Psychoacoustical demonstrations and experiments over the World Wide Web

Norma Welch

Faculty of Music
McGill University
Montreal, Canada.

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Abstract

The World Wide Web provides the capability of delivering multi-media presentations to a wide audience. This thesis details the design and development of the site *Psychoacoustical demonstrations and experiments* at McGill University; it discusses site organization, selection of materials and development methods. In order to evaluate the utility of the site, site usage data, feedback from readers and data from experiments are analyzed and discussed. The thesis examines the success of the site in attracting a wide audience and holding its attention, as course material, in gathering data from psychoacoustical experiments, and in obtaining feedback from readers. Suggestions for future sites of this type are included.

The text of the thesis should be read in conjunction with experiencing the World Wide Web site at http://www.music.mcgill.ca/auditory/Auditory.html.

Sommaire

Le WWW nous donne la capacité de faire voir des présentations multi-média à un public varié. Cette thèse détaille le design et le développement du site *Psychoacoustical demonstrations and experiments* à l'Université McGill: elle discute de l'organisation du site, de la sélection du contenu ainsi que les méthodes de développement. Afin d'évaluer le site, les donnés sur son utilisation, les réponses des lecteurs et les données d'expériences sont analysées et discutées. Cette thèse examine le succès du site à intéresser un public variéet à servir de matériel de cours, en ramassant les données d'expériences psychoacoustiques et en obtenant les réponses des lecteurs. Des suggestions pour de futur sites de ce style sont aussi inclus.

Ce document devrait être lû conjointement à une connaissance du site http://www.music.mcgill.ca/auditory/Auditory.html, sur le World Wide Web.

Acknowledgments

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Introduction

The World Wide Web provides a powerful method of delivering information and instructional material, including audio and visual materials, to interested people around the world who benefit from connection to the Internet. Hypermedia tools allow materials to be constructed in such a way that the viewer can choose the depth of material to correspond to their level of interest.

The Web site *Auditory Perception: Demonstrations and Experiments*, developed by the author, is in part a set of tutorials on selected aspects of Auditory Perception. The objectives of the site are:

1. to explain psychoacoustical concepts to a wide audience,
2. provide multimedia instructional material for use in courses
3. explore a variety of methods for obtaining two-way communication between readers and the author,
4. determine the feasibility of conducting psychoacoustical experiments over the Web.

Following a general discussion of the features of the Web, the thesis describes the design and construction of the Auditory Perception site, and its content, organization and major features. The techniques used to create and offer access to audio and to mount experiments are also discussed. This is followed by an analysis of the effectiveness of the site in holding readers' attention, serving as a resource for courses, in eliciting feedback from readers, and in obtaining experimental results.

The process of mounting experiments over the Web is discussed, including methodology, screen design and descriptions of two other sites that have mounted psychological experiments over the Web.

The thesis concludes with a summary of lessons learned that will be useful to developers of similar Web sites.

Section I World Wide Web - background

An increasingly popular addition to the Internet is the World Wide Web (WWW or the Web), which originated in March 1989 at CERN in Switzerland as a means of communication among high-energy particle physicists. Most information on the Web is in the form of Hypermedia documents, written in Hypertext Markup Language (HTML), and stored on a computer acting as a Web server. The reader reaches the information by running client software, called a browser, on any appropriately configured computer connected to the Internet. Popular browsers are MOSAIC [NCSA, 1994] and Netscape [Netscape Navigator, 1994]: these are available for many computer platforms. Hypertext is text that contains user-addressable areas (mouse, hot keys, touch screens etc.) which provide links to other places in the text or to other documents. Referenced materials may reside locally (on hard disk or CD-ROM), or remotely on any computer attached to the Internet. Hypermedia extends this concept by allowing links to other media, including graphics, playable audio files and video.

Central to the Web methodology is the standardization of the HTML protocols through which client and server software communicate. The first standard, MOSAIC 1.0, provided for hypermedia retrieval of information by the client. Only in 1994, with MOSAIC 2.0, did communication from the client back to the server become possible: this protocol allows the server to cause a standardized form to be displayed on the client machine, and the data entries to be submitted back to the server. Limited two-way communication between client and server became possible. Even more flexible connections between client and server are possible with more recent releases of Netscape and MOSAIC, and with the release of the programming language Java [Sun Microsystems, 1996].

Since 1994, the number of servers and the quantity of information on the Web have experienced exponential growth. The explosion of material on the Web has, fortunately, been accompanied by the development of catalogues (such as YAHOO) and search engines (such as World Wide Web Worm, Web Crawler, Lycos, AltaVista and Open Text). Search engines use programs, known as *spiders*; these programs navigate around the links of the Web, scan Web pages and construct databases of keywords and the Web addresses containing them. Readers are then able to query the search engines by keyword to obtain a list of potentially useful Web addresses.

The Auditory Perception Web pages exploit the two-way communication capability of the Web to conduct psychological experiments and to obtain feedback from readers on the effectiveness of auditory demonstrations. I have made use of the search engines to promote the pages.

Section II Development of Web site "Auditory Perception Demonstrations and Experiments"

2.1 History of site development

From my simultaneous fascination in Auditory Perception (stimulated by Dr. Al Bregman), computer sound synthesis (stimulated by Dr. Bruce Pennycook) and fascination with the emerging technology of the Web, the idea of a Web site explaining the concepts of Auditory Perception with auditory examples emerged in late 1994. The following major goals were established:

1. to explain the concepts of Auditory Perception to a wide audience,
2. to employ the emerging Web technologies to elicit feedback from readers,
3. to test the feasibility of conducting experiments in Auditory Perception over the World Wide Web.

I had hoped to be able to use links to basic psychoacoustic materials elsewhere on the Web, and to focus on demonstrations and experiments in auditory stream analysis [Bregman 1990], Shepard tone phenomena [Shepard 1964] and the Tritone Paradox [Deutsch 1991]. Unfortunately, no suitable introductory materials were to be found on the Web at that time. As a basic understanding and vocabulary are necessary to understanding the planned demonstrations and experiments, the site evolved to include tutorials in several basic concepts in Auditory Perception plus some historical information. These tutorials are still unique on the Web, and have been much appreciated by their readers.

The vocabulary of the multi-disciplinary field of auditory perception is quite complex. an extensive glossary (Appendix B7) clarifies this language for the reader. The site also includes an annotated bibliography (Appendix B8) and reference list (Appendix B9).

Most of the materials on the site were developed between February and June of 1995. During this period, no attempt was made to publish the site. Nonetheless, over seven hundred accesses to HTML documents (hits) were logged by one hundred and fifty readers. In June 1995, the site was discovered by the Darmstadt Auditory Research Group, Zoological Institute Darmstadt, who generously offered to create a European mirror site now available at
http://Web.th-darmstadt.de/biologie/auditory/Auditory.html.

In July, the McGill site was registered with a handful of search engines and the number of hits rose to forty-five hundred in August. Following further promotion, through many search engines and "What's New" lists, hits have risen to more than six thousand a month.

Changes to the site between August 95 and January 96 were minor: they reflect suggestions and comments from readers and the reaction to some biases observed in the usage statistics. Between January and March 1996 several technical improvements were made to the site, and in March 95 some new material was added.

The site has evolved to include about forty HTML pages about eighty physical pages), about seventy graphics files, twenty-one image maps and over four hundred audio files. There are also seven Perl scripts (about a thousand lines of code) controlling site organization and data collection.

2.2 Design and contents of the site

The contents of the site are designed to lead the reader to an understanding of the interesting and complex phenomenon of Shepard tones [Shepard 1964] and related phenomena. Along the way, the reader is introduced to the basic vocabulary of Psychoacoustics, invited to listen to pure tones, harmonic tones and octave-related complex tones, and exposed to the principles of auditory scene analysis and streaming. All discussions are accompanied by high quality (22,050 sample rate, 16 bits per sample, mono) audio demonstrations. Various theories on pitch perception of complex tones are discussed. (Both pitch perception and streaming are believed to contribute to the Shepard tone effect.) A final section introduces readers to the Burns tones (inharmonic complex tones based on stretched octaves [Burns 1981]) and the theory of dynamic pitch due to Nakajima et al [1991].

The Auditory Perception site is designed in two layers. The outer layer contains an overview and hypertext links to materials laid out as follows:

Introduction

Some Selected Moments from History

Basic Physics and Psychophysics

Enter our Auditory World to learn about and experience:

- Pitch Perception,
- Auditory Scene Analysis,
- Dimensions of Pitch and Shepard Scales,
- The Tritone Paradox.

Appendices

Links to related Web sites

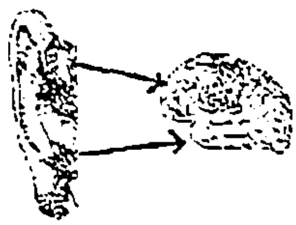
Figure 1 Contents of main menu

The *Introduction* describes the multidisciplinary field of Psychoacoustics, and *Some selected moments from history* details some of the major advances in the field from Pythagoras, through Zarlino, Sauveur, Rameau and Helmholtz to Terhardt. The section on *Basic acoustics and psychoacoustics* covers the physical basis of sound and hearing, defines the essential terms of psychoacoustics and discusses the relationship between physical variables (frequency, amplitude) and the psychoacoustical variables of pitch, loudness and timbre. In these sections, several pictures, graphs and diagrams are included and displayed as icons. The user can click on the icons to view them in more detail. These three sections can be found in Appendix B, which also includes the glossary, bibliography and reference list.

The real substance of the presentations, the experiments and all audio examples are in the inner layer, referred to throughout this thesis as *the Auditory World*. The reader has access to this through the *Enter our Auditory World* page. Client machines differ in the hardware and software used to interpret (and play) sound files, and in the audio formats that they can handle. The major formats used to transmit audio data are: .AIFF suitable for Macintosh and SGI machines, .WAV suitable for most PC systems and .AU suitable for Sun and Next computers. Rather than offering a choice of audio format within each demonstration, the *Enter our Auditory World* gateway (Figure 2) allows programs controlling the site to capture the reader's preferred audio format once and for all, thereby simplifying the visual interface within the individual demonstrations. Help and advice on audio formats is provided from this gateway, which also serves also to capture the reader's e-mail address or other identification for experimental and statistical purposes.

On selecting the *Enter our Auditory World* button, the reader is presented with the following form (Figure 2):

Auditory World



Welcome.

To enter the world of auditory demonstrations, please select your preferred audio file format .au

Do not be shy if you have no audio equipment -- there is lots of interesting reading too. Just leave the format at the default .au.

Please enter your email address or name. If you have been assigned a group name an experimenter, use this name

hit Enter

Figure 2 **Auditory World Gateway**

On completing the form and clicking the *Enter* button, the reader receives the *Auditory World* menu, or table of contents shown in Figure 3 below.

Auditory World: Demonstrations and Experiments

Pitch perception
- Pitch of simple tones
- Pitch of harmonic tones
- Residue or virtual pitch

Auditory Scene Analysis
- The auditory scene analysis problem
- Sequential organization
- Organization of simultaneous components

Octave-related complex tones
- Octave complex tones
- Dimensions of pitch and Shepard tones
- The ever-ascending (or descending) Shepard scale
- Risset glides

The Tritone Paradox

Inharmonic complex tones and dynamic Pitch
- Burns tones
- Dynamic pitch

Quick Access to our Experiments

Figure 3 Auditory World Menu

Each topic is clickable and leads to a separate Web page. The design of each page takes advantage of the power of hypertext to allow the readers to tailor their readings to their level of expertise and interest: some contain lower level links to easy explanatory material, others contain links to sophisticated material (on pitch theories for example) and some contain both easier and deeper links. Experiments appear within the pages, but can also be reached from *Quick access to our experiments.*

Appendix B includes a sample HTML page from each of the three major sections: Appendix B4 shows the page entitled *Pitch perception of harmonic tones*, Appendix B5 shows a page about the sequential organization of sounds and Appendix Bo shows an experiment in listening to octave-related complex tones

The material is intended to be read (and heard) in sequence, at least by readers unfamiliar with the field. However, the Web reader is naturally free to sample the materials in any order -- and they do!

2.3 Programs controlling the site

All of the programs controlling the site are Perl scripts residing on the server. Perl is a powerful interpretive programming language, which has proved very suitable for development in the Web environment [Wall and Schwartz 1991]. These programs (or scripts) create and serve the pages within the *Auditory World*, collect data from experiments, log usage and deliver a variety of reports to the end-user. One of these program can display, for the interested reader, all of the programs (including itself): others display various usage statistics and experimental data. The programs can be viewed from the Web site, by selecting hypertext link *Structural Design and Programming* in the Appendices.

According to the MOSAIC 2.0 standard, when a reader completes and submits any HTML form the data is passed to a specified program in the directory called *cgi-bin* on the server. The data is passed as a *URL-encoded* string of pairs, each of which represents the name of the form part (button, data entry box, etc.) and the value entered or selected by the reader. The program *cgi_bridge*, which I developed on the McGill Music server, is a general interface between HTML forms and a Perl function that acts on the data. *Cgi_bridge* parses the coded data and creates a Perl associative array of field name-value pairs, ready for further processing by a specified Perl function: it also performs some error checking activities.

The coding for the *Auditory World* gateway (Figure 2 above) exemplifies this technique. Appendix I shows the HTML coding of the form, and the Perl function *register* to which *cgi_bridge* passes the associative array containing audio file type and reader identification. The name of the module which acts on the data *(register)* is specified in the *goto_module* field of the form. The function *register* reads in the HTML document *worldmenu.html*, modifies it with the selected audio file type and typed-in user identification, and serves the revised HTML directly to the user-screen. The activity is also logged in the *auditory.log* file on the server.

Each of the psychoacoustical experiments asks the reader to complete a form. Data from these forms is received by *cgi_bridge* and passed as an associative array to experiment-specific functions in a program module called *store_data*, which simply logs the data and writes a thank you note to the reader. Retrieval of experimental data and presentation of other reports work in a similar manner, using the module called *seedata*.

Another way of triggering programs residing in the *cgi-bin* of the server is through an *HREF* (Hypertext reference). The simplest use of this technique is exemplified by the following line of HTML code from the Web site -- Usage statistics and Experimental data:

<A HREF="http://www.music.mcgill.ca/aud_summary_stats">
    Monthly Usage Stats</A>

This causes the program *aud_summary_stats*, resident in the *cgi-bin*, to compute and display the monthly usage statistics.

A variant of this technique is used to serve client-specific HTML documents within the *Auditory World*. When an HTML form contains a line such as

<A HREF="http://www.music.mcgill.ca/auditory_bridge
    ?sequential.html,.aiff,norma>Sequential organization</A>,

the program *auditory_bridge* is executed with the argument "sequential.html,.aiff,norma", and *auditory_bridge* serves the document *sequential.html* with ".au" replaced by ".aiff" and ".ID" replaced by "norma" This technique underlies the maintenance of audio type and user identification throughout documents served within the *Auditory World*. It is also used to display the *csound* (see next section) orchestra files, score generation scripts and sample score files. For example,

<A HREF="http://www.music.mcgill.ca/code_bridge?oct/Doct.sco">

Score for octave complex tones</A>

executes the cgi-bin program *code_bridge*, which creates a titled HTML document from the score file oct/oct.sco (the D is a coding for the full path to the file).

2.4 Preparation of audio

All of the audio signals were generated using *csound* [Vercoe, 1986], the most widely used sound synthesis and processing programming language. In this language, networks of tone generating and processing modules are assembled into *instruments*, in an *orchestra file*. The instruments then play from a *score file* -- a time-ordered list of performance instructions.

Many of the demonstrations are repetitive and therefore require a set of similar scores. Accordingly, I developed Perl scripts to automated their production. There is essentially one script for each demonstration and each experiment. In addition to producing a set of scores, these scripts *perform* the scores in *csound*, convert the resulting audio files to the three audio formats and move such files to their target locations -- all without manual intervention. This automation reduced the time needed to prepare (or modify) a demonstration from several days to an hour or so, and provided great flexibility for modifications of a set of demonstrations. Appendix H illustrates one of these sets -- that of the octave-related complex tones experiment. Sections in this Appendix show:

the orchestra file (Appendix H1),

the Perl script that generates the score file (Appendix H2),

a sample generated score file (Appendix H3).

All audio examples are monophonic and synthesized at a 22,050 sample rate and 16 bits per sample. This retains a good dynamic range and quantization noise ratios, while providing up to 10 kHz bandwidth. This is sufficient for the selected demonstrations. Other trials with 8-bit data proved to be far too noisy. There remains some concern that listeners using low quality acoustical equipment (such as inexpensive SoundBlaster type cards with budget speakers) may not hear the demonstrations in the appropriate manner.

2.5 Access to and delivery of audio

Three methods are used to allow the reader to access audio examples:

1. clicking on a labelled loudspeaker icon,
2. clicking on highlighted text,
3. clicking in a hot area of a "map".

Figures 4, from the pure tone demonstration, demonstrates the first method and Figure 5, from the Shepard scale demonstration demonstrates the second.

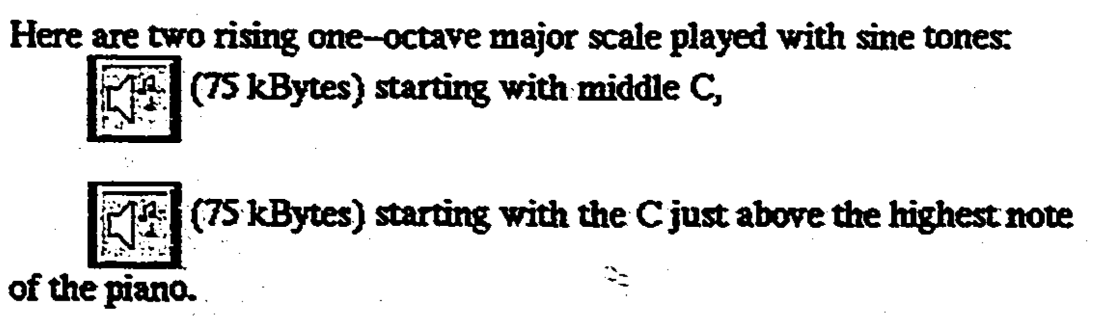


Figure 4 Loudspeaker icon from the pure tone demonstrations

Choose the length and direction of a scale to listen to:

Two octave ascending Size 520k Time 15 sec
Three octave ascending Size 780k Time 22 sec
Two octave descending Size 520k Time 15 sec
Three octave descending Size 780k Time 22 sec

Figure 5 Clickable text from the Shepard scale demonstration

An *image map* (map) is a graphic file embedded into the server environment and is sensitive to the physical area on the screen where the reader clicks with the mouse, much as one might click on a geographic map for detail about a geographic area. The image maps in the *Auditory World* were upgraded in March 1996 to take advantage of the client-side features of recent browsers: this provides more convenient and efficient use for readers. Use of a map is exemplified by the map of the chromatic circle of tones, shown in Figure 6 -- clicking on any of the note names automatically fetches and plays the associated audio file.

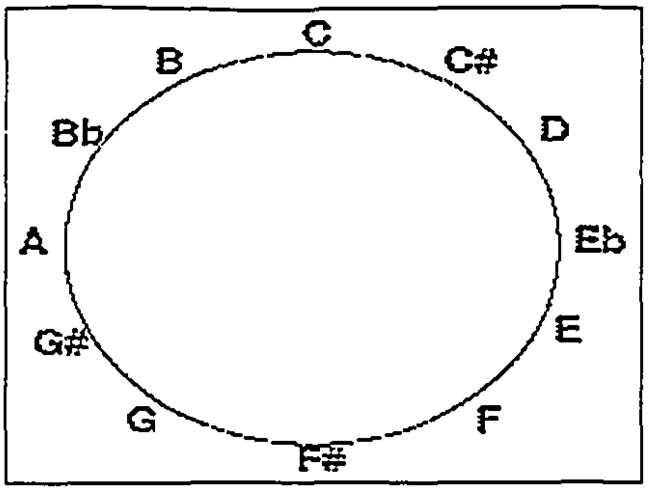


Figure 6 Clickable image map from the Shepard tone demonstration

Once selected, all audio is delivered to the client machine in the audio format selected by the reader. Depending on the setup of the client machine, it may be played immediately, or saved in a file from which it can be played repeatedly or processed by any suitable player program on the client machine. Currently (unfortunately), audio files must be transferred in their entirety before they are played. Every effort has been made to keep the examples as short as possible, but the transfer time causes frustration to readers who have slow connections to the Internet and is expensive to those who must pay for connection time or telephone time or both. I had hoped that technologies would emerge to alleviate this problem. Promising candidates are RealAudio, NetSound and Java.

RealAudio delivers a continuous stream of compressed audio over a UDP (User Datagram Protocol) connection: it requires special server and client software. NetSound delivers impressively small files of instructions from which the client machine renders the sounds: the software is not yet available. JAVA is a programming language supported by many computer platforms and compatible with Netscape -- the server causes program sections (called *applets)* to execute on the client machine. Applets for sound synthesis are not yet available. In the future, one of these technologies may be appropriate for delivery of audio demonstrations at a greatly reduced transfer time.

2.6 Preparation and delivery of graphics files

The Auditory Perception site contains about seventy graphics files, mostly in GIF format. They originate in three ways:

1. scanned images,
2. captured screens,
3. graphics created by drawing tools.

Preparation of graphics was laborious: different tools were used to edit and combine graphics from the various sources. The Xwindows tool "xv" (on a Silicon Graphics computer) was used for final preparation of most of the graphics files. An unexpected challenge comes from the diversity in computer display hardware, and the manner in which the browsers render the graphics on various hardware platforms. Sometimes a graphic that is almost too small to see via Netscape on the SGI fills almost a whole screen when viewed via MOSAIC on a PC. Many compromises were made to accommodate several popular browsers and client hardware.

In order to reduce download times, several of the graphics are displayed as thumbnails (or icons): the user may click such thumbnails to view a larger version of the graphic.

Many examples of graphics can be seen in Appendices B2 through B6.

2.7 The mirror site at Darmstadt

The offer by the Darmstadt Auditory Research Group to set up a mirror site came in May 1995 a time when most of the Auditory Perception material was in place. However, files were distributed over many directories and several computers connected to the network of the McGill Music Faculty. Many of the file addresses were explicitly specified in HTML documents and programs (Perl scripts). The programs were also located in several places. The first task in building the mirror site was to rationalize, as far as possible, the locations of HTML documents, programs, audio files and graphic files. Since some files must (for technical reasons) reside in special places on the server, it was not possible to completely organize everything within a single directory on a single computer. The next task was to prepare a large compressed file (20 megabytes) of all the material. Stefan Bleeck at Darmstadt downloaded this file via FTP. He then performed the laborious task of organizing the material on his server, and changing those address references that were needed to make the package function correctly. Since July, periodic transfers have been made to keep the mirror site up-to-date.

Section III Success of attracting visitors to the site

3.1 Publicizing the site

It is not sufficient to mount a site on the Web (however good or useful) and hope that the world will find it. During the four month development period of the auditory perception pages, they were found by a scant hundred and fifty readers. These may have arrived there through the McGill Faculty pages, or through a link from John Krantz's Psychology tutorials. In June 1995, the author took steps to promote the site: firstly by giving a paper at the Society for Music Perception and Cognition [Welch and Pennycook, 1995] and secondly by announcing the site to a few of the Internet search engine services, including YAHOO, Web Crawler, Lycos and the World Wide Web Worm. Once informed about a site, search engines enter the site into their database, and send computerized robots to determine keywords used in the text. In the case of YAHOO, the site is catalogued manually. After this process, readers who search for material by keywords such as *auditory perception* or *psychoacoustics* are pointed at the site. Taking advantage of the manner in which the robots work, the author altered the text somewhat so that a maximum number of likely search words occurred in the main page. This was particularly crucial since the pages within the *Auditory World* are invisible to robots. This advertising process raised the number of hits to thirty-five hundred in the month of July.

In the month of August, following much favourable feedback and a few minor corrections, the author felt that the site was sufficiently stable to be further promoted. Available on the Web is an automated program called *SubmitIt*, which registers a site with a large number of search engines and also with several *What's New* pages. Promotion, through *SubmitIt*, in late August increased the exposure of the site and resulted in over five thousand hits in September.

As there are continually new search engines arriving on the Web, promotional activity may not cease. The author continues to browse the Web, looking for lists of perception pages in which this site deserves to be included and verifying that new search engines have the site in their databases.

3.2 Measures of success

3.2.1 Total usage statistics

Though care must be taken in interpreting them, usage statistics provide one measure of the success of a site. In the six month period between July and December 1995, over 27,000 HTML documents were downloaded by over 4,000 different client machines[1]. Within the *Auditory World*, 7,400 HTML documents and 6,678 audio files were delivered to over 1600 readers.

More important, of course, is what our visitors were reading and how diligently they pursued the information. Counts of HTML accesses by page indicate that our reader's attention span is limited: some look at the main page and leave, others read a few pages before leaving, but there are a few who have looked at most of the almost forty pages on the site. Diligence is very hard to determine from the server data, but many readers have spent several hours at the site and some have returned on several occasions.

Downloadings of audio have been disappointing, with only thirteen hundred client machines downloading audio; of these thirty-four percent downloaded only one audio file. Some readers have written about problems with download times or with the audio quality delivered by their equipment - it is likely that these problems are fairly common.

[1] Accesses by McGill and CompuServe, which I often use have been filtered out.

Response to experiments is low in the context of the total number of people visiting the site, and even as a proportion of the visitors who have downloaded audio files. Nonetheless, we do have over fifty usable responses.

Usage data are examined in more detail in Section IV, and the experimental results in Section V.

3.2.2 Links to the site

One measure of whether a site has interest for its readers is the number of links that they create to the site. The Auditory Perception pages have attracted much interest and many links have been created to them, particularly by educational institutions -- indicating that it is fulfilling a worthwhile role in providing instructional material.

Appendix C lists some fifty known links to the Auditory Perception site. These are the Web equivalent of citations in the publishing world. This list was compiled from e-mail from some who asked permission to create the link and from the results of querying the search engine AltaVista with a *link* command. As not all pages containing links are likely to be known to AltaVista, it probably contains only a fraction of the actual links.

From Appendix C, it can be seen that links exist to the site from the major lists of music and psychology sites. As well, the links indicate that material from the site has been used in several college and University level courses: *Computer music* at Vanderbilt, *Sound system utilisation* at Leeward Community College, *Digital Media and Multimedia Applications* at USC, *Psychology of Music* at University of Arizona, *Psychophysics and Cognitive Psychology* at Stanford University, and *Honors Psychology* at University of Tennessee. As will be discussed in section 5.2, the experiments have been used in a Psychology class at Hanover College, Indiana.

Pointers to the site also exist at several medical sites, a handful of cultural centres, Web66 -- a resource for K-12 material, and many *Home pages* from around the world.

Following the listing of the site at the head of *What's Cool* in Canada's Science Web, the Auditory Perception site was the subject of a five minute feature on CBC's *Quirks and Quarks* radio show.

As well, the Auditory Perception pages are to be mounted in a standalone kiosk in an exhibition at Explora Science Centre, Albuquerque, New Mexico. The Explora Science Centre is a hands-on learning centre providing free entrance to a facility containing educational interactive exhibits and demonstrations for scheduled school groups of New Mexico. The exhibition is entitled *Interactions of Art & Science* and the exhibit is to be in an area dedicated to music, sound and auditory perception.

3.2.3 Written responses

The ability of the Auditory Perception site to elicit communication with the author has been positive. Most communication has been sent through the *send me E-mail* button on the main page, some has been received through the comments sections of experiments, some has been through the *Discussion Corner*, and a little has been solicited by the author when she found out that the site was being used as supporting material for courses.

In total, approximately a hundred written responses were received in six months. The main reasons for writing to the author seem to be:

- to say hello and thank you for the page,
- to ask for permission to place links to the site,
- to report on minor errors (spelling, factual details, failing links etc.),
- to ask for help in downloading audio files, or reporting on poor sound quality,
- to ask general questions about sound and hearing,

to express differing opinions, suggest a look at their own site, or to promote their own work.

Some described their own interests and asked for help in getting in touch with others sharing them.

Most e-mail fell into more than one of the above categories. Some of this response is categorised in Appendix D. Every effort has been made to respond to all e-mail in the appropriate manner, referring to colleagues and the auditory list for assistance when necessary.

An interesting feature of the e-mail received is that it clearly came from readers from a diversity of backgrounds and a wide range in their knowledge of psychoacoustics. While some point out minor errors in spelling, units and dates and some discuss their own research, others ask for help with basic ideas. That the site has attracted some young people is evidenced by several letters requesting help with *Science Fair* projects. Many of the questions are not directly related to the material in the site, but are about areas of psychoacoustics not there explored: respondents were happy (and expressed thanks) for just being given a reference. Perhaps this is a result of the paucity of materials on this topic that are available on the Web.

A few of the letters have pointed out errors in the site: either small spelling and factual errors or malfunctioning links. All of these were real problems, and I much appreciated being told about them and being able to fix them. This is one of the benefits of being a Web author. Most of these were pointed out in July and August, except for a couple of new link problems that were caused when I reorganised the site in November, 1995. Fortunately, a reader pointed out the missing links before they inconvenienced a large number of readers, and even verified that the problem had been corrected.

Problems reported about the quality of the sounds are of serious concern, and probably the tip of an iceberg. In conjunction with analysis of the download statistics, they indicate that many visitors to the site do not have audio equipment at all or of sufficient quality (or know how to use it) to benefit from the audio supplied.

The author has replied to all e-mail, sometimes with lengthy exchanges. Obtaining this feedback from the reader community is a notable advantage to World Wide Web authors, ... and their readers.

3.2.4 Use as course material

As discussed in section 3.2.2 above, the pages from Auditory Perception have been used as reading and reference material in several college level courses. I have received favourable e-mail from several students and the Professor of the Multimedia course at USC.

In order to give his students experience in running acoustical experiments, Psychology Professor John Krantz of Hanover College used one of the experiments on the site as part of his course. His comments on the experience follow:

> "This past fall, a sensation and perception class at Hanover college used the octave-complex experiment from the site. This experiment formed one of several laboratory experiences included in the class. In fact the use of this site shows one of the great advantages of the Web for educational purposes. Since a Web site can be accessed around the world it allows institutions to expand into areas limited in the past by their equipment. In addition, it allowed the second author, the instructor, to more thoroughly examine auditory phenomena in the classroom. Though auditory demonstrations from compact disks would have been possible at Hanover College, auditory laboratories were beyond the capabilities of the department. So the use of an experiment over the Web served to overcome one of the weaknesses of the Perception course. However, several obstacles needed to be overcome. This institution does not have many computers with sound capability and the psychology department does not at this time have its own set of networked computers. Thus the entire class had to use the instructors computer to collect the data -- this could have been difficult with a large class.

Fortunately, there were only twelve students in the class and a network laboratory for the department is under construction. Getting the students to use Web pages was easy. The basic point-and-click interface of web browsers seems easy for students to learn. The delays in downloading some of the sound files were a somewhat frustrating, but the browsers can be configured to keep the sound files in the sound player for easy repetition. A significant feature of the auditory perception experiments is the ability the ability for a class to collect data under its own group names and thus segregate their own data. Thus, the students were able to collect their own data and use it in their laboratory reports. The student reaction was generally positive. The ambiguity of the data results was frustrating but useful to teach students about individual differences, variability in perception, and the complexity of pitch perception. Therefore, it was a useful pedagogical tool. In addition, the students enjoyed using the sound feature as multimedia is generally novel for these students. The psychoacoustics experiment was very successful as a laboratory for a class since it has the ability to share the data, not just the conclusions across the Web. This is a strong and unique feature of the Auditory Perception site." [Welch and Krantz, 1996]

3.2.5 Response to the experiments

Only 2.4 percent of visitors (those who downloaded at least one content HTML page) submitted responses to experiments and many of these responses were unusable -- an apparently low response rate. However, if we consider only those readers who looked at the page containing the experiment and downloaded some of the audio, we get a different picture. Of those who downloaded more than one audio file from the trill demonstration twenty-five percent submitted a usable response, and of those who listened to at least one of the harmonic sounds in the *hearing out* experiment eleven percent submitted a usable response. Data on response to experiments is summarised in Figure 7 below.

Topic	Visitors	Listeners*	Responses	Usable
Trills	132	77	71	19
Hearing harmonics	337	187	27	21
Hearing OCTs	111	68	24	15
High Shepard	29	19	4	1
Total			126	56

*Number of visitors who listened to more than one audio file related to the experiment

Figure 7 Responses to experiments

Though the number of responses is low compared to the number of readers and HTML hits, it is consistent with rates of response to experiments at other sites (see sections 5.2 and 5.3). Obtaining free experimental data over the Web is simply a waiting game.

3.2.6 Activity in the Discussion Corner

The *Discussion Corner* was intended to be a forum for the discussion of auditory perception topics. Reaction to it has been both low and one-sided: only thirty readers have accessed the corner, and of these a mere thirteen have entered messages -- all of which are questions. For practical purposes there has been no discussion. The reason for this low interest in discussion is not known, but it seems that readers prefer to address their questions to the author. Perhaps the site contains so much material that the readers are exhausted before they reach the *Discussion Corner*.

In February 1986, I answered all the questions and removed the *Discussion Corner*. Readers are free to send me questions, as always, and the site contains a pointer to the Auditory List on the Internet - an appropriate place for technical discussion.

Section IV Statistical analysis of site usage data

4.1 Usage data and their interpretation

4.1.1 Difficulties inherent in interpreting Web usage data

Much care is needed in the interpretation of usage data. Firstly, usage data logs only the name of the client machine: client machines do not map one-to-one with readers since many readers may access the site from the same machine, or a single reader may access the pages from several machines. As a reader views HTML pages, he may even store URL (Uniform Resource Locator) references in a *hotlist* (a personal list of pages that a reader may want to revisit) and view them directly later from the same or a different machine: thus we have occurrences of clients who view internal pages, without appearing to pass through the main entry point. A further complication is access through online service companies such as America Online and CompuServe: in these cases the usage data shows the name of the computer at the service company that made the connection. Readers may also reach a page within the site through link provided by a friend, colleague, teacher or search engine.

Secondly, readers differ widely in their behaviour. While some return to the main menu before selecting the next item, others read to the end of the document and move on through the links that are provided to the next logical document. Even when readers return to the menu, this action may not be recorded in the server statistics because the document was stored on the client for reuse (cached). Also, some readers return to the same page more than once.

Thirdly, some accesses may not be logged at all because the reader was connected through a proxy server which may deliver the documents from its store of documents (cache).

Proxy servers are designed to reduce the traffic on the Internet and are becoming increasingly common; they store recently downloaded documents for future access by other machines connected to the same server.

The result is that the ratio of hits on internal pages versus hits on the menu page gives an unreliable estimate of the interest level of the average reader.

Usage data by reader could have been obtained by constructing a secure, password-protected gateway. However, this would have been an inconvenience to the reader and inconsistent with the aim of reaching a wide audience.

4.1.2 Particular difficulties due to site organization

Due to the design of the site, with its outer layer of real HTML and its inner layer of program-generated HTML, data on downloadings are generated on two separate files. Some statistics are gathered automatically by the server: these are the transfers of HTML, AU, WAV, AIFF, GIF, and JPEG files to the client machine. Each download procedure is date-stamped and identifies the client machine. A portion of the server log is shown in Appendix E1. As discussed earlier (Section 2.3), HTML documents within the Auditory World are customised and delivered by the program *auditory_bridge* on the server. The disadvantage of this methodology is that statistics on downloaded HTMLs are no longer generated automatically on the server. Rather, *auditory_bridge* itself accumulates statistics, together with experimental data, in a special log file called *auditory.log*. A portion of this file is shown in Appendix E2.

4.1.3 Approach to analysis

To counter the difficulties discussed above, several approaches and viewpoints have been taken to analyze and interpret site access data:

automated online analysis of the *auditory.log* file,

statistical analysis of the log files,

manual analysis usage on some randomly selected days,

detailed automated offline processing of the *server log*,

histogram analysis of several log files,

manual comparison of audio downloads with responses to experiments.

All of the analyses are based on the six month period from July to December 1995, when the site content was stable. Programs used for the analysis and some outputs can be viewed from the link to *Analysis of usage data* from the Appendices of the Web site. The various approaches will now be discussed.

4.1.3.1 Automated online analysis

Automated online analysis of the *auditory.log* file has been in place since June 1995. A former program in the *cgi-bin* made data and some statistics available for online monitoring of activity within the *Auditory World*. This program produced monthly counts of HTML and audio downloads: it also prepared HTML documents showing downloads per HTML page, a list of *serious* readers (those who stayed for more than twenty minutes and/or looked at more than six HTML pages), a complete list of data from experiments, and a detailed list of accesses by client machine. Written when site activity was low, this monster program soon became too slow and cumbersome, and has been replaced by a set of simpler programs. These programs are accessible through a form in *Site Usage and Experimental data* in the Appendices of the Web site. Data that may be displayed (and downloaded) now include:

Month-by-month HTML downloadings within the Auditory World,

A list of *serious* readers for a specified year and month,

Experimental data for any specified experiment,

The last specified number of entries in the *auditory.log* file.

Much of the logic formerly in the monster program has been incorporated into offline analysis programs.

4.1.3.2 Statistical analysis of log files

To obtain an overall picture of site usage, I analyzed both the *server log* and the *auditory.log* file. For the *server log*, I mostly used simple UNIX utilities to extract and count occurrences of various text strings. For the *auditory.log* file, I used variants of the online programs discussed above. Also much used in the analysis is a simple program, *anycnt.pl*: this utility program compiles a list of client machines and an associated count of the number of co-occurrences of a specified word. With suitable word specification, the program prints the total number of client machines that downloaded audio, average number of downloads per client and a histogram of the number of downloads per client. With other specifications *anycnt.pl* can determine how many readers downloaded the entry page more than once, or a histogram of HTML downloadings outside the *Auditory World*, or a listing of all clients that downloaded audio related to the trill experiment etc. This program has been very valuable for ad hoc analysis, as well as for cross-checking other reports.

4.1.3.3 Manual analysis of selected days

In order to obtain a better understanding of reader behaviour, I undertook a manual analysis of several randomly selected days. (Random numbers were used to select two days in each of the six months.) I worked with a reformatted and sorted combination of the two log files, and carefully followed the activity of each client. It rapidly became apparent that the number of HTML accesses was a poor measure of the quantity of content downloaded. The analysis clearly confirmed my suspicion that readers use their Web browsers in very different ways, and that this diversity of behaviour made it impossible to obtain a good measure of how many pages they had actually read by any simple counters or ratios. After analyzing four days of logs, I had systematised a convenient report format which concisely displayed several counts and times for each client session. (Small portions of this report are displayed in Appendix F1.) Two important items on the report are the number of *apparent* hits (HTML accesses), the number of *real* hits (non-duplicate accesses to content pages). The difference between these two numbers varies widely: some clients made five accesses to one or more of the three menus and looked at no content pages, and others made one menu access and many non-duplicate accesses to content. Clients who go straight to the *Auditory World* have three non-productive hits before they access a content page. The report also includes the length of time at the site and the number and type of audio files downloaded.

Further, the manual analysis caused me to think about how to determine whether a particular client had derived benefit from the site. Quite a few clients arrived at the site through a link directly to the *Physics and Psychophysics* page, downloaded the page and left. They made only one HTML hit and spend zero time at the site: did they benefit from the site? In many cases yes, because they had been given the page to study as a course assignment. I developed programs to analyze client sessions into the categories of *passersby* and *visitors*. A *visitor* is the record of a session in which the client does something (anything) more than flip through menus and the *Auditory World* gateway, and thus the reader potentially benefited from exposure to the site. These programs are the topic of the next section.

4.1.3.4 Offline processing of the server log

Naturally, this manual analysis had to be automated -- and taken further. I observed that only the *server log* file is strictly necessary for the task, however it needed to be preprocessed. Accesses to HTML documents within the *Auditory World* are logged as accesses to the program *auditory_bridge* with the name of the document as an argument, rather than as HTMLs. A simple preprocessor program converts the *server log* to a format similar to that of the *auditory.log* file, with dates in numeric format and with some extra tags to make subsequent processing easier.

Automation, by the program *get_stats.pl*, was tricky and resulted in a very long program. In its simplest form, the program must track each client session through other overlapping sessions. While tracking a session, it must maintain the last access time, various counts, and a list of unique content pages accessed by the client. All of this information is stored in a series of associated arrays organised by the machine address of the client. Each newly arriving client triggers a check on all current clients: any which has been inactive for sixty minutes or more is reported and then all related arrays are released. This was sufficient to reproduce the manual reports: disagreements between them were minor and all caused by manual errors! Once this logic was in place, it was easy to extend the program to produce a variety of useful additional reports: a particularly illuminating report is the monthly breakdown of activity between passersby and visitors.

As a further extension, *get_stats.pl* writes a file (*visitor log*) which mimics the *auditory.log* file but contains only unique accesses to content HTMLs and audio downloads by *visitors*. This file is amenable to further processing by UNIX commands or by *anycnt.pl*.

In its final form, *get_stats.pl* prints a variety of reports directly, creates a reader profile for each client session, prepares a *visitor log file*, and probably makes all previous programs redundant.

The reports are included in Appendix F2. The code can be viewed from the Web site.

4.2 Results of the analysis and their interpretation

4.2.1 Overall usage and interest

The overall statistics on HTML downloadings (Figure 8) give a picture of the distribution of activity and its change over time: the downloadings are broken down into the major categories of inside and outside the Auditory World. The number of hits on the main entry page is about thirty percent of the total and is shown as a category.

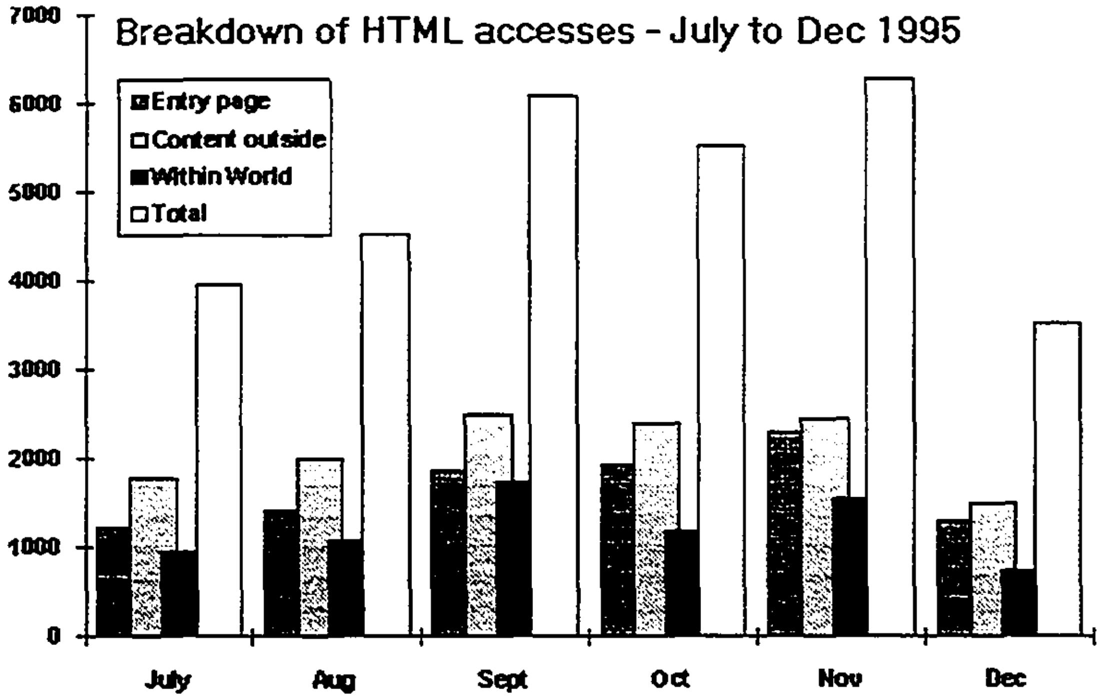


Figure 8 **HTML accesses by major category**

All categories show an increase in activity from July to September, the period during which the site was publicised and became known through links and search engines, followed by a correction in October. The boost in November is probably due to the listing of the site in several *What's New* lists, and the decrease in December is undoubtedly due to Christmas holidays. Activity in January and February has been at the November level and activity in March has increased by about ten percent. Clearly, the content pages outside the *Auditory World* are more popular than those inside: the relation between the two components is stable over the six months. In October and November, there was an increase in the number of hits on the main entry page relative to the number on content pages -- as will be further discussed in section 4.2.3, it appears that more casual readers were attracted to the site at this time.

At the next level of detail, we are interested in finding out what material was of most interest to readers. Appendix F2 includes a report of non-duplicate HTML hits by HTML page: the automated report has been manually annotated with descriptions of the page contents. I have aggregated these into several groups, to produce figures 9 to 12. In Figure 9, the count of menus includes the *Auditory World* gateway and internal menu, as well as the entry page to the site -- resulting in about one half of the accesses being classified as menu hits. Apparent now is considerable interest in the appendices and, surprisingly, a higher interest in the content pages outside the *Auditory World* than inside.

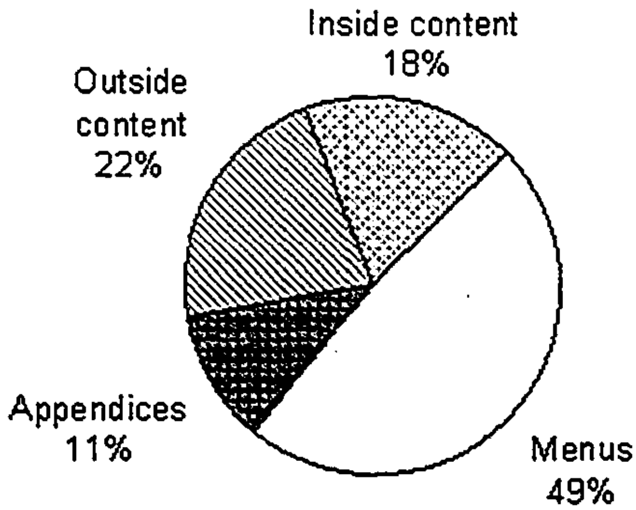


Figure 9 Breakdown of HTML accesses

Readers were interested in all of the content pages accessible from the main entry page, and showed a particularly strong interest in the tutorial on Physics and Psychophysics (Figure 10). Again, this may be because it was assigned reading in some courses. Interest in the history page has also been high.

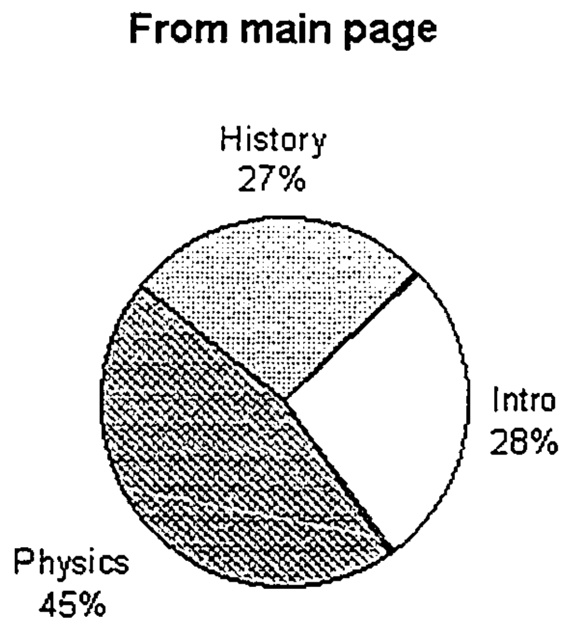


Figure 10 Accesses to content pages from main entry page

Figure 11 shows a breakdown of accesses to pages within the appendices of the Web site. I expected that the references and glossary would be valuable to students and practitioners in the field, but did not anticipate the high level of interest in methods used to prepare the site, or in the usage statistics and other data. More detailed analysis of the log files shows that this interest is somewhat superficial: of the almost three hundred readers who looked at the methods of site design, a mere sixteen looked at the code ... and they all looked at the same one, *auditory_bridge*. Of the almost four hundred readers who looked at the overall description of the methods of creating the audio demonstrations, none looked at any of the code.

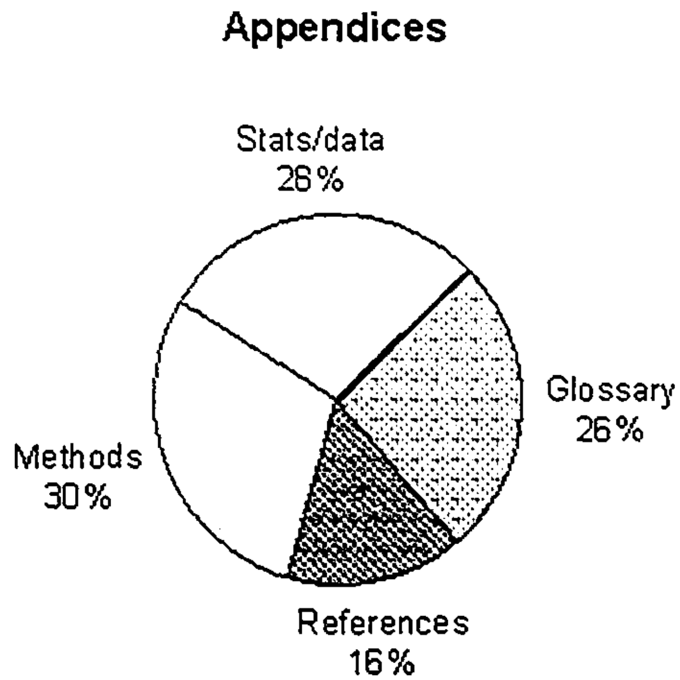


Figure 11 Interest in the Appendices

Inside the *Auditory World (Figure 12)*, activity was distributed between the major sections: pitch perception, auditory scene analysis and octave complex tones. (Pending review by the originator Diana Deutsch, the section on the Tritone Paradox was not available until March 1986.) All pages received some attention.

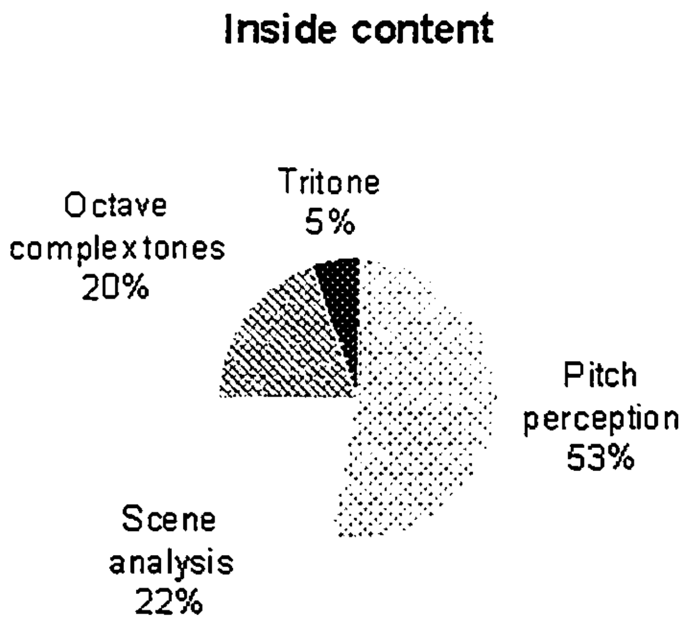


Figure 12 Accesses to content pages within the Auditory World

Not unexpectedly, the general tendency is for readership to decrease with the distance down the menu and with the depth of Hypertext. In fact, many entered the *Auditory World* and looked at only one of the sections, usually the first on pitch perception.

4.2.2 Observations from the manual analysis

The manual analysis of randomly selected days was undertaken in order to see what reader profiles could be established, and whether there was a trend over time. Analysis of the selected days in July and August was very encouraging for the author; there were occurrences of readers who arrived and left quickly, but on each of the selected days some readers looked at a lot of the material, and a few diligently looked at almost all of it. October and November were quite different; many of the hits were from readers who viewed only the main page and possibly the *Auditory World* gateway. I attribute this change in profile to the listing of the pages in *What's New*, thus attracting large numbers of casual readers. Appendix F1 lists, for comparison, part of the reader summary for July 15 and November 5.

My general impression from detailed analysis is that readers fall into one of the following groups:

1. Passersby who arrive at the site, look at the menu, maybe enter the *Auditory World* and look at the next menu, decide that is this is not for them and leave,

2. Casual readers who read one or two of the content pages accessible from the main page, and then leave,

3. Readers interested in listening to audio examples. These readers typically go straight to the *Auditory World* and examine one or two pages there,

4. Readers who are mainly interested in theory, and read several pages from the main page. Some of these read most of them, including the appendices, but make no attempt to enter the *Auditory World*,

5. Practitioners who want to see everything that is there. Typically, they are also interested in site development.

No useful measure as to whether the reader derived benefit from the site emerged. In fact, it became clear that no simple measure could even determine how many content pages had been accessed by an individual reader. Accordingly, programs were developed to automate this and develop a small set of measures to describe each session -- the subject of the next section.

4.2.3 Passersby, visitors and serious users

As discussed in section 4.1.3.3 above, a *visitor* is a client session during which the reader looked at least one content page. *Passersby* looked only at menus and possibly the *Auditory World* gateway. The numbers of each and the number of HTML documents downloaded by them are summarised in Figure 13 below.

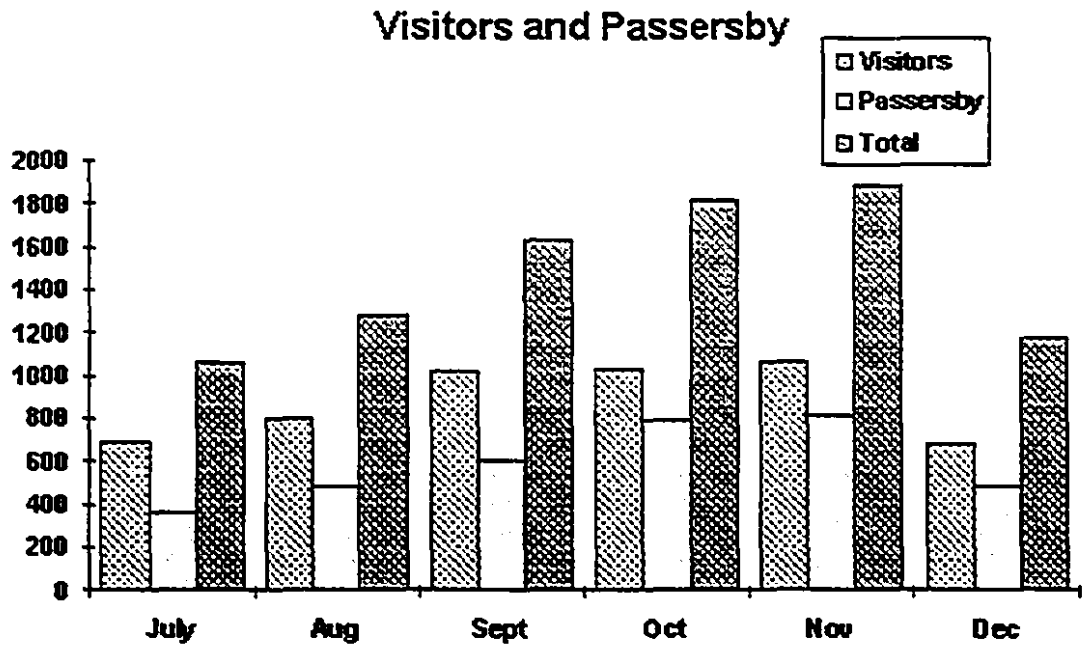


Figure 13 Visitors and Passers by

In July and August the percentage of *visitors* was high, at around sixty-five percent. In the months of October and November there was an increase in the number and proportion of *passersby*. A possible explanation is that during the summer month many of the readers were teachers and researchers. The search engines and *What's New* lists may also have attracted a less appropriate readership in September. In December, the ratio of *visitors* to *passersby* again increased. The overall percentage of *visitors* is sixty percent.

The question of how deeply visitors read the materials is in part addressed by the report of *diligent sessions* included in Appendix F2. For the purposes of this report, a *diligent* *session* is one in which the reader downloaded three or more non-duplicate content pages or remained at the site for more than twenty minutes. There have been twenty-five hundred such sessions -- a lower limit to the number of readers who have benefited from the Auditory Perception site.

The histogram of HTML hits by visitors (Figure 14) also shows that while many visitors looked at only one page, a significant number looked at many. (This histogram excludes hits on menus.)

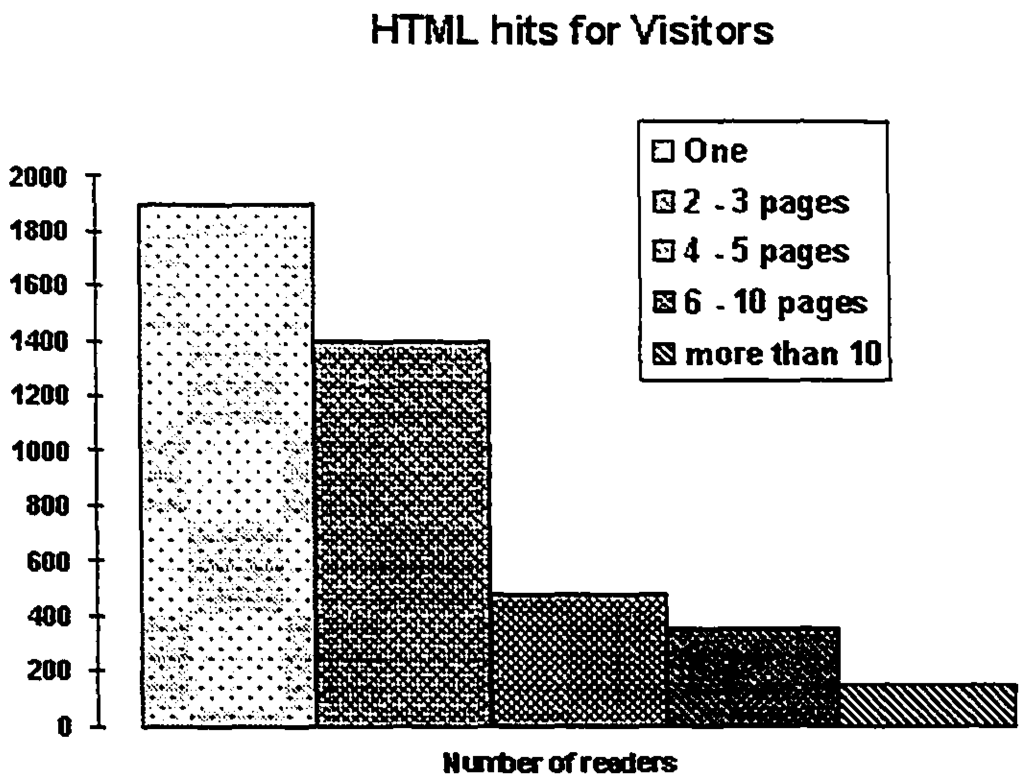


Figure 14 Histogram of HTML hits

Note that Figure 14 is based on client sessions and not on people or client machines. I believe that it gives a reasonable picture of readers as the factors affecting the difference work in opposite directions -- see section 4.2.5.

4.2.4 Audio formats used by clients

The program *anycnt.pl* was used to count the occurrences of the three audio formats in the *visitor log* file. Figure 15 below shows the distribution of the number of audio files downloaded in each of the formats .AIFF, .AU and .WAV.

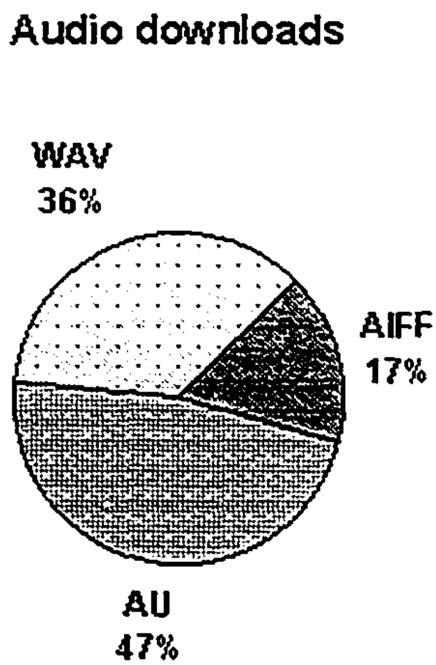


Figure 15 Distribution of audio downloads by audio format

It was clearly useful to offer the reader a choice of format. Since the default format is .au, we know that thirty-six percent of listeners deliberately chose .WAV format. This provides a lower limit on the proportion of readers accessing the Web pages from PCs.

The number of audio downloads per client session is summarised in the histogram below (Figure 16). Of five thousand *visitors*, only fifteen hundred downloaded HTML documents within the *Auditory World* and thus were offered the opportunity to listen to audio. Of these thirteen hundred downloaded one or more audio files. About five hundred (thirty-five percent) downloaded more than three audio files.

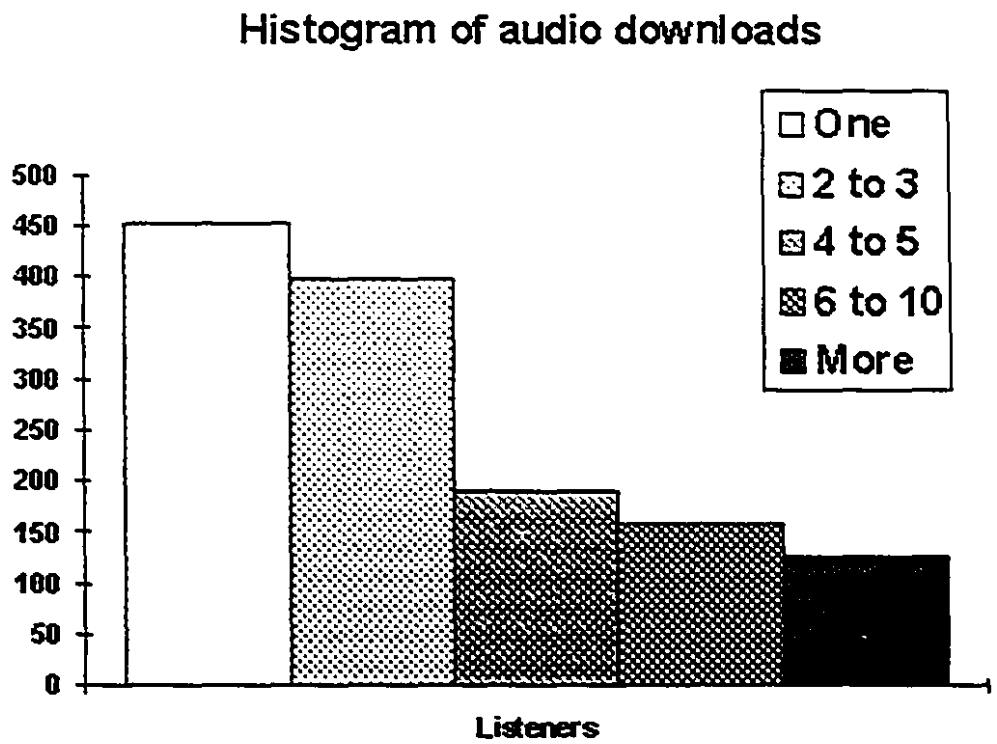


Figure 16 Histogram of audio downloads

We can only speculate as to the reasons for the low interest in the audio: some readers may not have proceeded into the *Auditory World* because they thought that they needed audio equipment to benefit, some may have not downloaded audio files because they had no equipment and others because they had slow connections to the Internet. Of some concern is the large number of readers who downloaded only one or two audio files: possibly they were unsatisfied with either the download time or the quality of sound delivered through their equipment. E-mail responses indicate that both of these factors caused problems for some readers.

The small number of readers who listened to audio must clearly reduce our expectations for obtaining responses to the psychoacoustic experiments.

4.2.5 Clients who revisited the site

The data analysis program (*get_stats.pl*) detects a revisit whenever the same client machine visits the site on more than one occasion. There is no way to determine from the *server log* whether this is the same person. The *Auditory World* gateway asks for a name or e-mail address, but an insufficient number of readers filled in this field for it to be useful for analysis. A revisit, as classified by the analysis, may result from any of the following four activities:

1. return by the same person on the same machine,
2. several people in the same laboratory or library using the same machine to access the site,
3. many people using the same access point via an online service company (such as Compuserve, America Online or Prodigy) or through a proxy machine,
4. search engines checking links and keywords.

The revisit report (Appendix F2) shows a histogram of visits by the same client machine, and lists all the client machines that accessed the site on more than five occasions. Analysis of the revisit reports combined with manual study of the e-mail addresses supplied indicates that there have been a significant number of revisits to the site by the same reader -- to be expected given the quantity of material there. The other three types of activity (apparent revisits) have the potential to distort the statistical analysis. The second type is known to occur, particularly from students in courses that have utilised the Auditory Perception site. Search engines and online service companies are evident in the list of machines accessing the site on more than five occasions. These apparent revisits will cause some analysis programs to understate the number of readers and overstate the number of pages read or audio files downloaded per reader. Readers using different machines in the same laboratory has the reverse effect. Overall, I believe that these effects are not large enough to seriously distort the analyses that I have provided.

4.2.6 Usage of the mirror site at Darmstadt

Due to the architecture of the Internet in Europe, and especially the German Forschungs network, the mirror site is primarily of benefit in Germany and its neighbouring countries. Access to the mirror site from educational institutions within Germany is impressive, almost reaching the speed of accessing the McGill server from within McGill. However, from the United Kingdom better service is obtained from McGill than from Darmstadt. Readers accessing the Internet via Compuserve in Europe are better served from McGill as all requests are forwarded by satellite link to Columbus, Ohio.

Accordingly, much lower usage rates are to be expected from the Darmstadt mirror site. Unfortunately, *server logs* prior to November 20 are not available. Analysis of the data for one month yields a similar visitor versus passerby pattern as McGill.

Section V Experimental data

5.1 Response and results from experiments

During the period of analysis (June to December 1995) four experiments were available in the *Auditory Perception* pages: a trill threshold experiment, a test of hearing out harmonics in a complex harmonic tone, an investigation as to how people hear octave-related complex tones, and an investigation as to whether the Shepard tone effect persists at high frequencies.

The Web tends to be a passive environment, where interactivity is reduced to clicking a button to select the next hypertext link. One reason for including the auditory experiments was to encourage the involvement of the reader: that is to have the reader listen carefully to the audio because someone cared about how he/she heard it, and to elicit responses. A further reason was a general validation of the results: experimentation over the Web is not sensible if we do not get the same results for previously well-researched phenomena. Also, we need to experiment with ways of presenting experiments to a Web audience that maximize the utility of the results that we obtain.

In all experiments there has been a high number of unusable responses (Figure 7). Some responses are duplicate and a large number contain no data. Several attempts to improve the screen design and instructions have had no noticeable effect. Puzzled, I manually analyzed the responses in conjunction with the audio downloadings, and found that almost all of the empty responses came from readers who had downloaded no audio files. At the same time I confirmed that, with a single exception, the completed responses came from readers who had downloaded a sufficient number of audio files to be able to make the responses. In February, I again simplified all response forms and added instructions to *submit* only if data had been entered. The rate of empty responses is now reduced, but not to zero. All responses can be viewed from the Appendix on the Web site.

In the *hearing harmonics* experiment, readers were given instructions as to how to hear out the individual harmonics in a complex tone. They were then asked to listen to a harmonic complex tone preceded by one of its components as a sine tone and report how many harmonics they were able to hear (the examples presented harmonics one through five). They are also given a box in which to enter their comments and a button to submit their response. About one half reported being able to hear two harmonics, and a few heard more: much as expected. Several supplied interesting comments. All current data can be viewed from the Statistics and Experimental data Appendix on the Web site.

In retrospect, this experiment could have been improved by asking questions about each harmonic -- "Did you hear the first harmonic?" etc. The instructions would have been less ambiguous and the data obtained would have been more useful.

In the trill experiment, readers were presented with repeating pairs of sine tones at various frequency separations. In an attempt to determine trill thresholds, they were asked to judge whether they heard the tones as unified or split. Again usable results were consistent with established findings with most answering *unified* only for the least separated pair of tones (Appendix G). The trill experiment was the most popular, probably because it appears at the top of a page that is early in the menu of pages in the menu within the *Auditory World*.

Octave-complex tones have ambiguous pitch, and this was confirmed by the variety of responses as well as by the certainty levels expressed by the respondents. (Readers were asked to match the pitch of several octave-related complex tones to that of candidate sine tones.) That we tend to hear in the 100 to 400 Hz range was confirmed by the results. To do this experiment requires listening to at least eight audio files, some of them more than once: this may be too much to ask of Web readers. The experiment yielded only fifteen usable responses, twelve of them from the class at Hanover College. Perhaps the task is too demanding to deliver over the Web, requiring a supervised environment such as that presented to the class at Hanover College (section 5.2). Also of interest is my observation that several readers listened to large numbers of the examples and failed to submit a response -- perhaps this is additional evidence that octave-complex tones have ambiguous pitch.

Few of the readers (only thirty) who listened to these tones went on to read the section explaining what they heard and how this is explained by several current pitch theories.

The last experiment explores the prediction of Terhardt et al (1982) that the Shepard tone phenomenon should not exist at high frequencies. The experiment simply presents the theory and asks for comments. Since writing the page, I have had the pleasure of discussing the prediction with Dr. Ernst Terhardt: he said that at the time of the prediction (1982), it was believed that sub-harmonics of high pitches were not heard and the model contained a filter, but later versions of the model do not have the filter and predict that the Shepard tone phenomena will still occur. The page is deep in the Web site and has been reached by only one hundred readers: there have been only two usable responses and both listeners heard the Shepard tone phenomenon, as now predicted by Terhardt's model. As in the octave-complex tone experiment, several clients who listened to many of these tones failed to submit a response.

Generally, the responses from all of the experiments are consistent with established findings and current theories.

5.2 Hanover College - visual perception

John Krantz and his colleagues at Hanover college have been among the first to recognize the potential of the Web for providing subjects for psychological experiments. They have mounted three experiments in the areas of social psychology and vision perception. The presentations to the reader are simpler: they deliver graphics files to subjects who are asked to make various comparisons between images. These sites exist solely to collect experimental data and make no attempt to give their viewers anything in return for their participation. In a private communication, John Krantz writes:

> "Two of the experiments are in the area of social psychology and the third deals with the column illusion that can be seen in Greek Doric columns [Krantz and Terry, 1994]. In the social psychology experiments, two female drawings are displayed in black and white. One is the standard which is given a value of 200 and the other is the figure to be judged for attractiveness. A simple form is used for subjects to enter the data, which is then recorded in a text file. One experiment presents a set of frontal views, and the other presents a set of side views. The column illusion study deals with the illusion in which Doric columns appear to lead apart when set next to each other. Simulated columns are drawn in pairs leaning towards or away from each other at varying angles. The angles were developed and calibrated using a spreadsheet. The columns were then smoothed using a paint program. In most programs edges are not smoothed and thus subjects can make judgments based on the jumps in the edges -- rather than their perceptions. Based on work with other discrete displays, it was determined that the edges could be adequately smoothed with four levels of grey [Silverstein, Krantz, Gomer, Yeh and Monty, 1990]. The subject selects the set of columns that look most vertical using the button input feature of the form. Generally, data collection has proceeded smoothly: over 150 subjects have responded to one of these social psychology studies in about four months. The column illusion study has not fared as well as the others due to the length of time it takes to download the images and the inability to compare across the images. However, data in all cases compares well to data gathered in laboratory settings [Krantz, Scher, and Ballard, 1995]."

Krantz and his colleagues have been pleased to receive about one hundred and fifty usable responses over a four month period [Welch and Krantz 1996]. They judge their results to be consistent with those from other experiments.

5.3 University of Colorado

In the Winter 1995 term, Professor Andreas Weigend made significant use of the Web in his graduate course in Music Cognition. As a project, his students conducted an experiments in auditory cognition over the Web. They mounted experiments in the following areas: attention in music, tempo and emotion, melody recognition and musicality judgements

In a paper at SMPC 95 (June 1995), Weigend reported that each advertisement on an Internet newslist resulted in about twenty responses during the following week.

I have recently corresponded with Lucky Vidmar, one of the student whose experiment on attention in music was the first listed on the Web page. He reports that during the initial three month period he received fifty-five usable responses, and that he has subsequently received seventy more responses without advertising. He expresses concern about the demographics of the Web and the lack of experimental control. Other students were less successful than Vidmar in obtain responses. In my view, this is simply due to their position on the page.

The number of usable responses received per month received by Lucky Vidmar is about double that of the Auditory Perception site.

Section VI Conducting experiments over the Web

The experience at McGill, Hanover College and the University of Colorado show that the Web does provide an inexpensive, feasible method of conducting psychological experiments. However, experimenters can expect but a tiny fraction of the estimated forty million Web readers to participate. With fairly aggressive advertising, responses from twenty subjects a week should be considered good. The evidence suggests that sites whose sole purpose is experimental are more successful at collecting data than those with a hybrid purpose.

Experimenters should be aware that participating subjects are unlikely to be as diverse as the general population. Web readers are more likely to be young, male and educated. Those who participate are also more likely to be interested in the area of the experiment. To some extent this is also true when, as is often the case, subjects are recruited from educational institutions.

Psychoacoustic experiments bring additional problems:

1. quality of the client's sound reproduction equipment,
2. lack of control of the experimental environment,
3. amount of patience needed on the part of the subject.

Though new technologies may reduce download times and the increasing prevalence of multimedia systems may improve sound quality, experiments should be chosen with these factors in mind.

Careful design and testing of the user interface to experiments can make a significant difference in the quality and number of usable responses. Server (and other) log files should not be forgotten as a source of verification that the experiments have been done correctly.

Section VII Conclusions

The McGill site has, by any standards, been very popular. In addition, it has managed to hold the attention of a large number of readers from around the world. The number of readers who stay for a significant length of time (or revisit) indicates that it is fulfilling a useful role as a tutorial in Auditory Perception.

The links to the site, particularly from educational institutions, show that it is valuable in providing course and reference material.

At present, download times and lack of quality audio equipment limit the number of readers who can benefit from the audio in the demonstrations. Response to experiments, though low, is significant. Together with the e-mail responses and comments on the experiments, this shows considerable potential for two-way communication (over the Web) between author and readers.

No profile of a typical reader could be established: some are interested in theory and references, others listen to sounds and some do the experiments. It is clear, however, that material that is further down the menu or at a deeper level of hypertext is read less often.

Conducting psychological experiments over the Web is feasible and reasonable. However, patience is required to collect results, the design of forms to capture the data requires great care and the experiments must be chosen with the limitations of the Web and the attention span of the Web reader in mind.

Appendix A

Glossary of Internet terminology

Appendix A Glossary of Internet terminology

AIFF	Audio format used primarily on Apple and Silicon Graphics computers.
AU	Audio format used by SUN and NeXt computers.
cgi-bin	Location on a server containing programs that are executable by the HTTP daemon, in particular programs that receive HTML form data.
GIF	Graphic Interchange Format. Commonly used lossless compressed graphics format.
Home page	An HTML page introducing its owner, and often containing links to his or her favourite sites.
HTML	Hypertext Markup Language. Used by most text documents on the Web. Allows links to other text documents and files in other media.
HTTP	Hypertext Transfer Protocol for transfer of documents between client and server systems.
JPEG	Joint Photographic Expert Group. An efficient but lossy method of compressing graphics.
robot/spider	Program, used by search engines, which navigates the links of the Web and analyzes documents for keywords

UDP	User Datagram Protocol. Often used for broadcast applications.
URL	Uniform Resource Locator. The Web address of an object, such as an HTML document, a sound file, a graphics file, or an executable program.
URL encoding	Coding in the form of a URL. Data is passed from forms filled out by the user to the server by this method.
WAV	Audio format commonly used by PCS

Appendix B

Some sample documents from Auditory Perception

Appendix B1 Introduction

Auditory Perception - Introduction

The study of Auditory Perception is multi-disciplinary, including (at least) the disciplines of Physics, Psychology, Physiology, Computer Science and Music.

The aim of the field is to understand, at some level, why and how we make sense of our auditory world from the sounds that reach our ears. The Physics of sound production and propagation is well-understood, the mechanisms by which these sounds are transmitted to the inner ear are quite well-understood, but less is known about how we derive understanding of our world from the sensations received at the inner ear.

Physiologists, working with both human and animal subjects, have learned much about the neural processes that take place between the ear and the brain. Psychologists construct and test conceptual models of the perception process. Psychoacousticians focus on the perceptual effects of various sounds, and attempt to build theories based on the responses of many subjects. Computer Scientists and Engineers have built computer models to make predictions from and test various theories. Musicians, from earliest times, have been concerned with how the listener perceives music; they have (consciously or not) exploited the properties of the auditory system.

The multi-disciplinary nature of the field causes the problem of a huge multi-disciplinary vocabulary. The glossary of terms is provided to alleviate this problem.

Some practical applications resulting from the study of Auditory Perception are: developing better hearing aids, designing work environments, efficient coding of sound for transmission, musical listening environments, computer sound generation, computer-based speech recognition and synthesis.

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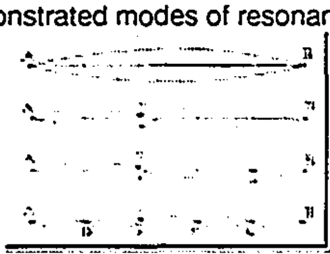
Appendix B2 Some Selected Moments from History

Selected Moments from History

Experiments in acoustics started a long time ago! Pythagoras experimented with strings: using a monochord, he determined that identical strings whose lengths were in the ratio of 2:1, 2:3 and 3:4 produced two tones an octave, a perfect fifth and a perfect fourth apart, respectively. He is credited with the design of the scale based on these *perfect* intervals.

Music theorist Zarlino (1517-1590) based his theory of consonance on mathematical proportions.

It is to Joseph Sauveur (1653-1791!!) that we owe the word "acoustics", first used by him in a lecture in 1701, to organise materials on music theory and the physics of sound. He was also the first to use a logarithmic measure for interval size, to work with frequency ratios instead of string lengths and to systematically investigate equal divisions of the octave. Also in 1701, he demonstrated modes of resonance (harmonics) of a stretched string - compare this diagram  with those in today's physics texts - and described string vibrations as consisting of several harmonics sounding simultaneously. He called them "ondulations compliqu&eacutees": today we call them "complex tones" [Sauveur 1710-1713].

Unaware of Sauveur's work on harmonics, the great music theorist Jean Philippe Rameau (1722.) looked back to Zarlino, and argued philosophically for a harmony built on tones related by ratios of small numbers. Rameau was excited when he heard of Sauveur's experiments with harmonics; he believed that these results confirmed the importance of low number ratios, performed several experiments with instruments himself, and used the results as a basis of his later texts, such as Generation Harmonique (1737).

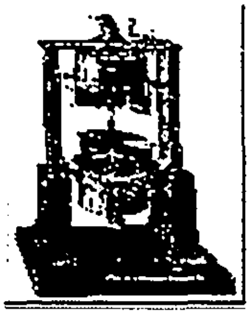
Rameau had ideas in every aspect of music theory: ideas that provided the topics for generations of theorists to come. His most important contribution to the theory of harmony was the concept of the "basse fondamentale".

Scientists of the nineteenth century created laboratory sounds with a variety of mechanical apparati. The first siren was constructed in 1819, by Cagniard de la Tour. Essentially, bellows were used to pump air through holes in a rotating disk. The "instrument" created regular puffs of air and made a pitched sound of frequency determined by the speed of rotation.

The great scientist of the nineteenth century, Hermann Helmholtz, discovered much about the physics of sound and our perception of sound. Like Rameau, he was particularly interested in the connection between mathematics and music. In "On the Physiological Causes of Harmony in Music", a lecture he gave in 1857, he discusses pitch:

> First of all, what is a musical tone? Common experience teaches us that all sounding bodies are in a state of vibration. This vibration can be seen and felt; and in the case of loud sound we feel the trembling of air even without touching the sounding bodies. Physical science has ascertained that any series of impulses which produce vibration of the air will, if repeated with sufficient rapidity, generate sound. The sound becomes a musical tone, when such rapid impulses recur with perfect regularity and in precisely equal times. Irregular agitation of the air generates only noise. The PITCH of a musical tone depends on the number of impulses which take place in a given time; the more there are in the same time the higher or sharper is the tone. And, as before remarked, there is found to be a close relationship between the well-known harmonious musical intervals and the number of the vibrations of the air. If twice as many vibrations are performed in the same time for one tone as another, the first is the octave above the second. [Helmholtz 1873].

To demonstrate these assertions, he built the complex two-drum version of the siren shown



here.

His instrument has two rotating cylinders, both receiving air from the bellows. Each box has four concentric circles of equally spaced holes: the lower circles have 8, 10, 12 and 18 holes, and the upper has 9, 12, 15 and 16. One set of holes in each box can be opened by stops. Air escaping through the holes causes the two cylinders to rotate at the same rate. When the series of 8 holes is opened and the cylinders rotate at 33 revolutions per second, there will be 264 (8 x 33) puffs of air per second and the pitch of middle C is produced. Another pitch can be produced simultaneously by opening a set of holes in the other box. Many consonant musical intervals can be produced by opening two hole sets with the number of holes in the appropriate ratios. For example, choosing 8 and 16 holes produces two pitches an octave apart, choosing 8 and 12 produces a perfect fifth, and 12 and 15 produce a major third.

Helmholtz's siren also had a device for mistuning the intervals. The handle attached to the top disc could be turned, resulting in a slightly different speed of rotation for the two drums. Helmholtz used this device to experiment with consonance and dissonance, and to demonstrate that consonant intervals required the exact ratios between the two tones [Helmholtz 1873].

Other important pioneers in the theory of sound (acoustics as we understand it today) were Sir Isaac Newton (1642-1727) and the following nineteenth scientists: Jean Fourier who showed that any complex waveform could be analysed into a unique set of sinusoidal components, Georg Simon Ohm who confirmed that we can hear pitches corresponding to the Fourier components of a periodic sound, and Lord Raleigh.

Today's theories of pitch perception all have their roots in the nineteenth century. A. Seebeck (*Uber die Sirene*, Annalem de Physik und Chemie, 1843, 60, 449-481) used the siren to generate various periodic patterns of puffs, and found that the pitch heard corresponded to what we would today call the *period of the waveform* -- he formulated the first *periodicity theory* of pitch perception. The phenomenon is referred to as the *pitch of the missing fundamental.* Ohm, followed by Helmholtz, believed that the place of vibrations of the basilar membrane performed a spectral analysis of the incoming sound -- the first *place theory* of pitch perception. His place theory had problems explaining the pitch of the missing fundamental: Helmholtz believed that it was created by distortions in the inner ear, but for once he was wrong. Experiments by J.F.Schouten in 1938 and Licklider in 1954 showed that the pitch corresponding to the fundamental is **not** present at the receptor level [Warren, 1984, pp 264-265]. Periodicity theory has led to many experiments and theories as to how timing information might be used at the physiological level. Place theory forms the basis of several "pattern recognition models", which assume that spectral pitches are extracted by the basilar membrane and processed by a neural pattern matcher or a neural processor that looks for familiar sounds.

In the 1960s, Ernst Terhardt developed the "virtual pitch" model of perception [Terhardt, 1972]: according to this model the familiar and learned harmonies of speech form the basis of pitch perception. Whereas Helmholtz believed that harmony was a product of cultural learning (evolving with music), Terhardt believes that speech learning is the basis of pitch perception. In "The Concept of Musical Consonance: A Link between Music and Psychoacoustics" Terhardt (1984) shows that the fundamental note sequence (which Rameau tried so hard to put on a solid footing) can be found as the virtual pitch of chords. Like Rameau's models, Terhardt's have difficulty explaining minor harmony. Richard Parncutt's refinements and extensions to Terhardt's model place the harmony of Western music on a solid psychophysical footing [Parncutt 88,89]. Rameau wanted to find harmony in nature - he would have been excited to hear the natural voice could be the basis for musical harmony.

Appendix B3 Physics and Psychophysics

Basic Acoustics and Psychoacoustics

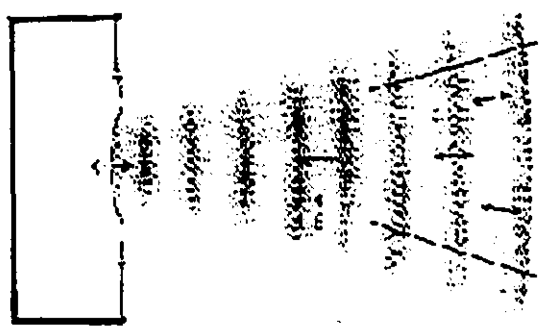
This section deals with the basic physics of sound, or what is sound and how is it produced and transmitted, and the relationship between the physical variables which measure sound and the perceptual variables which measure our response to it.

What is sound?

Sound originates from a disturbance of the air by any object. For example, two hands clapping cause a disturbance of the air around the hands: the hands are the source of the sound. The local region of air has increased energy caused by the motion of the air molecules. This energy spreads outwards in sound waves.

The analogy between sound propagation through air and waves in water was understood as early as Marcus Vitruvius Polio in the first century BC.

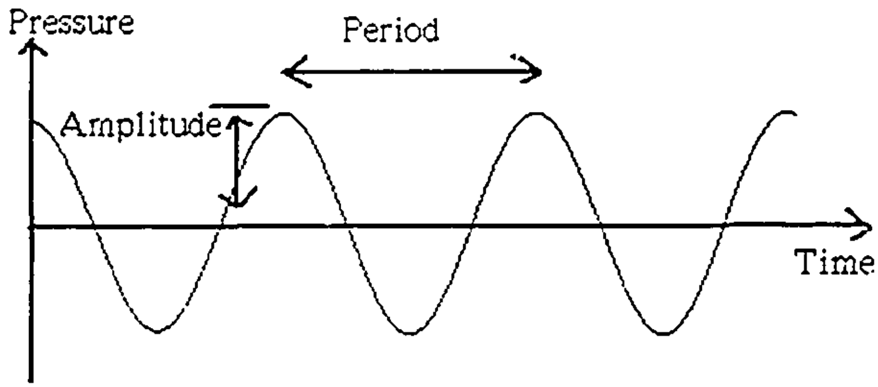
An interesting source of acoustic energy today is the loudspeaker: the cone of the loudspeaker vibrates in the air causing disturbances dependent on the electrical signals reaching the loudspeaker from the sound system. Effectively, the loudspeaker converts electrical energy into sound energy, which travels through the air as waves radiating from the loudspeaker:



Sound travels through the air at about 340 metres per second.

Physical Variables

Here is a graph of the variations in air pressure over time, for a *pure sine tone* -- the sound produced by a tuning fork or an electronic oscillator.



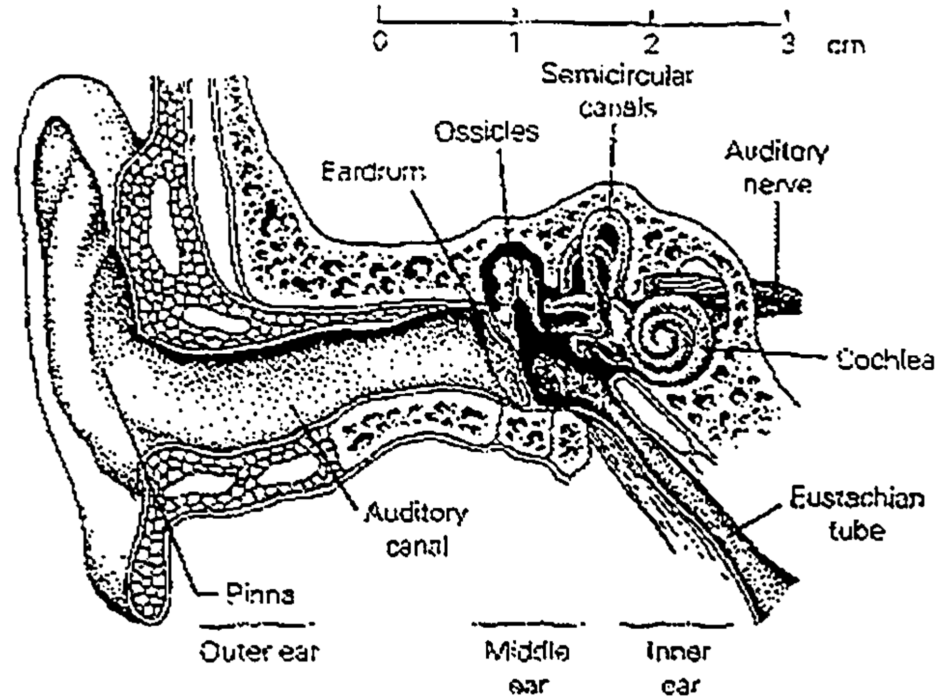
Two physical measurements, illustrated above, describe this wave completely: they are the *amplitude* and the *period.* We usually speak, not of the period, but of the *frequency* of vibrations, which is simply the inverse of the period of (1/period). The frequency simply measures the number of waves that travel by in each unit of time. It is usually measured in hertz, 1 hertz is 1 cycle per second. (1 kHz = 1000 Hertz). The range of human hearing is from 20 Hz to 20,000 Herz.

Intensity is a measure of the power in a sound, as it contacts an area such as the eardrum, and is directly proportional to the square of the amplitude of the waveform. Intensity is expressed as power per unit area and measured in Watts per square meter. The decibel scale is logarithmic and provides the most convenient physical measure of intensity. One bel (named after Alexander Graham Bell) is defined as the ratio between two sounds whose intensities have a ratio of 10:1, and a decibel (dB) is one tenth of a bel. Note that the Decibel is a unit for sound level differences between two sounds. In acoustics, dB is often used as an absolute measure of intensity - in this case, it is a measurement relative to the threshold of hearing of 10 (power -12) Watts per Sq. meter. Here are some sample intensity levels in decibels:

Threshold of hearing	0
Leaves rustling in the breeze	20
A quiet restaurant	50
Busy Traffic	70
Vacuum cleaner	80
Threshold of pain	120
Jet at takeoff	140

Psychophysical Variables

When the waves reach our ear, they cause our eardrum to vibrate and transmit the vibrations to the inner ear. Here they are converted, by a remarkable organ called the cochlea, into neural (nervous) energy for interpretation by the higher levels of the auditory system.



In the early nineteenth century, scientists started to attempt to measure the response of subjects to sounds with controlled physical characteristics. They determined that the perceptual attributes of *loudness* and *pitch* were strongly related to the physical variables of *amplitude* and *frequency*.

Pitch

All perceptual attributes are hard to define and to measure. Here is the accepted definition of pitch: "the attribute of auditory sensation by which sounds can be ordered on a musical scale".

Only periodic (or nearly periodic) sounds have pitch: we cannot ascribe a pitch to noise. Sounds made by musical instruments, the human voice and tinkling wine glasses are regular and have pitch. Those that we describe as sounding higher have a higher pitch.

To a first approximation, pitch of a pure tone is proportional to the logarithm of frequency. This breaks down at very high or very low frequencies.

The piano below shows the relationship between the keys on a piano keyboard, musical notation and frequency. As you can see, notes played on a piano have frequencies between

27.5 Hz and 4,000 Hz.  (click to expand)

The notes of the piano are such that roughly equal increases of pitch are heard between any pair of adjacent keys. In terms of frequency, the ratio of frequencies between any two keys is constant (approximately 1.06). Therefore, the logarithmic scale for frequency matches up with the constantly spaced piano keys in this diagram.

In the case of complex tones, such as the sound of a bell, pitch may be ambiguous. In Psychoacoustic experiments, the pitch of a complex sound can be measured by asking a subject to adjust a sinusoid until its pitch matches that of the sound.

Loudness

Loudness is the attribute of sound that allows us to organise sounds on a scale from soft to loud.

Loudness increases with the intensity of the sound source, but is also influenced by the spectral content. These equal loudness contours, developed by Fletcher and Munson in 1933, have stood the test of time and appear in every book on psychoacoustics. They show the uneven manner in which the auditory system responds to tones of different frequencies:

 (click to expand)

The ear is most sensitive to tones at frequencies between 200 and 5000 Hz, which is also the region of human speech sounds. At low frequencies, high intensities are needed to make a tone audible. The ear has extra sensitivity in the region of 2000 Hz to 4000 Hz, or around the resonant frequency of the auditory canal. As a matter of interest, this is the frequency region of both male and female screams.

The unit of loudness level is the phon, and is defined as the sound pressure level in dB of a 1000 Hz with the same subjective loudness.

Timbre

Sounds made by musical instruments have another perceptual attribute: that of timbre or tone quality. We may describe sounds as being tinny, full, brassy, trumpet-like, etc. Timbre allows us to identify instruments by their sound.

Timbre is defined as that attribute of a sound that allows us to differentiate between two sounds of the same pitch, intensity and duration.

It used to be thought that timbre was related only to the relative strengths of the harmonics produced by an instrument, but recent research in computer synthesis of instruments has shown that the pattern of change over time of each of the components contributes to timbre.

Instrument recognition is also dependent on the sounds that are associated with the "attack", for example the noise at the start of a trumpet sound, and to a lesser extent on the "release", as when a piano key is released.

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Appendix B4 Auditory Scene Analysis: sequential organization

Sequential Organisation

The Trill Phenomenon

Albert Bregman (1990) attributes the first scientific studies of sequential stream segregation to George Miller and George Heise(1947), who experimented with two rapidly alternating tones to see how close they needed to be for the listener to experience a holistic *trill.* Listeners reported two different effects: when the frequency difference was small they heard the pitch moving continuously up and down (ie. a trill), but when it was large they heard two interrupted and unrelated tones. Miller called the breaking point the "trill threshold", and noted that it increased with the frequency of the lower tone. Below is a demonstration of the effect. At high separations (24% is about a major third or 4 semitones), you will probably hear a pulsing of the lower tone and be unable to track the rhythm of **both** tones. The lowest separation corresponds to an interval of less than one semitone and sounds like a trill. At intermediate separations, you may be able to decide how you hear the sequences. or you may hear them in different ways at different times.

As you listen to each example, please click in one of the radio buttons below to indicate whether you heard the sounds as unified or as two separate tones. Before leaving the page, please move down and click the submit button.

24% I heard a unified trill two pitches

20% I heard a unified trill two pitches

16% I heard a unified trill two pitches

12% I heard a unified trill two pitches

8% I heard a unified trill two pitches

4% I heard a unified trill two pitches

When you have selected your responses, please click to submit.

If you are interested in the musical intervals corresponding to the above percentage differences in frequency, here is a rough table for conversion.

This is not a scientific way to determine trill threshold. I have plans for setting this up so that you could work with a partner, who would use one of the psychological testing models, request custom audio and graph your responses.

Several psychologists have noticed the similarity between the trill phenomenon and the ideas of the Gestalt psychologists about the grouping of visual objects. The phenomenon is analogous to the visual grouping of objects by proximity, extensively studied by Gestalt psychologists: in figure 1 below we see the x's and y's as separate "objects", but in figure two we see a single xzxzxz object.

x x x x x x

z z z z z z

Figure 1

x z x z x z x z x z x z

Figure 2

In the auditory domain, the vertical dimension is replaced by frequency and the horizontal dimension by time. Here are the *trills* in musical notation. Notice the similarity with the xz visual figures.

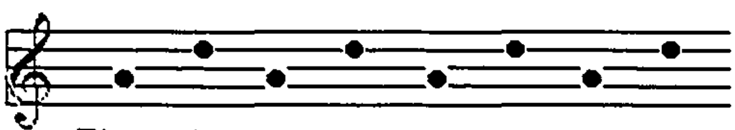


Figure 1

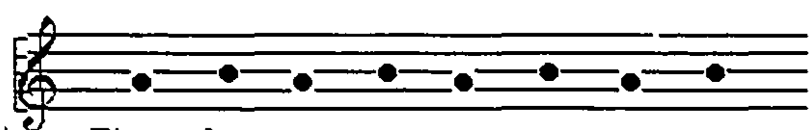


Figure 2

Overlapping Melodies

An interesting demonstration of the formation of auditory streams is due to Jay Dowling. In 1973, he overlapped two simple melodies: recognition was impossible when the tunes were in the same frequency range, but when one of the melodies was transposed the tones segregated into two recognisable melodies [Bregman 1990, p140].

The galloping rhythm of van Noorden

In *trill* experiment, the speed of the sequence was constant. In the visual domain, proximity is determined by the relative separation in the X and Y coordinates. Here is what happens if we compress the notated music in the X dimension.

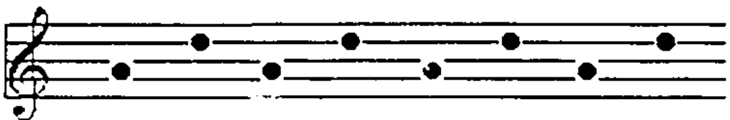


Figure 1

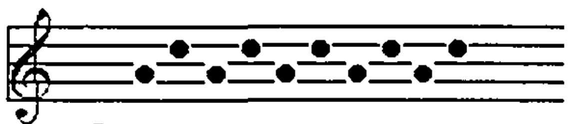


Figure 1A

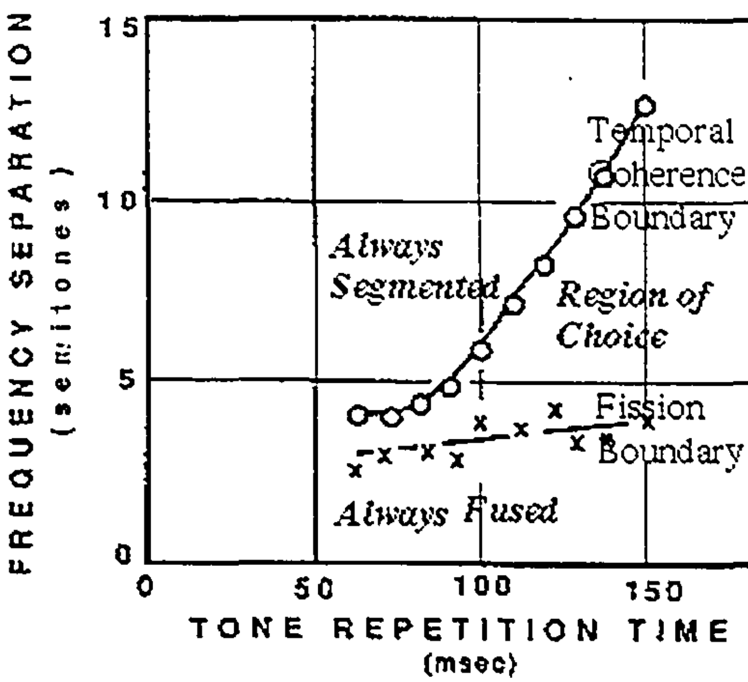
We are more likely to group the two notes visually. If we compress the time dimension will we be more likely to hear notes which are further apart in frequency as belonging together? This is the test performed by van Noorden, a prominent researcher in the field of auditory scene analysis.

When stream segregation occurs, we are generally unable to attend to the events in both streams at the same time. We experience a general temporal confusion and have trouble hearing the overall rhythm of the sequence. Leo van Noorden cleverly exploited the change in apparent rhythm as a method of ascertaining whether segregation had occurred in rapid sequences of sine tones. He used "galloping" rhythm produced by the compound sequence

```
V-V-V-V-V...
-F---F---F...
```

to investigate the relative effects of both frequency separation between the F and V tones and the speed of the sequence. When the sequence is integrated, listeners hear a repeating galloping rhythm, and when it has segregated into streams they hear two pulsating tones. For each speed, he varied the frequency of the V tones and asked subjects to indicate when they heard the galloping rhythm. One group of subjects was asked to try to hear the sequence in a particular way as much of the time as possible. Van Noorden developed boundary graphs in the frequency - repetition time domain:

In the graph shown below, the "fission boundary" is the curve, below which listeners had no choice but to hear the galloping rhythm, and the "temporal coherence boundary", the curve above which listeners were incapable continuing to hear the galloping rhythm. His major findings were that sequences were always integrated for frequency separations below about 4 semitones (the fission boundary), but that the temporal coherence boundary was very sensitive to the speed of the sequence. Between the two boundaries, the listener can elect to hear the sequence as two segregated streams or as a single "melodic" sequence. The fission boundary is closely related to the trill threshold, discussed above.



Try listening to some of these "gallops" by clicking in the squares in the map below. Each example is about 200 kBytes. As a suggestion, a 3 semitone separation at 75 msec time interval will probably give you a nice gallop and 9 at 75 msec a good segregation with a pulsing in two voices.

At which note separation and onset to onset time do you hear the galloping rhythm? Do you agree with van Noorden's boundaries?

Separation (semitones)	50Msec	75Msec	100Msec	125Msec	150Msec
1					
3					
5					
7					
9					

Bregman [1990, p60] argues that the temporal coherence boundary shows the point at which the auditory system is forced, by primitive and automatic processes, to segregate the auditory input into two streams. On the other hand, the fission boundary measures the limited power of attention.

These findings are consistent with the practise of music. Popular folk melodies, in all cultures, make use of a limited range (usually less than an octave) and generally move in small steps of frequency. Thus they avoid segregation and the melody is heard as a united whole. Conversely, when composers want the music to segregate into melody and harmony, they place them in different registers. Given time, many more examples could be discussed.

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Appendix B5 Pitch of Harmonic Tones

Pitch of harmonic tones

(Hearing an experiment)

Sounds of everyday life, including musical sounds, have a more complex waveform than a sine wave. Jean Baptiste Fourier (1786-1830) proved that any complex waveform can be analysed mathematically as the sum of a set of sine waves. These are referred to as the Fourier components, or partials of the given waveform. Analysis of a waveform into sinusoidal components is known as Fourier analysis.

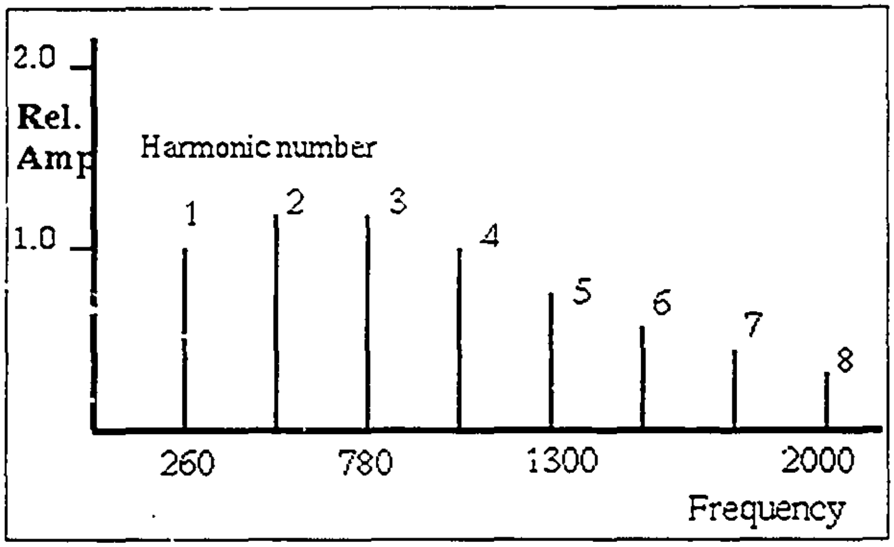
As a complex tone can be separated into sinusoidal components, so can the reverse take place: we can construct a waveform out of a set of sinusoids. This process is referred to as Fourier synthesis.

For a periodic waveform, the lowest component is called the *fundamental*. Fourier also proved (mathematically) that the partials of a **periodic** waveform have frequencies that are integral multiples of the frequency of the fundamental, that is if the fundamental has frequency f, then the partials occur at the frequencies 1f, 2f, 3f, 4f, ... They are referred to as harmonics, and are numbered from 1 ie. if the fundamental has frequency f, the third harmonic has frequency 3 x f. This allows representation of a complex tone as a amplitude spectra, in the frequency domain. Listen to this complex tone.


(66 kBytes)

Here is the waveform in the time domain:

and here is the spectra diagram, showing the relative amplitudes of each of the harmonics:

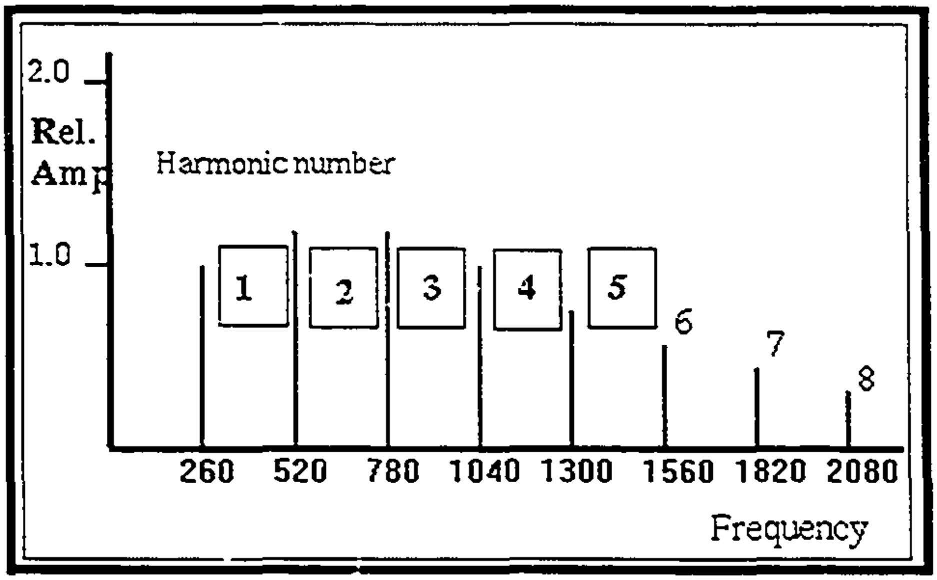


Another nineteenth century German physicist George Ohm, most famous for Ohm's electrical law, formulated *Onm's Acuustical Law*, which states that the relative phases of the components do not affect perception. He also showed that we can hear, to some extent, the sinusoidal components of a complex tone

Generally, we hear complex sounds holistically; Helmholtz used the word *synthetic* to describe this mode of listening. When presented with a harmonic tone we usually hear the pitch as that of the fundamental component. It is also possible (by Ohm's Law) to listen to complex sounds *analytically* and "hear out" some of the lower partials. Helmholtz discussed methods of hearing out partials of a piano tone and of the singing voice. Here is his method for hearing out the partials of a piano tone:

> "In commencing to observe upper partial tones, it is advisable just before producing the musical tone itself which you wish to analyze, to sound the tone you wish to distinguish in it, very gently, and if possible in the same quality of tone as the compound itself. The pianoforte and harmonium are well adapted for these experiments, because the both have upper partial tones of considerable power.
>
> First gently strike on a piano the note *g'* [G above middle C], and after letting the digital [piano key] rise so as to damp the string, strike the note *c* [an octave below middle C], of which *g'* is the third partial, with great force, and keep your direction directed to the pitch of *g'* which you had just heard, and you will hear it again in the compound tone of *c*. Similarly, first stroke the fifth partial *e''* gently and then *c* strongly." [Helmholtz, 1877, p 50]

Here is an electronic version of the method. Select one of the green boxes in the diagram below. You will hear a pure sine tone, silence and then a harmonic tone. Listen carefully to the first sound, a pure sine tone that matches one of the harmonics in the second sound. See if this helps you to hear out the partial in the harmonic sound. You may need some practise! (Each example is 120 kBytes.)



Helmholtz claims that the odd numbered partials are easier to hear than the even numbered partials. Do you agree?

How many partials were you able to hear out? (If you were not able to hear any, please enter zero (0).)

Feel free to comment or describe your experiences

When you have entered your response, please click to submit.

To clear your reply and retype, you can press Reset Helmholtz adds that after practise harmonics can be heard without the aids, but "a certain amount of undisturbed concentration is always necessary for analysing musical tones by the ear alone". He also advocated the use of resonators "to direct the attention of the ear to the required tone" [Helmholtz 1877, p 51].

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Appendix B6 Octave-related complex tones (OCTs)

Octave-related complex tones

Octave-related complex tones are complex tones comprised of only components which are separated by octaves, eg. the tone comprised of sinusoids at the frequencies 100, 200, 400, 800, 1600 Hz. These tones have an organ-like quality, and their pitch is usually quite ambiguous.

Let us listen to some and try to make pitch judgements.

Compare the pitch of these octave-related complex tones with each other, and with the candidate sinusoids given below.

1 2 3 4

Candidate sinusoids:

1 50 Hz 2 80 Hz 3 100 Hz

4 200 Hz 5 400 Hz

Here is a form for you to tabulate your answers: after you have entered values, please move down the page and submit your responses.

Complex 1 matched with sine tone Sure?

Complex 2 matched with sine tone Sure?

Complex 3 matched with sine tone Sure?

Complex 4 matched with sine tone Sure?

Estimate the quality of your audio system Poor

Feel free to comment or describe your experiences

After you have entered your responses, please click to submit.

If you need to clear the entries, you may Reset.

Are you curious about what you heard, and why?

Appendix B7 The Glossary

Glossary A | B | D | H | I | P | R | T |

Absolute pitch
: Comparatively rare ability to identify any musical note, or to produce orally any named note.

Acoustic energy
: Variation in air pressure produced by the vibration of an object

Amplitude of a sound wave
: Maximum pressure variation, a force per unit area measured in Newtons per square meter.

Analytic listening
: Listening for the pure tone components of a complex tone, as opposed to holistic (synthetic) listening.

Audiogram
: Graph of threshold intensity for hearing pure tones as a function of frequency.

Auditory cortex
: Region of the cortex devoted to the analysis of sound information

Auditory nerve
: Bundle of nerve fibres which carries information from the cochlea to the higher stages of the auditory system.

Auditory stream
: Sequence of sounds grouped together because they are attributed to the same source (sonic event). Note that Warren uses the term "parallel auditory continua".

Glossary Top |**Use Back in browser to return to previous document.**

Basilar membrane
: A membrane inside the cochlea which vibrates in response to sound. It is here that sound energy is converted into neural impulses.

Chord
: Three or more notes sounded simultaneously.

Chroma
: Musical note name, without specification of the octave register.

Chromatic scale
: A scale of twelve equal steps per octave, each step being a semitone.

Cochlea
: A coiled, fluid-filled chamber in the inner ear, containing the basilar membrane, where mechanical (sound) energy is converted into neural energy. Resolution of a complex sound into its components occurs in the cochlea.

Complex tone
A tone composed of a number of sinusoids at different frequencies and phases (not necessarily harmonic).

Component
One of the sinusoid that is part of a complex sound.

Cycle
That part of a periodic function that occurs in one period.

Glossary Top |**Use Back in browser to return to previous document.**

Difference threshold
Minimum amount by which stimulus intensity must be changed in order to produce a just noticeable change in sensation.

Equal loudness contours
Curves plotted as a function of frequency, showing the sound pressure level required to produce a given loudness level.

Envelope
The envelope of a function is a smooth curve passing through the peaks of the function. eg. spectral envelope.

FFT
Fast Fourier Transform. A specific efficient spectral analysis program.

Formant
A resonance in the vocal tract, which causes a peak in the spectral envelope of a speech sound.

Frequency
For a sine wave, the frequency is the number of repetitions per unit of time. 1 cycle per second = 1 hertz. Usually referred to in kHz, or number of repetitions per msec.

Fundamental
Lowest component of a harmonic complex tone.

Fundamental frequency
The fundamental frequency of a periodic sound is the frequency of repetition of the waveform.

Glossary Top |**Use Back in browser to return to previous document.**

Habituation
The process by which an organism ceases to respond to some recurring or familiar stimulus.

Harmonic
A component of a complex tone, whose frequency is an integral multiple of the

fundamental frequency of the complex. The third harmonic is at the frequency 3f, where f is the fundamental frequency.

Harmonic comp.ex tone
Complex tone whose partials are all harmonics ie. all partials have frequencies that are integral multiples of the fundamental frequency. Harmonic complex tones are periodic.

Hear out
Hear, by careful analytic listening, the components of a complex tone.

hertz
Unit of frequency. 1 Hz = 1 cycle per second.

Holistic listening
Normal mode of perceiving the whole without being aware of the components of a complex tone. Opposite of analytical. Also called **synthetic**.

Glossary Top |**Use Back in browser to return to previous document.**

Intensity
Sound power transmitted through a given area. Intensity is proportional to the square of the amplitude and, expressed as power per unit area, it is measured in watts per square meter. The threshold of audibility is 10 power -12 W/ sq m.

Logarithmic scale
A scale in which the logarithm of the raw value is used instead of the raw value. The effect is tat equal steps in the raw value are replaces by equal ratios eg. dB scale.

Loudness
Attribute of auditory sensation corresponding to intensity. Sounds can be ordered on a loudness scale from quiet to loud.

Mel scale
A proportional scale, in which equal intervals (measured in mel) correspond to equal perceived interval sizes. The mel scale is roughly proportional to the logarithm of frequency but becomes linear at low frequencies.

Noise
Usually refers to unwanted sound. Noise is not periodic. White noise is a sound with constant power per unit bandwidth over the audible frequency range.

Octave
The interval between two tones when their frequencies are in the ratio 2:1. Musical notes an octave apart have the same letter name.

Octave-related complex tone
Complex tone whose components are separated by octaves.

Glossary Top |**Use Back in browser to return to previous document.**

Partial
One of the sinusoidal components that is part of a complex sound.

Perfect fifth
Interval between the first and fifth degrees of a major scale, or interval between two pure tones whose frequencies are in the ratio 3:2, or 7 semitones.

Perfect fourth
Interval between the first and fourth degrees of a major scale, or interval between two pure tones whose frequencies are in the ratio 4:3, or 5 semitones.

Perfect pitch
See absolute pitch.

Period
The smallest time interval over which a function repeats itself.

Periodic sound
A periodic sound has a waveform which repeats regularly over time.

Phase
Relation in time between two pure tones of the same frequency. In phase - both waveforms peak together.

Pitch
The attribute of auditory sensation by which sounds can be ordered on a musical scale ie. by which sounds can be judged relatively high or low.

Pitch ambiguity
A sound has pitch ambiguity if holistic perception may yield one of several different pitches depending on attention, context,..

Pitch shifts
Change in pitch of a tone due to intensity or masking.

Proximity
Gestalt principle of organisation referring to the perceptual tendency to group together objects that are near to one another. In the auditory perception, "near" means close in the frequency-time domain.

Psychophysics
Branch of Perception that is concerned with establishing quantitative relations between physical stimulation and perceptual events. A science which arose in the early part of the twentieth century.

Pure tone
A tone whose soundwave is sinusoidal. quantitative relations between physical stimulation and perceptual events.

Glossary Top |**Use Back in browser to return to previous document.**

Relative pitch
Ability to identify a musical interval. An ability which can be learned.

Residue pitch
Also known as low pitch, virtual pitch, periodicity pitch. Pitch of a complex tone, under normal listening. The name "residue" refers to the phenomenon of the missing fundamental - the pitch perceived comes from the "residue".

Salience
Perceptual prominence, or likelihood of being noticed.

Semitone
The notes corresponding to adjacent keys on the piano. The interval that results when the octave is divided into 12 equal intervals.

Similarity
Gestalt principle of organisation referring to the perceptual tendency to group together objects that are similar in texture, size, shape, pitch, loudness, timbre,...

Sine wave
A waveform whose variation over time is the sine function. The most efficient form of oscillating motion.

Spectral analysis
Mathematical analysis of a waveform into sinusoidal components, as by Fourier analysis.

Spectral dominance
Effect by which the pure tone components in the range 200 Hz to 2000 Hz have the greatest influence on the perception of a complex sound. The spectral dominance function (averaged over many subjects) for pure tones has a broad peak around 700 Hz.

Spectrum
A spectrum graph shows the power (or amplitude) in each of the component frequencies.

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Timbre
Relates to the quality of a sound. Timbre depends on the frequency and amplitude of partials, and on their evolution over time.

Tone
A sound wave that evokes a sensation of pitch.

Virtual pitch
The pitch of a complex tone with synthetic (holistic) listening. See residue pitch.

Waveform
Waveform of a tone refers to the graph of sound pressure to time.

Glossary | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

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Please use the Back button of your Browser to go back.

Appendix B8 References on Auditory Perception

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A | K | B | T | W

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Appendix C

World Wide Web links to Auditory Perception site

Appendix C World Wide Web links to Auditory Perception site

Several of these links were known to the author because those placing the links asked for permission. The remainder were found using the search engine AltaVista, with link queries of the form "link:

In all cases below, the quoted URL is the URL of the HTML page containing the link. Other information shows, when available, the name of the organization which placed the link and the path from their Home page to the page actually containing the link.

1. From Psychoacoustic and Musical sites

http://sound.media.mit.edu/~dpwe/AUDITORY/
Home Page of the Auditory List
    Other sites

http://www.th-darmstadt.de/fb/bi· 'agl/welcome.htm
The Darmstadt Auditory Research Group's Home Page
    Auditory Links from DARG

http://www.dur.ac.uk/~des3den/capella/acoustics.html
Douglas Nunn, Durham Music Technology, Concurrent DSP Group, School of Engineering, Durham University.
    the ACOUSTICS page and Music Links Page

http://www.yahoo.com/Science/Acoustics
YAHOO
    Science:Acoustics

http://www.lancs.ac.uk/users/music/research/hotspots.html
CTI Music (Computers in Teaching Initiative, Music area)
    Web Links
        Musical links
            Other Interesting Pages

http://www.neurophys.wisc.edu/www/aud/aud_educ.html
the Auditory Home Page at the Department of Neurophysiology,
University of Wisconsin - Madison
    Auditory Educational Resources

http://www.santafe.edu/~kramer/icad/barrass.html
The International Conference on Auditory Display
Perception Pages - Auditory Demonstrations

http://interact.uoregon.edu/MediaLit/FC/WFAERespsy
World Forum for Acoustic Ecology (WFAE)
Gateway to online information
Research in Ecoacoustics
Psychoacoustics -- Auditory Perception

2. From Psychology sites

http://www.indiana.edu:80/~iuepsyc/PsycJump.html
Psychology Department, Indiana University Behavioral and Social Sciences Division
The Psychology Jumping Stand
Sensation and Perception
Audition

http://psych.hanover.edu/APS/exponnet.html
American Psychological Society
Psychology Experiments on the Net
Sensation and Perception

http://www.bhs.mq.edu.au/aps/resource.html
Australian Psychological Society
Psych Resources on the Net
Perception

http://psych.hanover.edu/Krantz/tutor.html
Psychology Tutorials

3. From Educational sites

http://web.wwnorton.com/norton/struc/chap_05/allres.html
Classroom Assistant
An Internet Ancillary to PSYCHOLOGY, 4th edition by Henry Gleitman
Publisher W. W. Norton
Chapter 5 Sensory Processes
Internet Resources
Auditory Perception

http web wwnorton com norton struc chap 06 allres html
Chapter 5 Sensory Processes
    Perception
"The Music Faculty of McGill University has put together a very fine multimedia presentation of selected topics in Auditory Perception, including auditory demonstrations, discussion and experiments in perception A few of these may require special hardware "

http www grolier.com links scilink.html
Grolier online
    Link madness
        Science

http://scienceweb.dao.nrc.ca/cool/resour.html
Science Web:An index and news service about Canadian science and technology
    Cool and Useful Resources
        and
    What's Cool - Hall of Fame

http://www.radio.cbc.ca/radio/programs/current/quirks/sites.html
CBC: QUIRKS AND QUARKS June 3
    Recommended Science and other sites

http://www.radio.cbc.ca/radio/programs/current/quirks/nov4.95.html
QUIRKS AND QUARKS November 4
    Radio broadcast by Peter Lupinican be heard in Real Audio from this site
    INTERNET: SOUND PERCEPTION

http://artsedge.kennedy-center.org/ir/music.html
The Kennedy Center's ArtsEdge: linking the Arts and Education through Technology
    ArtsEdge Music Resources
    ArtsEdge Music links
        Primary Sources

http://www-sci.lib.uci.edu/SEP/physical.html#8
UCI SEP - Physical Science
    Frank Potter's Science Gems - Physical Science I
        Vibrations and Wave Motion

http://www.bayne.com/ExpressWay/school/edu-sci.html
USA Net
    Education Resources
        SCIENCE- GENERAL

http://web66.coled.umn.edu/new/Oct95.html
Web66 What's New (A K-12 resource)
October 17

4. From medical sites

http://www.umanitoba.ca/Medicine/Pediatrics/ILSA/index.html
International Lung Sounds Association (ILSA)
Reference sources

http://unixg.ubc.ca:880/psychiat/neurosci/ns_home.html
UBC Faculty of Medicine Department of Psychiatry. Division of Neurosciences

http://www.cmhc.com/guide/pro20.htm
Mental Health Net - Sensation and Perception
OTHER RESOURCES
TUTORIALS

5. Sites using Auditory Perception as course material

http://www.vanderbilt.edu/Blair/Courses/MUSC216/syllabus.html
Computer Music (syllabus for MUSC 216, Blair School of Music at Vanderbilt University, Instructor Brian Evans)
Introduction and fundamentals
Physics & psychophysics of sound

http://166.122.32.61/Minasian/sound.html
Leeward Community College:The Commercial Music Department
MUS 140 Sound System Utilization
Related Web Sites

http://spidey.usc.edu/~ee599/Assignments/audio.html
EE599: Digital Media and Multimedia Applications (USC)
Reading
Audio Resources

http://aruba.ccit.arizona.edu/~hedden/
University of Arizona
Music 654 - Psychology of Music (Prof Stephen K. Hedden)
Resource material for The Hearing Pathway and Isolated Parameters of Sound

http www-leland stanford edu class music151
Stanford University Music 151 Psychophysics and Cognitive Psychology for Musicians
Pointers to other useful sites
Auditory Perception at McGill University (has direct pointers into many pages)

http://www utm.edu/~zachry/honpsy html tutorials html
University of Tennessee at Martin
Honors Psychology 110 - H
Online Tutorials and Searches
Tutorial No 6

6. From Home Pages and other

http://www.ahandyguide.com/com/cal.htm
A Handy Guide
Companies Beginning With "AK to AZ"
Auditory Perception

http://www.vuw.ac.nz/~trills/psy_res.htm
Judi's Home Page at Psychology Department, Victoria University, Wellington, New Zealand
Hotlinks
Psychophysics Pointers
Psychophysics

http://maury.ief-paris-sud.fr:8001/~thierry/pointers/pointers.html
la page de garde de Thierry Rochebois
Web Pointers
Knowledge
and Ailleurs & Higher
Pedagogie

http://www.ls.sesp.nwu.edu/Learning_Sciences/students/bsmith/music-ptrs.html
Home Page of Brian K. Smith, PhD student in the Learning Sciences, Northwestern University
Pointers to music related sites

http://www.tp.umu.se/Space/hotlist_andris.html
Andris Vaivads's Bookmarks
Auditory perception

http . bagan srce hr info-znanost aku html
Akustica

http . info lut ac uk departments hu groups speechlab linksaud html
Speech & hearing laboratory, Loughborough University, England
Other Speech and Hearing Sites

http ://www eecs umich edu/~mrozek audio html
Eric Mrozek's Audio/DSP Page
Other Info

http //www teleport com/~arden/arts htm
Department of Fine Arts
COMMERCIAL MUSIC AND ENTERTAINMENT

http://199.190.118.2/science.htm
Science

http.//www.cs.auckland.ac.nz/~slobo/lecture7-18-95.html
S. Lobodzinski, University of Auckland, 07.408 paper
Psychoacoustics - Auditory Perception

http://icogsci1.ucsd.edu/~tdmiller/
Home Page of Tiyen Miller, Cognitive Science, University of Birmingham, England
A small handful of sites: Novel Web Pages

http://www.rain.org/~mkummel/science.html
Treebeards Home Page
Culture Index
Science

http://sound.media.mit.edu/~paris/
Paris Smaragdis' Home Page
(graduate student in Machine Listening Group at MIT)
Auditory Research

http://tk.clarke.sonoma.edu/Perception.HTML
Rohnert Park, California 94928
School of Business and Economics
Consumer Behavior Students
Good Stuff for Studying Consumer Behavior
Perception
Something on sound perception

http www haverford edu psych CogPsy html
Cognitive Psychology Links

http www mes net ~mrutan rutanpgs hearing html
Auditory Perception Extravaganza

Acoustics - Psychoacoustics

http dragon bus camosun bc ca humanity psych psych htm
Psychology

http://www.physics.iastate.edu/numaps/poudel/history.html
history of sound

This anonymous tutorial points at several parts of Auditory Perception

Appendix D

Summary of e-mail received by the author

Appendix D Summary of e-mail received by the author

Date	Congrats	Links	Errors	AudioProb.	Quest.	Sugg.
3 Jun,95	x	x (European mirror site)				
17 Jul,95	x		x			
25 Jul,95	x				x	
6 Aug,95	x			x		
10 Aug,95	x			x		
18 Aug,95			x			
22 Aug,95				x		
23 Aug,95	x					x
24 Aug,95			x			
15 Sep,95			x			
15 Sep,95	x				x	
19 Sep,95	x					
24 Sep,95	x					x
29 Sep,95	x	x				
1 Oct,95					x	
4 Oct,95	x				x	
5 Oct,95*		x		x		
5 Oct,95*		x				
5 Oct,95*		x				
5 Oct,95*		x (teacher - wished more material)				
6 Oct,95	x	x				
7 Oct,95	x	x				x
12 Oct,95	x					
13 Oct,95	x		x			
13 Oct,95	x					x
11 Nov,95					x	

Date	Congrats	Links	Errors	AudioProb.	Quest.	Sugg.
[illegible]	x	x				
[illegible]	x				x	
[illegible]					x	
[illegible]	x	x	Science Web			
[illegible]					x	
[illegible] Dec,[illegible]	x	x	(request to use in Science Museum)			
[illegible] Jan,[illegible]	(invitation to list in Internet YellowPlaces)					
[illegible] Jan,96					x	
10 Jan,96	x					x
12 Jan,96					x	
18 Jan,96	x	x				
24 Jan,96	x	x				
26 Jan,96	x				x	
29 Jan,96	x	x				
29 Jan,96	x	x				
3 Feb,96			x			

*solicited responses when I found out that the materials were being used in a Multimedia course at USC.

Appendix E

Samples of raw data logs

Appendix E1 Section of server statistics

```
lecaine - - [04/Jul/1995:20:50:17 -0400]
"GET /~welch/auditory/graphics/toroid.jpg
HTTP/1.0" 304 0

lecaine - - [04/Jul/1995:20:50:17 -0400]
"GET /~welch/auditory/graphics/penrose.gif
HTTP/1.0" 304 0

lecaine - - [04/Jul/1995:20:50:27 -0400]
"GET /cgi-bin/auditory_bridge?highshepard,.au,
HTTP/1.0" 200 2723

ai.kyushu-id.ac.jp - - [04/Jul/1995:21:29:39 -0400]
"GET /~welch/auditory/Auditory.html
HTTP/1.0" 404 -

gl15.bio.th-darmstadt.de - - [05/Jul/1995:11:20:20 -0400]
"GET /~welch/auditory/SND/munsonS/tone522.au
HTTP/1.0" 200 30898

idefix.physik.uni-konstanz.de - - [05/Jul/1995:11:23:11
-0400]
"GET /~welch/auditory/helpaudio.html
HTTP/1.0" 200 1598

idefix.physik.uni-konstanz.de - - [05/Jul/1995:11:23:15
-0400]
"GET /~welch/auditory/graphics/speakericon.gif
HTTP/1.0" 200 833
```

Appendix E2 Section of the file auditory.log

```
950705 152302 d115.bio.th-darmstadt.de worldmenu .au LOOK
950705 153616 vpt009.vetmed.lsu.edu worldmenu .au LOOK
950705 153623 vpt009.vetmed.lsu.edu pure .au LOOK
950705 153632 vpt009.vetmed.lsu.edu pure .au LOOK
950705 153905 vpt009.vetmed.lsu.edu harmonic .au LOOK
950705 153918 vpt009.vetmed.lsu.edu harmonic .au LOOK
950705 155726 i-21.das.mcgill.ca worldmenu .au LOOK
950705 155737 i-21.das.mcgill.ca residue .au LOOK
950705 155857 i-21.das.mcgill.ca worldmenu .au LOOK
950705 155911 i-21.das.mcgill.ca shepardscale .au LOOK
950705 155934 i-21.das.mcgill.ca highshepard .au LOOK
950705 164723 psychlab1.hanover.edu worldmenu .wav LOOK
950705 164742 psychlab1.hanover.edu harmonic .wav LOOK
```

Appendix F

Sample of reader analysis from two selected days

Appendix F1 Portions of reader analysis on selected days

These automated summaries by session were produced by the program *get_stats.pl*, which analyses by session. A session is considered to be terminated when no activity has occurred for at least one hour.

The column "Min." reports the time difference in minutes between the first and the last recorded activity from a single client.

The "App. HTML hits" reports the actual number of HTML document requests. For each session, the program compiles a list of "real" hits -- that is non-duplicate hits on content pages. The difference between the apparent and real hits varies widely, depending on the reader's use of menus, the back button in the Browser, use of cache and their path through the site. The list of real hits shows what various readers were interested in. The reader's identification is shown, when it is available.

* indicates a *diligent session*, defined as one that lasted longer than 20 minutes or which downloaded 3 or more non-duplicate content pages.

July 15

```
Arrival              Min.  HTML hits  Minutes    Audio
                           Real(App.) in World  Type No.
95:07:15/001833       11   4 (   6)       0          0
corpgate.nt.com
      intro,history,physics,helpaudio
    *
95:07:15/003339        2   3 (   5)       0      aiff  2
eberg.sp.trw.com
      biblio,methods,helpaudio
```

```
95:07:15/011610      0    1 (   2)        0              0
anytuc.stg.trw.com
      physics

95:07:15/014007      0    1 (   2)        0              0
igatel.hac.com
      physics

95:07:15/015953      2    1 (   3)        0              0
ppp057-stdkn2.ulaval.ca
      intro

95:07:15/031816      4    1 (   2)        0              0
slip45.cc.flinders.edu.au
      proposal

95:07:15/045247      1    1 (   3)        0              0
nz13.rz.uni-karlsruhe.de
      physics

95:07:15/060239      1    1 (   3)        0              0
corpgate.nt.com
      intro

95:07:15/063823      0    0 (   1)        0              0
infix.ida.liu.se

95:07:15/071630      1    1 (   2)        0              0
maestro.despres.co.jp
      intro
```

95:07:15/093353 1 0 (2) 0 0
ppp3_099.bekkoame.or.jp

95:07:15/091722 36 4 (10) 5 wav 3
dmsslip.rti.org
intro,physics,pure,helpaudio
* wilson

November 5

Arrival	**Min.**	**HTML hits Real (App.)**	**Minutes in World**	**Audio Type**	**No.**
95:11:05/000838 diala15.magic.mb.ca	7	0 (5)	0		0
95:11:05/004048 tortoise.oise.on.ca	0	0 (2)	0		0
95:11:05/003733 piweba4y.prodigy.com	0	0 (1)	0		0
95:11:05/004927 nickel.laurentian.ca	0	0 (1)	0		0
95:11:05/005514 okc-sip122.ionet.net	0	0 (0)	0		0
95:11:05/011122 remote91.compusmart.ab.ca	10	0 (2)	0		0
95:11:05/012122 anxrm13.mit.csu.edu.au	0	0 (1)	0		0

Appendix F2 Statistics for six months

Output of the program get_stats.pl.

input file: reformatted, output file:report, anycnt:forany

Linecount	68394
Number of Sessions	8835
Number of Visitors	5291
Number of Passers by	3544
Number of HTML hits	27266
Audio downloads	6678

Accesses by HTML page

(* indicates a page within Auditory World)

Total page hits 27266, distributed as follows:

Auditory	9456	the Main entry page
world	3511	entry to the Auditory World
physics	2442	Physics and Psychophysics tutorial
intro	1604	Introduction to the field of Auditory Perception
history	1529	Selected moments from history
pure	1495	*Pitch perception - pure tones
glossary	787	Glossary
harmonic	743	*Pitch perception - harmonic tones
data	648	Site statistics and experiment data
scene	367	*Auditory scene analysis
methods	366	Methods of creating audio, including csound listings
residue	351	*Residue pitch
helpaudio	335	Help for selecting audio format
sequential	327	*Stream analysis - sequential sounds
oct	262	*Octave-related complex tones

worldmethods	245	Programming design details
tritone	244	*Introduction to the tritone
shepardscale	214	*Shepard scale demonstration
scenepicture	190	*Pictorial description of scene analysis problem
mapmiss	173	*Reader clicked incorrectly in a map!
references	167	References
freqresponse	166	Fletcher-Munson graphs
dimensions	165	*The dimensions of pitch - Shepard
biblio	155	Bibliography
readings	146	List of other readings
worldmenu	145	*Main menu within the Auditory World
simultaneous	124	*Streaming of simultaneous sounds
proposal	122	Special project proposal
group	117	Instructions for setting up group experiments
highshepard	106	*Shepard phenomenon at high freq.?
rissetglide	102	*Risset glides
contents	75	List of site contents
pitchtheory	68	*Discussion of pitch perception theories
csound	67	Page pointing to *csound* information
gestalt	59	*Discussion of Gestalt psychologists
experiments	40	How to run group experiments
auditory	31	A former site address
octexpl	29	*Discussion of OCT experiment, what you heard?
AuditoryWall	25	Access to Discussion Corner
detail	22	A look at some site usage statsitics
percent	17	
serious	13	A look at site statistics
Others	16	Typing errors and obsolete pages

Audio file downloads by type

aiff	1120
au	3170
wav	2384

Month	Visitors		Passersby		Total		Percent
	No.	#HTML	No.	#HTML	No.	#HTML	Visitors
07	694	3156	367	434	1061	3590	65
08	796	3536	481	559	1277	4095	62
09	1022	4815	608	697	1630	5512	63
10	1030	4200	784	895	1814	5095	57
11	1066	4618	815	1128	1881	5746	57
12	683	2672	489	554	1172	3226	58
all	5291	22997	3544	4267	8835	27264	60

Diligent sessions (20 minutes and/or 3 hits)

Month	Number diligent
07	330
08	399
09	518
10	466
11	547
12	290
all	2550

Machines visiting more than 5 times

129.115.45.10	6
157.142.16.120	7
165.213.131.21	11
198.179.232.101	7
202.20.188.135	6
204.62.245.32	8
acer8.iie.edu.uy	6
ai2.bpa.arizona.edu	19
ai4.bpa.arizona.edu	7
allserv.kiho.be	6
axius.usc.edu	6
ball.uunet.ca	8
chaos.kulnet.kuleuve	6
crimpshrine.atext.co	37
erigate.ericsson.se	8
extra.ucc.su.oz.au	6
foley.ripco.com	6
lycos-tmp1.psc.edu	17
macbrunon.univ.tries	10
mc006.lib.uci.edu	6
net.auckland.ac.nz	19
palona1.cns.hp.com	6
piweba1y.prodigy.com	6
piweba4y.prodigy.com	8
poppy.hensa.ac.uk	8
ppp16.francenet.fr	6
proxy.kodak.com	7
proxy0.research.att.	9
psychlab1.hanover.ed	16
query1.lycos.cs.cmu.	8
query2.lycos.cs.cmu.	9
s_mac-snv-3859.psych	9
sapega.mac.trincoll.	7
scooter.pa-x.dec.com	42
sgigate.sgi.com	8
swav-pc.cs.auckland.	6
webgate1.mot.com	15
www-a1.proxy.aol.com	6
www-c1.proxy.aol.com	7
www-c3.proxy.aol.com	6
www-d4.proxy.aol.com	6
www01.btx.dtag.de	7

Summary of revisits

One	3611
2-3	457
4-5	59
more	42

Appendix G

Sample Experimental data - the Trill phenomenon

Appendix G Sample Experimental data - the Trill phenomenon

In the data below, the numbers 4, 8, 12, 16, 24 refer to the percentage frequency separation of the two tones. The associated "split" or "unified" is the response.

```
950705 181446 psychlab1.hanover.edu .wav
TRILL 12 split, 16 split, 20 split, 24 split, 4 split,
8 unified,krantzj@hanover.edu

950709 234156 netcom18.netcom.com .wav
TRILL 12 split, 16 split, 20 split, 24 split, 4 unified,
8 split,solomani@netcom.com

950912 134532 pstwoe.gis.saic.com .aiff
TRILL 12 split, 24 split, 4 unified, bloritsc@gis.saic.com

950917 022454 cust36.max1.atlanta.ga.ms.uu.net .wav
TRILL 12 split, 16 split, 20 split, 24 split, 4 split,
8 split, vaylor@msn.com

950918 010520 mikasa.iol.it .au
TRILL 12 split, 16 split, 20 unified, 24 unified, 4 split,
8 unified,quadrant@iol.it

950919 065540 jericho2.microsoft.com .wav
TRILL 12 split, 16 split, 20 split, 24 split, 4 unified,
8 split,nickb@microsoft.com

950921 230713 lvl-mac031.usc.edu .au
TRILL 12 split, 16 split, 20 split, 24 unified, 4 split,
8 split, .ID

950922 073957 comserv-d-13.usc.edu .wav TRILL 12 split,
16 split, 20 split, 24 split, 4 split, 8 split,
jyi@scf.usc.edu

950924 010819 swbi_a02.spectraweb.ch .wav
TRILL 12 split, 24 split, 4 split, HPF@spectraweb.ch

950927 122652 client-71-239.online.apple.com .aiff
TRILL 12 split, 16 split, 20 split, 24 split,waian@cerf.net
```

950930 212737 lvl-sun701.usc.edu .au
TRILL 12 split, 16 split, 20 split, 24 split, 4 unified,
8 unified,adelacru@scf.usc.edu

951009 151138 espresso.gsfc.nasa.gov .wav
TRILL 12 split, 16 split, 20 split, 24 split, 4 split,
8 split,lynch@gsti.com

951010 142312 psy-jflowers3.unl.edu .wav
TRILL 12 split, 16 split, 20 split, 24 split, 4 unified,
8 unified,jflowers@unl.edu

951017 122918 130.225.147.124 .wav TRILL 12 split, 16 split,
20 split, 24 split, 4 unified, 8 split, jcd@dou.dk

951026 001348 loisterml.mwsu.edu .au
TRILL 12 unified, 16 unified, 20 unified, 24 unified,
4 unified, 8 unified, FAKE - did not download any audio

951027 062631 music.md.huji.ac.il .aiff
TRILL 12 unified, 16 unified, 20 split, 24 split, 4 unified,
8 unified,israel@music.md.huji.ac.il

951027 162830 mac276.bt-sys.bt.co.uk .aiff
TRILL 12 unified, 16 split, 20 split, 24 split, 4 unified,
8 unified,simon.broom@bt-sys.bt.co.uk

951114 212557 198.105.194.169 .wav
TRILL 12 split, 16 split, 20 split, 24 split, 4 split,
8 split,

951117 061325 ip243.phx.primenet.com .wav
TRILL 12 split, 16 split, 20 split, 24 split, 4 split,
8 split, mikeyj

951208 052126 tiffany.cs.mcgill.ca .au
TRILL 12 split, 16 split, 20 split, 24 split, 4 split,
8 split,jonathan@cs.mcgill.ca

951213 001152 imschris2.usc.edu .wav
TRILL 12 split, 16 split, 20 split, 24 split, 4 unified,
8 unified,ckyriak@mizar.usc.edu

Appendix H

Generation of audio files

Appendix H1 OCT experiment: Orchestra file

```
sr = 22050     ;sampling rate
kr = 441       ;control rate
ksmps = 50     ;because csound does not know how to divide
nchnls = 1     ;mono

instr 1     ;comparison sine tone
  idur = p3
  iamp = ampdb(p4)
  inote = p5
  k1 linen iamp, .1*idur, idur, .1*idur  ;amplitude envelope
  a1 oscil k1, inote, 1             ;function 1 (sine tone)
     out a1
endin

instr 2     ;octave complex tone
  idur = p3
  iamp = ampdb(p4)
  inote = p5                            ;frequency in Hertz
  k1 linen iamp, .1*idur, idur, .2*idur ;amplitude envelope
  aout oscil k1, inote, 2        ;use complex gen function 2
     out aout
endin

instr 3    ;OCT used for "fundamental" above 900
           ;only three components to avoid aliasing
  idur = p3
  iamp = ampdb(p4)
  inote = p5                            ;frequency in Hertz
  k1 linen iamp, .1*idur, idur, .2*idur ;amplitude envelope
  aout oscil k1, inote, 3        ;use complex gen function 3
     out aout
endin
```

Appendix H2 OCT Experiment: Perl script to generate Score file

```
#  oct.gen
#Perl script to generate octave complex tone at several
fundamentals
# and several test tones
#Type perl oct.gen to run the script

###############################################
#<b>Part 1 - generate score files octX.sco</B>
#  where X is the example number
################################################
#
#generate the OCTs
@fundlist = (400, 1800, 100, 900, 3600, 200, 50);
#Example no.  1     2    3    4     5    6    7

$i = 0;

foreach $fund (@fundlist) {
  if ($fund >= 900) {$genfn = 3;} else {$genfn = 2;}
  $i++;
  $file = "oct$i";                #eg oct1 for example 1
  push (@files, $file);
  $scorefile = $file . ".sco";    #eg. oct1.sco
  print "scorefile $scorefile\n";
  open (SCOREOUT, ">$scorefile");

    #print header and first two score lines
  print SCOREOUT <<EOFILE;

;Score for OCT example no 1
f1 0  4096 10  1                                ;sine tone
;GEN09 pna stra phsa - use partial nos 1, 2, 4, 8, 16
     ;for low OCTs
f2 0  4096 09  1 1 0   2 1 0   4 1 0   8 1 0   16 1 0
     ;for "high" OCTs
f3 0  4096 09  1 1 0   2 1 0   4 1 0

;instr  start  duration     amplitude  fundamental(cps)
    i$genfn  0       1.5              70         $fund
 ;octave complex tone
e
EOFILE

  close SCOREOUT;}     #end of do over all fundamentals
```

```
#Now generate comparison tones
@sinelist =
(50,80,100,200,300,400,450,600,900,1200,1800,3600);
# 1  2   3    4    5    6    7    8    9   10    11    12

$i=0;

foreach $sine (@sinelist) {
  $i++;
  $file = "sine$i";                    #eg. sine2
  if ($sine < 100) {$db = 80;}         #make low tones louder
  elsif ($sine == 100) {$db = 79;}
  else {$db = 77;}
  push (@files, $file);
  $scorefile = $file . ".sco";         #eg. sine2.sco
  print "scorefile $scorefile\n";
  open (SCOREOUT, ">$scorefile");

    #print header and first two score lines
  print SCOREOUT <<EOFILE;

;<PRE>
;Score for comparison sine tone
f1 0  4096 10  1                              ;sine tone

;instr  start   duration   amplitude(dB)  pitch(cps)
   i1   0       1          $db            $sine    ;sine tone
e
EOFILE
}      #end of do over all frequencies in @sinelist


###########################################################
#<B>Part 2 - write a shell script to create the audio
files</B>
#
#  1.run each generated Csound file,
#  2.play the .aiff for audition,
###########################################################
open (SHELLOUT, ">make_files");
foreach $file (@files) {
  print SHELLOUT <<EOSHELL;
  csound oct.orc $file.sco -A -g -o ../../SND/$file.aiff
  sfplay ../../SND/$file.aiff
EOSHELL
}
print SHELLOUT
"  cp oct2.sco model_score
```

```
  rm *.sco
  rm score.srt\n";
close ('make_files');
system "chmod +x make_files";  #make the script executable

############################################################
#<B>Part 3 - write a shell script to convert and copy to
/mlf
#  1.move each sounds to required location on /mlf
#  2.convert it in ../SND (make .WAVE and .AU files)
############################################################
open (SHELLCONVERT, ">convert_and_copy");
print SHELLCONVERT <<EOF;
  mkdir /mlf/Home_Page/auditory/SND/octS
  rm /mlf/Home_Page/auditory/SND/octS/*.*
EOF

foreach $file (@files) {
print SHELLCONVERT <<EOF2;
  cp
/Net/sound/Users/welch/public_html/auditory/SND/$file.aiff
        /mlf/Home_Page/auditory/SND/octS
  sfconvert /mlf/Home_Page/auditory/SND/octS/$file.aiff
        /mlf/Home_Page/auditory/SND/octS/$file.wav
        channels 1 format wave rate 22050
  sfconvert /mlf/Home_Page/auditory/SND/octS/$file.aiff
        /mlf/Home_Page/auditory/SND/octS/$file.au
        channels 1 format next rate 22050
EOF2
}
print convert_and_copy "Now type make_files\n";
close ('convert_and_copy');
system "chmod +x convert_and_copy"; #make the script execble

print "\nType make_files\n";
print "\nWhile logged on as HTTP, type convert_and_copy\n";
```

Appendix H3 OCT experiment: Sample orchestra file

```
;Score for OCT example no 1
f1 0  4096 10  1                        ;sine tone
;GEN09 pna stra phsa - use partial nos 1, 2, 4, 8, 16
f2 0 4096 09 1 1 0  2 1 0  4 1 0  8 1 0 16 1 0 ;for low OCTs
f3 0  4096 09  1 1 0   2 1 0   4 1 0  ;for "high" OCTs

;instr  start   duration     amplitude  fundamental(cps)
    i3  0       1.5              70        1800
;octave complex tone
e
```

Appendix I

Programs controlling the site and gathering data

Appendix I1 Auditory World Gateway - HTML coding

Part of the source HTML to display the entry form, from world.html

```
<TITLE>Auditory World</Title>

<H2>Auditory World
<IMG ALIGN=TOP SRC="http://lecaine.music.mcgill.ca/auditory
                          /graphics/ear2brain.gif">
</H2>
 <FORM METHOD="POST"
ACTION="http://lecaine.music.mcgill.ca/cgi-bin/cgi_bridge"
 <INPUT TYPE="hidden" NAME="came_from"
VALUE="auditory/world.html">
 <INPUT TYPE="hidden" NAME="goto_module"
     VALUE="welch/public_html/auditory/perlcode/register">

Welcome.
<P>
To enter the world of auditory demonstrations, please select
your preferred
audio file format
 <SELECT NAME="audio" SIZE=1>
  <OPTION SELECTED> .au
  <OPTION> .wav
  <OPTION> .aiff
 </SELECT>
<P>
```

Appendix I2 Processing the form data - the register function

```
##################
### register  ####
##################

### Perl subroutine that responds to the "submit" button
###   from the gateway to the Auditory World

### This function is included and executed from the
###  script cgi_bridge (resident in the cgi-bin)

### Values from the form filled in by the reader are
###   available form the associative array called %assoc

sub register {

### Debugging of arguments received
  print "register\n<BR>" if $DEBUG;  #desperate debugging
  foreach $key (sort keys (%assoc)) {
    print "key $key,  value $assoc{$key}\n<br>" if $DEBUG;}

### Extraction of expected arguments
  $audio = $assoc {'audio'};
  $identifier = 'None';
  $identifier = $assoc{'identifier'};
  print "$audio,$identifier<BR>\n" if $DEBUG;

### Prepare the world menu from worldmenu.html
### This code is the same as that in auditory_bridge
#REPLACE .au and .ID in
welch/public_html/auditory/worldmenu.html
  $basetext =
'/Net/NeXT/Users/welch/public_html/auditory/worldmenu.html';
  print "reading file $basetext<P>\n" if $DEBUG;
  open (INPUT, $basetext)  || print "Missing file
$basetext<BR>\n";
  @input = <INPUT>;
  print "<H2>Last $nolog lines of file auditory.log</H2>";
#use the tail command to output to a temp file
  system "tail -$nolog auditory.log > $outputfile";
#dump the file to stdout
  open (INPUT,  $outputfile);
  @input = <INPUT>;
  $output = join ('<BR>', @input);
  print "$output <P>";
  system "rm $outputfile";}   #remove temp file
```

Appendix J

References

Appendix J References

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Welch, Norma and John Krantz. *The World-Wide Web as a medium for psychoacoustical demonstrations and experiments: Experience and results*. Behaviour Research Methods, Instruments, & Computers. Psychonomic Society, In.c. In publication 1996.

World Wide Web addresses

McGill site - Auditory Perception;Demonstrations and Experiments
http //Web.music.mcgill.ca/auditory/Auditory.html

Mirror site at Darmstadt, Germany
http://gl15.bioth-darmstadt.de/biologie/auditory/Auditory.html

Experiments in visual perception at Hanover College
http://psych.hanover.edu/deptres.html

Music cognition experiements at University of Colorado
http://www/cs.colorado.edu/~andreas/Teaching/Music/Experiments.html