | 9.00 | 295 | 286 | 69 | 0.967 | 20.4 |
| **71** | 62.0 | 6.82 | 47.6 | 4.82 | 3.89 | 7.78 | 5.12 | 165 | 198 | 56 | 0.847 | 24.6 |
| **72** | 59.2 | 5.50 | 45.3 | 3.86 | 3.29 | 6.26 | 4.30 | 150 | 182 | 40 | 1.039 | 24.8 |
| **73** | 75.4 | 19.68 | 61.4 | 14.20 | 11.52 | 22.88 | 15.31 | 530 | 612 | 163 | 0.868 | 20.0 |
| **74** | 72.0 | 15.56 | 59.7 | 12.17 | 9.22 | 16.64 | 12.04 | 417 | 447 | 105 | 0.907 | 17.0 |
| **75** | 80.3 | 23.22 | 61.6 | 12.46 | 9.73 | 15.45 | 12.73 | 330 | 391 | 106 | 1.289 | 35.4 |
| **76** | 65.6 | 10.03 | 52.7 | 3.03 | 2.25 | 3.84 | 3.00 | 118 | 74 | 23 | 0.964 | 30.8 |
| **77** | 79.0 | 25.45 | 66.3 | 22.45 | 15.60 | 29.12 | 20.70 | 647 | 746 | 196 | 0.756 | 12.8 |
| **78** | 76.6 | 20.71 | 64.9 | 16.81 | 12.28 | 19.94 | 16.00 | 607 | 538 | 129 | 0.961 | 13.7 |
| **79** | 86.8 | 35.75 | 72.7 | 25.49 | 18.56 | 29.52 | 24.59 | 763 | 845 | 202 | 0.952 | 18.7 |
| **80** | 84.8 | 31.23 | 71.3 | 20.58 | 15.89 | 24.36 | 20.77 | 754 | 776 | 156 | 1.101 | 19.0 |

Table E.22. Correlations between all metrics calculated for Purdue test signals, in $R^2$ values. Numbers in (parentheses) refer to correlations where the correlation coefficient is negative. Metric acronyms are given in Table 4.1.

| | **PL** | **ZN**$_{max}$ | **ASEL** | **SN**$_{15}$ | **LN**$_{Et}$ | **SN**$_{max}$ | **LN**$_{max}$ | **dZN**$_{max}$ | **dSN**$_{max}$ | **dLN**$_{max}$ | **S**$_{max}$ | **Dur** | **H** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PL** | 1 | 0.918 | 0.979 | 0.714 | 0.770 | 0.699 | 0.768 | 0.626 | 0.636 | 0.690 | N/A | 0.227 | (0.052) |
| **ZN**$_{max}$ | | 1 | 0.918 | 0.814 | 0.863 | 0.798 | 0.862 | 0.712 | 0.729 | 0.785 | N/A | 0.176 | (0.073) |
| **ASEL** | | | 1 | 0.777 | 0.829 | 0.760 | 0.828 | 0.699 | 0.707 | 0.751 | N/A | 0.202 | (0.099) |
| **SN**$_{15}$ | | | | 1 | 0.961 | 0.930 | 0.961 | 0.820 | 0.862 | 0.909 | N/A | 0.025 | (0.304) |
| **LN**$_{Et}$ | | | | | 1 | 0.969 | 0.99986 | 0.883 | 0.914 | 0.955 | N/A | 0.097 | (0.266) |
| **SN**$_{max}$ | | | | | | 1 | 0.971 | 0.859 | 0.906 | 0.984 | N/A | 0.057 | (0.31) |
| **LN**$_{max}$ | | | | | | | 1 | 0.883 | 0.914 | 0.956 | N/A | 0.096 | (0.269) |
| **dZN**$_{max}$ | | | | | | | | 1 | 0.972 | 0.901 | N/A | 0.122 | (0.269) |
| **dSN**$_{max}$ | | | | | | | | | 1 | 0.942 | N/A | 0.087 | (0.309) |
| **dLN**$_{max}$ | | | | | | | | | | 1 | N/A | 0.069 | (0.301) |
| **S**$_{max}$ | | | | | | | | | | | 1 | N/A | N/A |
| **Dur** | | | | | | | | | | | | 1 | 0.082 |
| **H** | | | | | | | | | | | | | 1 |