Spring 5-2007

Efficiency of Wireless Transmissions Through Various Mediums

William Matthew Fortunato
University of Tennessee - Knoxville

Christopher Ray Walker
University of Tennessee- Knoxville

Efficiency of Wireless Transmissions Through Various Mediums

William Fortunato, Brice Leffel, *Member, IEEE,* Christopher Walker, *Member, IEEE*

Abstract— **As the IEEE 802.11, "Wi-Fi," family of standards has become an inexpensive, reliable, and widespread means of wireless communication between computers, new applications of the technology have been envisioned. One such application is the use of an IEEE 802.11 system as a platform for the transmission of wireless streaming video in security systems. Our line of research attempts to determine how well such a system can transmit data for live viewing, and later processing, in real-world conditions. In the experimental process, we used off-the-shelf components, and subjected them to microwave interference while broadcasting streaming video through various distances and materials. Our investigation into the robustness of Wi-Fi video transmission has shown that the standard, while fine for ordinary use, needs to be made more robust for streaming live data. Based on our studies, it is our recommendation that future researchers should find a method to circumvent the channel sharing features inherent to IEEE 802.11, which may require obtaining FCC approval. Wi-Fi is a capable, inexpensive and widely available platform, but researchers should look into modifying the IEEE 802.11 Wi-Fi standards to better suit their needs for wireless video streaming.**

Index Terms— **Digital Signal Coherence, Streaming Video, Wireless Communication**

I. Introduction

WIRELESS computer communications give users unprecedented mobility and flexibility, but are vulnerable to interference and environmental effects. As such, any system that uses a wireless means of communication needs to be able to anticipate and correct these effects. Of particular note are systems that send streaming video, as they cannot use several standard error resiliency schemes. Mobile video streaming systems are of special interest for Military, Police, Industrial and Consumer applications, as they can be used in mobile security checkpoints, hazardous environment robots and Wireless Personal Area Networks (WPAN).

This report covers the design, and execution, of experiments to determine the performance limitations of streaming videos over an IEEE 802.11 network. These experiments were designed to research the effectiveness of adapting the inexpensive, popular, and commonly available, IEEE 802.11, "Wi-Fi," standard for transmitting streaming video data through a variety of environments and interference conditions.

II. Background Information

In the modern world, wireless communication means are growing in popularity and importance. Wireless communication allows for mobile devices and stationary devices, both those that have been hardwired to other networks, and those that have not, to connect to other devices, and even the Internet. Wireless transmissions between computers often use Wi-Fi standards. Wi-Fi is a brand name for the communication standards governed by the IEEE 802.11 protocol and its amendments. Several varieties of IEEE 802.11 exist, the most common currently being used for inter-computer wireless communication are 802.11a, 802.11b and 802.11g[1]. The 11g amendment to IEEE 802.11 is an evolution from the 11b amendment and the operating characteristics for the two standards are very similar, in fact, several wireless cards incorporate both communications standards so that users may switch back and forth between standards as the situation requires. [6,7,8]

The experimental process involves communication with IEEE 802.11 because of both its widespread use, and its vulnerability to interference from common sources. IEEE 802.11b and 11g both operate at 2.4 GHz[2] with an approximate range of 10m –30 m.[3] IEEE 802.11 uses a Carrier Sense Multiple Access with Collision Avoidance system (CSMA/CA) to ensure that users do not attempt to communicate on the same frequency at the same time[5]. The

W. Fortunato is an Electrical Engineering student at the University of Tennessee. He graduates May 2007 with a Bachelor of Science degree. (e-mail: wfortuna@utk.edu).

B. Leffel is an Electrical Engineering student at the University of Tennessee. He graduates May 2007 with a Bachelor of Science degree. (e-mail: bleffel@utk.edu).

C. Walker is an Electrical Engineering student at the University of Tennessee. He graduates May 2007 with a Bachelor of Science degree. (e-mail: cwalker8@utk.edu).

[1] When referring to the IEEE 802.11 standard, except where otherwise noted by the inclusion of the amendment's specific identifying letter, this report will use the term IEEE 802.11 to refer to the common aspects of the 802.11b and 802.11g standards or the standard as a whole. Since IEEE 802.11a operates at a different frequency band than either 802.11b or 802.11g it was not used in this experimental process and will not be mentioned again.

[2] IEEE 802.11 occupies frequencies ranging from 2.4 GHz to 2.5GHz. This spectrum is divided into several smaller channels each with a central carrier frequency 1 MHz apart [5].

[3] As with any radio signal, the transmission distance is affected by the antenna design, broadcast power and conditions in the medium of transmission [2, p106]. The IEEE 802.11 standard sets neither distance requirements nor limitations for broadcast/reception [5]. The numbers 10m – 30m is based off of procedural evidence gathered in the lab where the main experiment dealt with in this paper took place.

system, if it detects sufficient power on its channel, will simply wait until the channel is clear to broadcast its information. To operate an IEEE 802.11 network in the United States, users must follow certain broadcast power restrictions imposed by the FCC.[4] These power restrictions, and the crowded frequency range that IEEE 802.11 operates in, leaves it vulnerable to interference from Bluetooth devices, cordless phones, and microwave equipment, including microwave ovens. The variable distances and mediums through which the signal must propagate also make it vulnerable to multipath interference.[5] As a digital communications standard, IEEE 802.11 addresses these interference sources in a variety of manners.

As a digital signal, IEEE 802.11 is affected by, and can attempt to address, interference differently than an analog signal would. Analog signals that have been corrupted by noise undergo a steady degradation in quality as the amount of interference increases. Digital signals can maintain a near perfect signal in light interference conditions, but the signal will rapidly become unintelligible in heavier interference conditions [2]. Methods to combat signal interference include Frequency Hopping (FH) and Direct Sequence Spread Spectrum (DSSS) techniques. Frequency Hopping moves the carrier frequency periodically, allowing the signal to avoid localized interference. Frequency Hopping can be used by both analog and digital systems, but whereas the original IEEE standard allows for the use of FH, neither the b nor the g amendments use such methods [2,5,6,8]. A DSSS system operates by multiplexing the message data at the Transmitter with a string of Pseudo-random Numbers (PN)[6], thus spreading the signal over a wider bandwidth, but maintaining the same overall power. At the Receiver, another multiplexing takes place, with the same PN string, which reverses the spreading of the original message. The benefit to this complex process is that during the reversal, any signal that was not originally spread by the Transmitter (e.g. an interfering signal) will be spread out, and therefore, be easier to filter from the desired signal [2, pp672-695]. Both IEEE 802.11b, and IEEE 802.11g, incorporate a DSSS solution [5,8].

Digital signals are unique in that they can maintain a near perfect transmission of data through error correction methods. Since digital signals are comprised of a series of 1's and 0's the Receiver is only looking for two values, and if a value is in doubt, the Receiver can make an estimate as to what the correct value is. Additional information is added to each signal to use for the detection and correction of errors in the signal. The detection of errors takes less additional information than the correction of errors. If an error has been detected, the Receiver can request a re-transmission of the data, which is known as Automatic Repeat Requesting (ARQ). This system, while efficient in low interference conditions, and simple to implement, is not as robust in higher interference conditions as a Forward Error Correction (FEC) system that can detect, and change, the binary values of incorrect message bits. IEEE 802.11 uses an ARQ system to ensure that the received data is correct; it also uses a collision detection system to avoid transmitting in a currently occupied bandwidth (whether the bandwidth be occupied by legitimate signals or noise). The data being transmitted by an IEEE 802.11 system may have its own system in place for correcting bit errors, but due to the wide array of data that can be transmitted it is impractical for IEEE 802.11 to devote a large amount of its message length to correction bits, especially when its data may hold the necessary correction bits. Data that seems to be in error will elicit retransmit responses from the Receiver until the data is deemed correct; or it will be dropped from the stream of data. [2, pp546-610]

The data being transmitted over an IEEE 802.11 network will most likely have some sort of FEC system in place for dealing with its errors. In the case of this experiment, the data is streamed video compressed by the MPEG-1 and MPEG-2 standards[7]. These standards allow for the data to use less space, both in terms of bandwidth, and storage space on a computer. It also makes proper error coding critical, as there is less redundant data in a compressed file. The end result in compression is a loss of data; typically most of this data is redundant and discarding it has no noticeable adverse effect on the video. MPEG compression operates by using three different types of video frames with varying degrees of compression. The frames can make reference to no frames, the previous frame, or previous *and* following frames. As a very simplified explanation, it can be taken that MPEGs compress video not by storing every video frame, but by storing only some video frames, and the data needed to change from one frame to the next. While this may sound like a convoluted approach, it is very effective at compressing data, and in fact, this format is used extensively in DVDs and in High Definition Television today. The popularity, ease of use, and high fidelity of MPEG compressed video makes it a natural choice for experimentation. [3]

Video streaming, which is at the heart of the experimentation process, poses special challenges in its implementation. When video is streamed over a network, it acts much like a television signal, in that the data is viewed, but not necessarily saved, by the Receiver. Data will be received, and used, by the Receiver so long as data is being sent from the Transmitter. A protective buffer, or cache, can also be built up by the Receiver to be used in the event of a temporary loss of good data, so that any observer will not notice a drop in performance.

[4] Part 15 of the FCC Rules and Regulations puts a cap on broadcast power of IEEE 802.11b/g at 2500 mV/m [1, 15.245]. Licensed Amateur Radio Operators may broadcast at higher powers. As part of the FCC rules unlicensed operators of IEEE 802.11 must also accept any interference from these licensed users.

[5] Multipathing is a phenomena that occurs in data transmission where the data reaches the Receiver with two or more paths from the sender. This leads to varying amounts of destructive and constructive interference in an individual signal and can pose an obstacle for determining the correct sequence of data reception.

[6] The numbers themselves are either 1 or –1, which makes the reversible multiplexing possible. The sequence of these numbers is what is actually pseudo-random [2, pp672-695].

[7] The program used to broadcast the saved MPEG files re-encapsulated the data in the MPEG-2 Transport Stream format. TS uses packet lengths of 204 bits with 16 error correction bits using a Reed-Solomon error correcting code [3, FAQ]. More information on the MPEG formats can be found in the Technical Approach section of this report.

The inclusion of a cache can add significantly to the robustness of a streaming system, as the protocols used in streaming the video will account for its presence by broadcasting for a longer period of time, and allow the stream to weather a period of poor signal quality. Streaming protocols include the User Datagram Protocol (UDP) and the Real-time Transport Protocol (RTP) varieties. UDP is one of the simplest digital streaming protocols. It operates by sending data in short, discrete packets, with minimal overhead. The small overhead, and short overall length of UDP packets, allow UDP to be very efficient in data streaming, and keep the probability of error in the message low, but leads to problems in data ordering and reliability. Packets are often lost, or received out of order, with UDP streaming. RTP, which is frequently used for streaming video, builds on UDP by adding Delivery Monitoring, Time Stamping, Payload Tags and Sequencing. While these features make the data rate of RTP less efficient, it makes the system much more reliable and measurable in its performance. RTP suffers less from lost packets or misordered packets than a similar UDP system does, but is more vulnerable to delays in the data stream. RTP was specifically designed to transport audio and video information over the Internet and is used in Voice Over IP (VoIP) phone services as well as teleconferencing. [9,10]

III. Technical Approach

Prior to streaming video across a wireless network much research needed to be conducted. This research included gaining an understanding of how video streaming operates and what options were available for use in the project. Additionally, a method was needed to be able to measure the quality of transmissions, in order to present an analysis of the methods and approach used in the project. Accomplishing these two goals led to setting up a variety of conditions for the streaming; each of these brought unique challenges that needed to be addressed.

Video streaming works in a host of different ways; a combination of these options, with emphasis on analysis, required exploration. The obvious tool to measure quality would be an objective bit-by-bit deconstruction of the video steams. However, this approach would require either the purchase, or development, of specialized software, and the goals of setting up the transmission system required priority. Once these setup goals were achieved, a method for generating interference, such that it approximated common work-place environments, would next be devised. Analysis, though important, necessitated all other aspects of the project be in place before studies could begin to judge the transmission quality.

Before video streaming between the two computers could begin, a closed connection between the machines needed to be established. This is commonly known as an ad-hoc network, or a peer-to-peer network, which is easily implemented in Windows XP SP2 edition. Once the peer-to-peer network was set up, files were sent from one computer to the other using standard Windows copy-and-paste methods. This method did not stream the files; rather it copied all the data from the original file to a duplicate on the other computer. The computer continues to send the data until all of the information has been properly received. Whereas this did not simulate the later goal of streaming, it ensured that a stable connection had been established. Another approach used to ensure the stability of the connection involves a network command known as pinging. Pinging works by sending packets of random data from a host computer to a client computer, then back to the Host where analysis is done on the time required to send the packet and on the quality of the data received. With the first goal met, research proceeded to delve into the possibilities, and limitations, of video streaming.

Video streaming appears neat and simple from the perspective of the end user, all that is needed to view streaming media is a compatible media player, and an Internet connection. For the purposes of this project, control over all aspects of the streaming process was needed so as to measure the quality of the signal itself. Traditional video streaming that one finds on popular websites such as Youtube, Google Video, Apple, or other websites involve a special media server designed to handle the specific requirements of multimedia streaming. Some of these requirements include on-demand access to the stream, the ability to pause, restart, fast-forward, and to choose different sizes of media. Such servers can be run on desktops, though specialized software is required to emulate a dedicated server on a desktop. Servers pose another issue in that they use caching, or the storing up of stream data during an initial delay to compensate for interference or interruptions. Though this increases the output quality of the stream for the end user, the project makes use of real-time streaming; the video is being viewed as it is recorded, which cannot use caching. While a dedicated media server exceeded the scope and focus of this project, a few alternatives existed; HyperText Transfer Protocol (HTTP) web streaming, or a hybrid simulated media server based on a desktop machine. [11, Streaming Servers]

HTTP Streaming involves using the existing infrastructure developed for transmitting, and loading, web pages to view videos hosted on the web. HTTP streaming, however, poses a problem for the project definition; it requires the video to be hosted on a web server, instead of on a singular computer such as the project outlines. A method exists where the video can be streamed through HTTP using a specific port to access the video directly, without having to load it off a webpage; however, the HTTP protocol does not support the robust error correction methods needed to ensure quality video streaming. Disregarding HTTP streaming, research began into a hybrid simulated server that could make use of protocol specifically designed to support streaming video. [11, HTTP Streaming]

Two programs were found, that while able to simulate a local media server, also had the added benefit of being free: Windows Media Encoder, and VLC Media Player[8]. Windows Media Encoder required the use of proprietary Windows

[8] Helix Universal Server, from RealNetworks, was another possibility though this server did not meet the needs of this project. Helix utilizes proprietary Real Media to broadcast streaming media, a difficult format to customize, save, and analyze.

streaming formats to stream. The Windows encoder converts whatever file it streams into the Windows Advanced Systems Format (.asf), a media format which, though designed for streaming, does not work well across different operating systems (OS), and can be difficult to encode and post process. VLC Media Player, an OS independent media player, and server, is capable of streaming many different types of files across different protocols, and met the needs of the project; including the need to be free. VLC additionally can support both ends of the streaming process, acting both as a host and a client server. Critical to the project, the VLC Media Player can output the contents of a received stream directly into a file for later review and analysis. Before any of these features could be utilized, the matter of the file format needed to be addressed; different formats yield different benefits and detriments.

Although the Windows Media Encoder failed to meet the needs of the project, the Windows Media format still needed to be tested for its application; directly opposed to it, however, was the cross-platform Motion Picture Experts Group format (MPEG). Windows offered the benefits of being native to the Windows OS currently being used, and supporting a wide range of encoding qualities, including a specialized streaming format. MPEG offered cross-platform support, included well-known, and established, format standards such as Video CD (VCD) and Digital Video Disc (DVD), worked well with the VLC Media Player, and included specific support under VLC by one of the chosen transmission protocols. After testing both methods, MPEG became the format of choice, mainly because of its cross platform support, and its accepted use in commercial products such as DVDs[9]. Two types of MPEG communication formats are available, MPEG-PS, known as Program Stream, supports use of MPEG accessed from a hard disk, or removable media, and is experienced every time a DVD is played. The other format, MPEG-TS, known as Transport Stream, supports error correction, and exhibits other qualities designed for transmission as a streaming media. Finally, VLC Media Player's implementation of the Real-time Transport Protocol (RTP) transmission protocol, a transmission protocol considered for this project, utilizes MPEG-TS, making MPEG an easy choice. [3, Technologies]

Several transmission protocols could have been used in this project, the most popular being HTTP, User Datagram Protocol (UDP), and Real-time Transport Protocol (RTP). A discussion of HTTP has already been made, but to expand slightly: HTTP supports a wide variety of formats, including Windows Media and MPEG, though it was designed primarily for static images and text common on web pages. New approaches have made multimedia easier using HTTP, but at the same time, protocols have been developed particularly for streaming media, such as UDP and RTP.

UDP details a transmission protocol that does not check whether every packet actually arrived, enabling UDP to be faster and more efficient for many lightweight, or time-sensitive purposes. UDP finds implementation in streaming media applications such as Internet Protocol Television (IPTV), Voice over IP (VoIP), Trivial File Transfer Protocol (TFTP), and online games. In each of these cases, the data being sent is small enough that a momentary interruption doesn't affect the output, for example, online gaming is notorious for lagging, but as it isn't a critical application, this is accepted. This hinders UDP's use as a streaming media protocol, particularly where real-time transmission is envisioned that can be used in security purposes; even a momentary loss of data can be detrimental. [9, p3]

RTP defines a standardized packet format for delivering audio and video over the Internet. Compared to UDP, it utilizes a system for ensuring packet reception, enabling the protocol to reconstruct data even if it has arrived out of order from how the Host intended it to be sent. RTP became the protocol of choice for this project mainly because of its design intention for video and audio. [10, Overview]

Having all components of the transmission technology decided upon, VLC Media Player, MPEG, and RTP; it remained to determine how to analyze streaming quality. The first avenue explored involves a process known as packet sniffing, or the capture of data packets as they are being sent between one computer and another, such that it can be analyzed. Because packet transport is a well ordered process, packet sniffing can detect irregularities in packet transmission, such as packet lagging, where packets are delayed in transit by either interference, or multiple relays; or packet drop, where packets are lost entirely because of interference, or errors, in data transmission.

The first program explored to address this approach was Wireshark, a free packet sniffing project that displays the contents of the packet, the transmission time, and source and destination information. However, Wireshark is a work in progress, and as yet, does not fully support the RTP protocol, especially as it relates to video streaming, nor does it record bad, or lost, packets over RTP; this invalidated its use in our project.

Another program, PingPlotter, works by flooding a particular address, or network, with packets full of random data, and analyzes the packets after they have returned to measure transmission time, and quality of the packets received. However, the information provided by PingPlotter is a poor representation of video streaming performance as the program waits for each packet to return up to a certain time limit before the packet is declared lost; video streaming cannot allow this delay, which would manifest itself in lagging or skipping in the video output.

A final attempt at garnering analytical results out of a third-party program involved using statistics that the VLC Media Player itself maintains as it transmits or plays a video file. These include statistics for the decoded audio, and video, blocks compared against the actual number of blocks to determine how many were actually displayed, and how many were dropped, or lost. One issue with VLC Media Player though, is that it doesn't stop counting received packets when the video stream ends; it appears to be receiving packets when in fact, the packets do not contain any audio or video data.

[9] Two quality based format standards were used in the project, MPEG-1, an earlier format used in VCD standards, was used in the low quality videos and MPEG-2, the format currently used in DVD technology, was used in the high quality videos. MPEG also lends well to future work by easily converting to MPEG-4, which is used for High Definition (HD) support.

These attempts, and challenges, combined to make quantitative analysis an untenable goal for this project.

Several interference sources were explored during the research phase of the project, including adding distance between the transmitters, a home-made Faraday cage, a common household microwave oven, cellular phones, and/or Bluetooth devices. Creating space, or adding distance between the transmitters, stresses the system by requiring more power to be applied to the signal, and increases the possibility of error, by increasing the inference potential. In a building there are any number of interference sources, such as: competing IEEE 802.11 networks, cellular phones, microwave ovens, cordless phones, power lines, walls, and other interfering signals in the unregulated band. Walls and doors pose other problems due to their varied structures. These structures can add to multipath effects and Gaussian surface effects. [2]

A Faraday cage is an enclosure formed by conducting material, or by a mesh of such material that forms a Gaussian surface. Such an enclosure blocks out external electrical fields by neutralizing them on its surface. The purpose of the Faraday cage in this project would be to cancel out the transmissions of the wireless antennas, thereby providing another interference source as some structures, such as elevators, act as natural Faraday cages. The Faraday cage consisted of two aluminum soft drink cans covered in aluminum foil that were placed over the receiving antenna in an attempt to block the signals on the outer surface of the cage and prevent transmission. This attempt proved fruitless and the "cage" had no discernable impact upon the quality of the video transmission. Faraday cages rely on the encasing material to be appropriate for the signal that it attempts to block. The aluminum foil proved insufficient to block the transmissions.

The microwave oven proved the best source of interference available. Microwave ovens operate at the same frequency as cell phones and IEEE 802.11; assuming the microwaves are not fully contained within the oven, transmission can be disrupted. The cooking enclosures in microwave ovens are designed to be Faraday cages during operation, such that all radiation is trapped within the oven. However, most microwave ovens leak some radiation externally, and this leakage can interfere with any device that operates in the microwave band. The microwave used in the project was built in 1984, and due to either aging materials or less advanced shielding techniques, leaks enough radiation to over the IEEE 802.11 signals and create noticeable interference. Figure 1, captured using a spectrum analyzer, displays the ad-hoc connection and the University of Tennessee nomad networks.

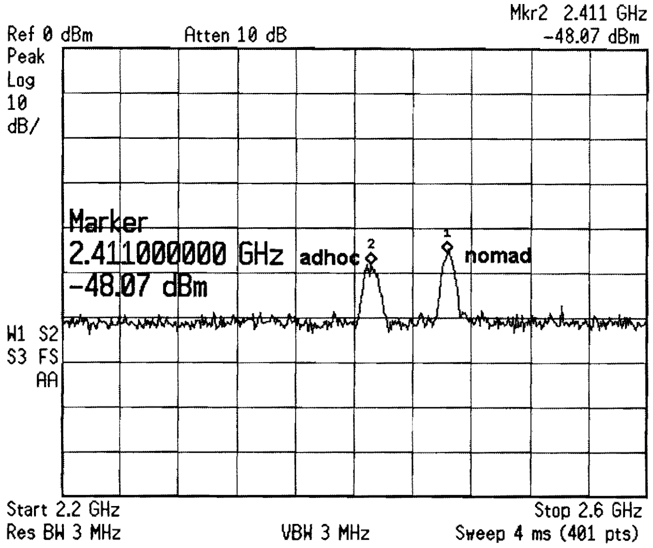


Fig. 1. Spectrum analyzer capture of the two detected IEEE 802.11 networks. Notice the ad-hoc wave representing the project signal and the nomad wave representing the University of Tennessee's wireless network. Both signals exist in the proper 2.4GHz to 2.5GHz range.

The broadband microwave interference can easily be seen in Figure 2, where the frequencies being used by the IEEE 802.11 networks are drastically overpowered by random interference.

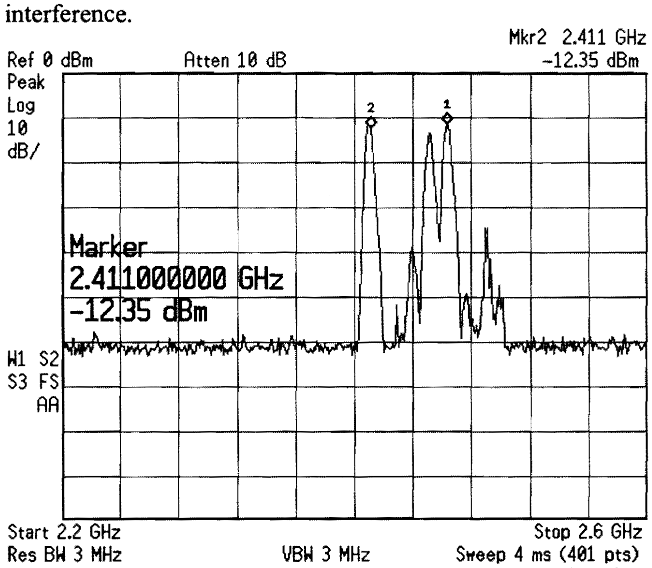


Fig. 2. Spectrum analyzer capture showing the usual frequency location of the two detected IEEE 802.11 networks while the microwave was running. The microwave has introduced broad spectrum high power interference across the bandwidth.

Testing involved transmitting several MPEG videos of varying qualities, and content, across the wireless network using VLC with RTP protocol while generating interference at chosen intervals to determine the impact of interference on the transmission. To achieve this, public domain[10] video clips were used of two types. The first type involves animation

[10] Public domain includes the body of knowledge and innovation upon which no person or entity can claim proprietary control. Such information is available for anyone to use for commercial or non-commercial use. In this case, the videos were downloaded from www.archive.org.

while the second involves quick, live action. The two types were chosen to give a variety of video types, making it easy to see various forms of decaying quality. Short, forty-five second clips were produced in both low quality and high quality formats, with a time-code stamp placed on the video to allow for easy comparison with the original video.

IV. Experiment Design and Development

The first step in the development of the experimental procedure to determine the effectiveness of wireless transmission over various distances was to first define the problem to be addressed. The problem was defined as finding a systematic way by which the effectiveness of the transmission can be determined. With the problem defined, the next step was to begin brainstorming methods by which to approach the problem. The first idea that was deemed feasible was to observe the decay in transmission effectiveness through a quantitative analysis of performance. Initial indications showed that this method for evaluating performance had promise.

The quantitative approach to performance analysis would have several advantages. One advantage of the quantitative approach is that the testing could be done at anytime that is convenient for the researchers. Also the quantitative approach would allow for easy statistical analysis of the performance data. However, the quantitative approach presented a variety of challenges. The first obstacle in the quantitative method is determining the performance statistics which would offer the best indication of the transmission effectiveness. Among those properties considered were dropped packets, frame rates, and signal strength. Each of these properties would have provided sufficient means by which the total effectiveness of the transmission could be gauged. The next hurdle, and ultimate reason for abandoning this approach, was to find a method for observing and recording these statistics. Several computer programs were examined, to determine whether or not they would be able to aide in the acquisition of data. Upon investigation of these programs, it was determined that there were no programs that were robust enough to handle the requirements that fit in the budget of the project. Thus it was decided that the quantitative approach would have to be abandoned.

Upon returning to brainstorming, it was decided to take a qualitative approach and have test subjects evaluate the wireless transmission effectiveness. The qualitative approach presented a new set of advantages and disadvantages. The qualitative approach allows for a method of analysis that can be done without the use of costly software. The disadvantages to this approach include both the necessity of working with test subjects as well as dealing with larger amounts of data. Working with test subjects, meant that the testing times had to be scheduled to work for all parties involved. The amount of data required for the qualitative analysis is greater, because the test had to be repeated by each of the test subjects. The decision was made to continue and develop an experimental procedure that makes use of qualitative analysis of a large number of test subjects.

The initial approach to qualitative analysis involved having the test subjects observe a series of video clips being streamed from several locations with, and without, generated interference. In this experimental configuration the test subjects would rate different properties of the video on a predefined rating scale. Examination of the testing procedure led to the conclusion that transmitting videos for each test period would extend the length of the testing, making it more difficult to find test subjects that could participate in the study. It was then determined that a more effective approach would be to create a video library of streamed video clips that were saved to the computer. These clips would contain the original information sent in the video stream, and would be able to be played with a significantly reduced time between videos. This allows the test periods to be shorter, making it easier to accommodate more test subjects, as well as providing a common baseline by which comparisons can be made.

After further evaluation of the testing procedures, the final testing process emerged. The experimental setup has several unique features that allow for a more successful measurement of the transmission effectiveness. Among these features is the use of different transmission distances that affect the effectiveness of the transmissions. The varying of distances shows how the video streams degrade with respect to distance between the transmitting and receiving components. Additionally, the experiment features the effects of an electromagnetic interference source that hinders the wireless transmission. This portion of the experiment allows for studying the response to common types of interference that can be found in the application of wireless streaming video technology.

One of the most unique features of the experimental design is the use of a level of abstraction, to prevent bias on the part of the test subjects. It was determined that the test subjects, being aware of the location and configuration of the transmission, could create bias. For instance, they might suspect that a certain configuration should behave in a certain manner, and thus grade the video according to their preconceptions. By having a level of blindness in regards to the video configuration, better results could be obtained. This level of blindness is created by having a predefined playlist that is played for the test subjects with a filler video played between each streamed video to allow the test subjects to complete the test form. The test subjects are not made aware of the configuration of the video that they are watching, which prevents the influence of bias. Additionally, the original video clips were included in the video library to provide for a control base.

According to the experimental design, the transmission quality is measured by evaluating several clip properties using a predefined rating scale. Both the properties, and the rating scale, are described in detail in the testing portion of this report. The use of a common testing standard, and not a mere subjective analysis by each test subject, allows for a method of analysis that can be transferred into performance data. During the course of the experimental development, an additional experiment was conceived to provide a base point for research into a new method for handling wireless transmission. This experiment made use of undersampling, dropping a specified number of frames in the video clips, to determine the visual appeal of the videos; essentially whether or not the test subjects found that they could stand watching the videos. This experiment was designed as an addendum to the primary experiment, and was simply a binary survey by which the test subjects rated the videos as acceptable, or unacceptable.

V. Testing

The physical setup for the testing process, described previously, was two laptop computers that were placed at predefined distances. One laptop was deemed the transmitting computer, and was used to send the video stream to the second laptop which remained stationary. The transmitting laptop sent a variety of video clips of different qualities from multiple distances. The videos were then saved on the receiving computer to be viewed by the test subjects. The electromagnetic interference source, which was a microwave oven, was placed next to the receiving computer and switched on and off to provide two different configurations for each of the transmission locations.

The video library used in the experiment was generated by transmitting three different video clips from three different locations with, and without, interference. The three video clips utilized in the experiment were videos freely available to the public that were edited to more manageable lengths. The videos were a low quality animation, a low quality live action clip, and a high quality animation. In subsequent charts and graphs each of the videos is abbreviated: FHLQ, LVLQ and FHHQ respectively. The three locations from which the videos were transmitted are shown in Figure 3. The figure shows a diagram of the area on the fourth floor of the Science and Engineering Research Facility at the University of Tennessee, immediately surrounding room 410, which served as the laboratory for this experiment. The distances for the three locations are as follows: in the room, approximately 13 feet; in the hall, approximately 54 feet; and outside in the lobby, approximately 70 feet.

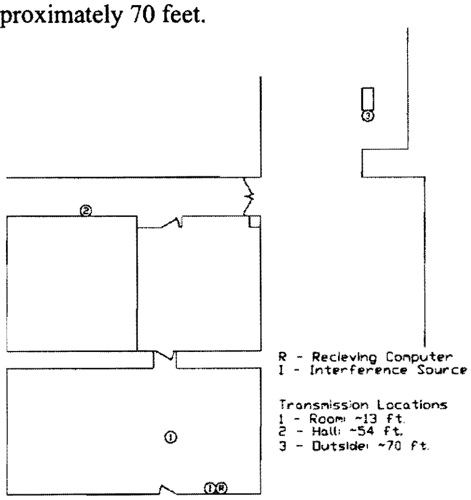


Fig. 3. Overhead view of the testing area with the various locations marked and distances given.

The video library was created by transmitting individual clips three times at each location with the interference source engaged, and three more with it disengaged. The videos were saved by the receiving computer, and organized to allow for later access. The original video clips were also included as part of the video library. The video clips for the supplemental undersampling experiment were generated using a video editing software, and were stored on the receiving computer to be viewed at the end of the testing period by the test subjects.

The video library was then used to create a series of six video playlists, each with a length of twenty-one clips. The playlists were generated by choosing seven clips from each of the three base clips. These clips could have been clips transmitted from any of the three locations with, or without, interference, or even the originals. The only restraint on the playlist generation was that each of the video clips in the video library was used at least twice in the six playlists combined. The test subjects were then assigned one of the playlists when they arrived for the testing period. The undersampling experiment also necessitated a playlist. A separate set of six video clips containing two clips of each of the following ratio of frames displayed: 1:2, 1:4, and 1:8. These clips were shown to every test subject at the conclusion of the experimental period.

The experiment is designed such that every test subject in the experiment is anonymous. The test subjects would come into the lab, where they were provided with data sheets to record their observations. The test subjects were also given a brief overview of the scope of the project and the terminology used in the testing process. The test subjects were then shown each of the original videos to provide a base against which they could compare each of the succeeding videos. The test subjects were then shown the playlist that their specific test group had been assigned. The playlists were equipped with a filler video between transmitted clips to allow for recording of observations. At any point the test subjects could request to view the original video again to reestablish a base of comparison. Once the entire playlist had been viewed, and the ratings recorded on the data sheet using the rating scale, the test subjects were then shown the playlist of six videos for the undersampling experiment. For this portion, the subjects were asked to evaluate the videos as either acceptable, or unacceptable, to watch.

Five qualitative properties were selected for evaluation by the test subjects: picture quality, sound quality, lagging, skipping and synchronization. These properties were selected because they would be easy to observe during the course of the testing process. In order to ensure that each of the test subjects was using a common definition for each property the following descriptions were provided.

> **Picture Quality** – This property refers to the quality of the picture being displayed. Included in this property are things like static on the picture and merging of different frames in such a way that makes the video difficult to see. An extreme example is a

simple black screen while the video clip should be playing.

Sound Quality – This property refers to the quality of the audio of the video clip. Aspects of sound quality that can be noticed include changes in volume or static. Also observable is a complete loss of sound during transmission.

Lagging – This property can be observed when the video clip is playing and momentarily pauses and resumes from where it stopped.

Skipping – This disturbance occurs when the video clip either jumps to another part of the video or when the video resumes at a new location after pausing.

Synchronization – This property deals with the synchronization of the video and sound. This property is simply evaluated by judging if the video and the sound line up the way they are intended.

Each of the properties was rated on the same rating scale. The rating scale, shown below, used a numerical system to assign a rating to each of the properties. These values were compiled and averaged to provide for data analysis.

1) Change Not Noticeable
2) Change Slightly Noticeable
3) Change Noticeable
4) Change Very Noticeable
5) Video is Completely Unintelligible

Typical screenshots of the video results are shown below. These results show: a clip that was transmitted without distortion, a clip with a little distortion, and a clip with significant distortion, for each of the three video clip types. Figure 4 shows a screenshot of the low quality animated clip that was sent from inside the room (approximately 13 feet) without the interference of the microwave. This image shows no noticeable distortion.

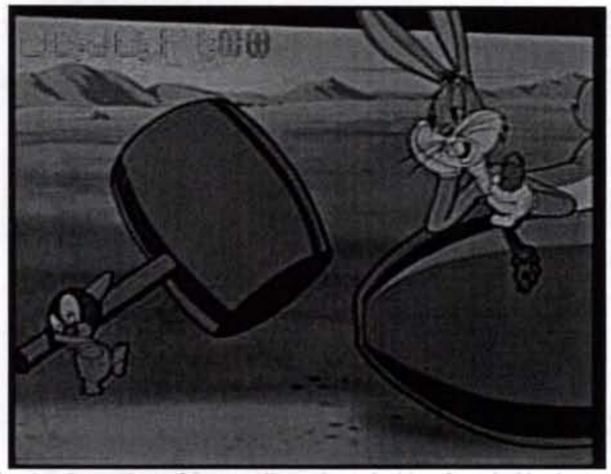


Fig. 4. Screenshot of low quality animated video from inside the room without interference showing no distortion

Figure 5 and Figure 6 are both screenshots of different low quality animation clips taken from inside the room with interference. Figure 5 shows a slight amount of distortion; whereas Figure 6 shows significant distortion.

Fig. 5. Screenshot of low quality animated video from inside the room with interference showing light distortion

Fig. 6. Screenshot of low quality animated video from inside the room with interference showing heavy distortion

Figure 7 is a screenshot of the transmission of the high quality animated clip from inside the room without interference, and shows no distortion. Figure 8 and Figure 9 are screenshots of the high quality clip that was transmitted from the hall (approximately 54 feet) without interference. They show slight distortion and high distortion, respectively.

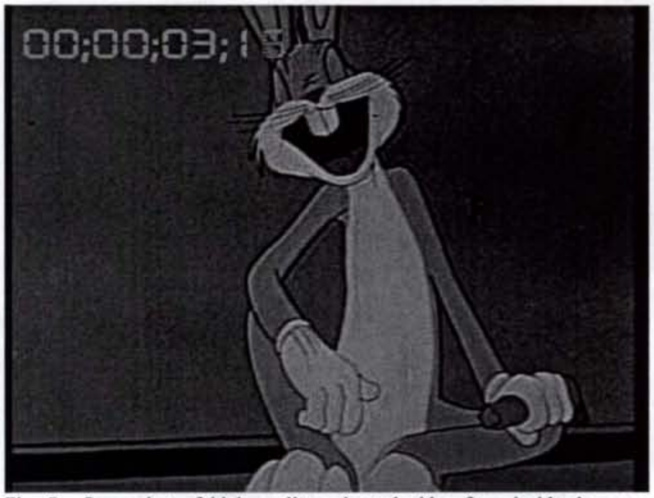


Fig. 7. Screenshot of high quality animated video from inside the room without interference showing no distortion

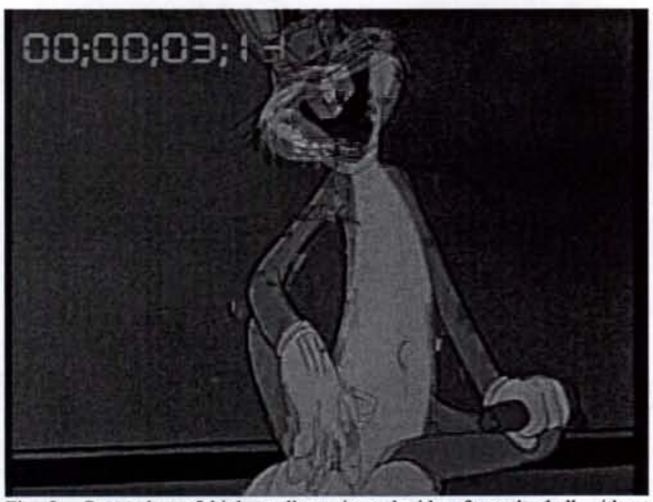


Fig. 8. Screenshot of high quality animated video from the hall without interference showing light distortion

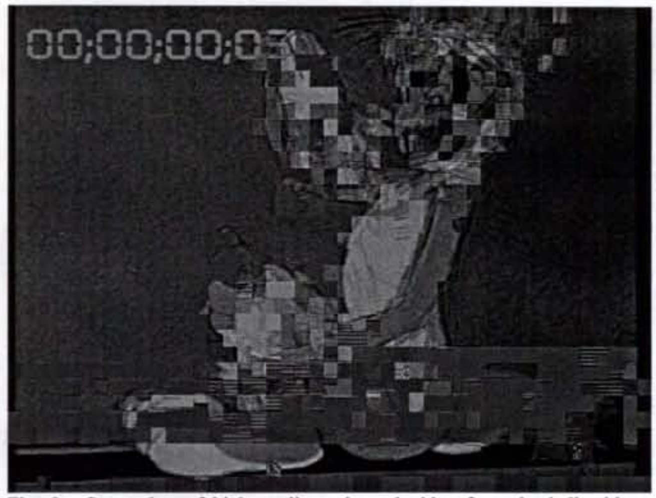


Fig .9. Screenshot of high quality animated video from the hall without interference showing heavy distortion

Figure 10 shows the undistorted low quality live video sent from inside the room, without interference. Figure 11 shows a distorted screenshot of the low quality live video that was transmitted from inside the room with interference. Figure 12 show a highly distorted screenshot form the low quality live video transmitted from inside the room with interference.

Fig. 10. Screenshot of low quality live video from inside the room without interference showing no distortion

Fig. 11. Screenshot of low quality live video from inside the room with interference showing light video distortion

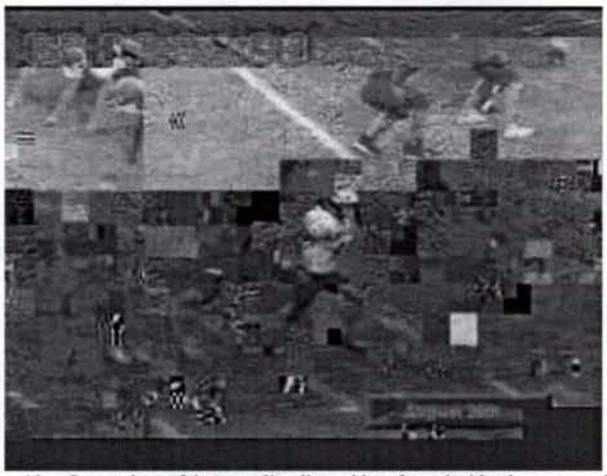


Fig. 12. Screenshot of low quality live video from inside the room with interference showing heavy distortion

Screenshots from clips that were transmitted from other locations are not included because they are either similar to those shown, or show nothing because the video was unintelligible. These screenshots show that a wide array of distortion was possible for the test subjects to make evaluations on video quality. The audio, and tracking errors, showed a similar range of degradation in similar conditions, which will be shown in further detail in the Data Analysis section.

VI. Data Analysis

The results from the qualitative testing were tabulated and then sorted according to transmission configuration, which included the video clip transmitted, location of transmission, and whether or not there was interference. The data was then averaged for each of the individual clips in the video library, as well as the total for all clips transmitted from each configuration. The tabulated results can be found in Appendix A and the graphs of the average data can be found in Appendix B. Appendix B also includes graphs of the percent similarity to the original video for each of the five properties for each video clip. These graphs show the percent similarity versus the increase in distance of the transmission location. Each graph contains two data sets, one with interference and one without. The percent similarity calculations were done using the following equation, the average rating is the average for all of the clips transmitted under each configuration.

$$\text{Percent Similarity} = 100-(\text{Average Rating} - 1)*25$$

The graphs of percent similarity versus transmission distance for each of the five properties observed in the study can be found in Figures 13 through 17, and also in Appendix B. These graphs show the percent similarity for each of the videos with, and without, interference using the previously stated naming patterns.

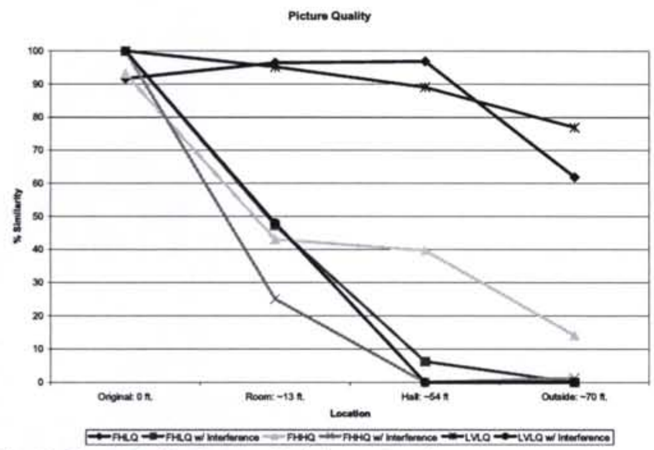


Fig. 13. Picture Quality: Percent Similarity vs. Location

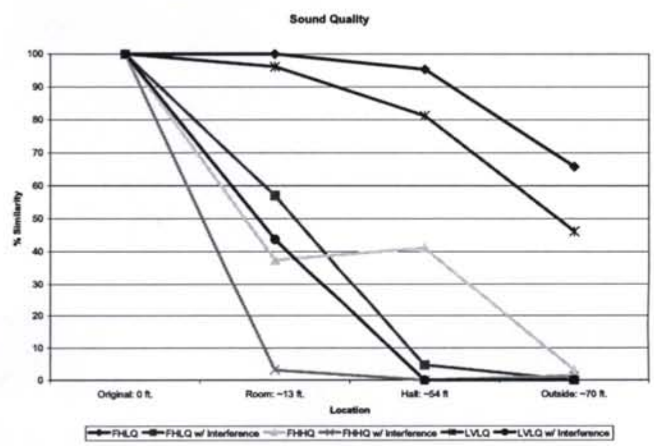


Fig. 14. Sound Quality: Percent Similarity vs. Location

Fig. 15. Skipping: Percent Similarity vs. Location

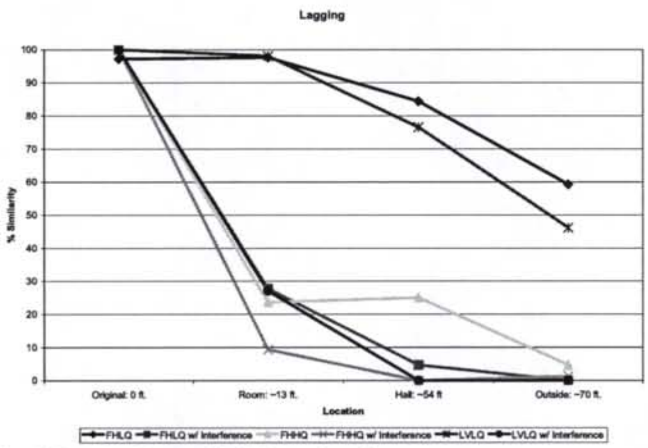


Fig. 16. Lagging: Percent Similarity vs. Location

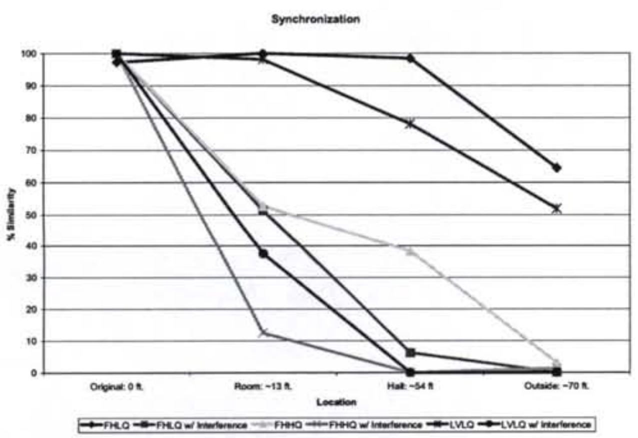


Fig. 17. Synchronization: Percent Similarity vs. Location

The data represented by the graphs of each of these five properties indicate that the trends in degradation of one property follow those of the other four. Thus analyzing the effectiveness of the wireless transmission is made easier by extrapolating the results across all five properties. These results support several conclusions about the effectiveness of the transmission scheme. The first of these conclusions is that the ability to transmit data effectively is dependent upon distance. Any signal will degrade over distance as given by the following formula where: L is the free-space loss, ℓ is the distance between transmitter and receiver, λ is the wavelength, c is the speed of light and f is the frequency.

$$L = \left(\frac{4\pi\ell}{\lambda}\right)^2 = \left(\frac{4\pi f\ell}{c}\right)^2 \text{ [2, p106]}$$

The farther apart the transmitting and receiving computers were situated, the less effective the transmission. Also, the graphs show significant difference between the transmissions without interference and the transmissions with interference. The transmissions with interference had a much quicker degradation with regards to distance than did the others. This shows that wireless transmission is susceptible to electromagnetic interference, and that interference should be taken into account when designing applications that make use of streaming video transmissions. Additionally, the data supports that the effectiveness is also dependent on the size of the file being streamed. The higher quality video, which was a much larger file transmitted over the same time span, showed a more drastic degradation in effectiveness as the distance was increased. The dramatic degradation curves also coincide with those that would be expected from digital transmission. In digital transmission there is no gentle fading of signal quality like that which exists in analog transmission.

The data from the supplementary undersampling experiment was recorded into a graphical format in Figure 18. These results show that almost all of the test subjects found that seeing only one out of every two frames is acceptable and that a majority found that seeing only one out of every four frames is acceptable. The test subjects, however, found that seeing only one out of eight frames was not acceptable. These results show that there is promise in the development of a modified version of the IEEE 802.11 standard which drops packets, and requests the next packet, instead of requesting the same packets repetitiously.

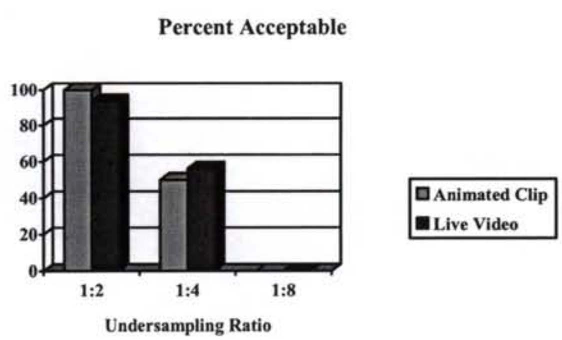


Fig. 18. Percentage of Videos found to be Acceptable to the test subjects in the Undersampling Experiment

VII. Conclusion

Experimentation with the IEEE 802.11 standard for transmitting streaming video has yielded positive results, and has opened several additional avenues of research. The results from the main transmission experiment show that IEEE 802.11 signals function as basic, digital signals; degradation occurs rapidly in interference, higher data rates are lossier, and error resiliency schemes play an important role in the quality of received data. IEEE 802.11 can be seen by these results as a non-ideal method for heavy traffic, wireless communication in the presence of interference or over significant distances. However, results from the secondary undersampling experiment show that, for human use, most video contains a level of redundant visual data. Taking these results together, it can be noted that it may be possible to modify IEEE 802.11 to perform more robustly in adverse conditions, but more research, and experimentation, is required.

Further work can be done to extend the research done in this study of wireless transmissions through various media. One of the first steps in further research should be in obtaining FCC licensing for amateur radio broadcasting. Amateur licensing will allow future researchers to use a greater array of antennas, higher broadcast powers, and the ability to forgo the collision avoidance detection system in IEEE 802.11, as licensed transmitters do not have to work around interference generation as gingerly as non-licensed transmitters. [1]

The use of antennas will also improve the range of research open in this field. As laptop computers with internal antennas were used in the experimentation process, research was necessarily limited. The use of external antennas will give future researchers the option of changing antenna configurations (such as length, shielding and directionality). The implementation of external antennas will also allow testing of new interference types more easily as material 'cages' can be built to surround the antenna. Work on building a Faraday Cage to transmit through was abandoned due to the research switch from desktop computers with external antennas to laptop computers with internal models.

Additional interference sources are a natural extension of the current research and experimentation. The results gathered for this experiment only used one additional source of interference: a microwave oven set on high power placed next to the Receiver. Variations of this configuration can be used for future work (e.g. the microwave may be placed next to the Transmitter or set to different power levels) or additional, new interference may be used, such as cordless phones or simultaneous broadcast on the same IEEE 802.11 channel by other users.

Further research should ideally be conducted without human test subjects. While using human reviewers was an acceptable method of determining whether or not a video had undergone noticeable changes during the broadcast process, a more robust packet sniffing algorithm, or a custom program made to compare saved streamed data against an original reference file, would provide a more finely gradated set of results, would be less time consuming to test, and provide a much finer quantification of the results. Such a program would require funds to purchase, or a separate design project to complete however. Whereas human test subjects were adequate in rating video quality, they proved to be indispensable for the rating of the undersampled video data. The use of a software based reviewing system would not have been appropriate for the undersampling experiment, but would be preferable for any future work in general reviews of streaming media.

The undersampling experiment raised some particularly interesting new avenues of research, especially when coupled with different broadcast techniques. As the greatest signal degradation caused the data to be retransmitted and the channel to be seen as occupied by IEEE 802.11 standard's CSMA/CA system, working on a method to avoid retransmitting, or awaiting the clearing of a channel, would prove to be advantageous for transmitting data through noisy media. As the undersampling experiment showed that the majority of test subjects found video transmitted at roughly 7.5 frames per second to be acceptable[11], error resiliency could be incorporated by merely transmitting the same frame multiple times, thus making the video jumpier, but hopefully making retransmission of data a moot issue. This method would work particularly well with high-resolution cameras that cannot capture images at a full video rate of roughly 30Hz or 60Hz[12]. Such a method would require research into changing the actual broadcast standard slightly to account for the removal of retransmissions, but still detect whether or not a frame is sufficiently uncorrupted for use. If the data is not to be used explicitly by humans, but instead for a purpose such as software facial identification, the broadcast can accommodate even more redundant transmissions as the jumpy nature of the video will not matter. Having several copies of a video frame should even prove to be advantageous for software applications, as an average video frame can be compiled, to be used as an additional source of error resiliency. [2, pp546-610]

The next avenue for further research may hinge on obtaining licensing for amateur broadcast from the FCC. Such licensing allows for a system that does not have to abide as strictly by the rules governing the generation and acceptance of interference as in the unlicensed system used in the experiments documented in this report. This is of special importance since FCC approval would allow for the circumvention of the CSMA/CA system present in the IEEE 802.11 standard. For most applications where a wireless streaming video system can be envisioned, such as mobile surveillance robots or hastily implemented military checkpoints, full ownership of the channel of broadcast spectrum to be used is a natural assumption. While the spectrum may be in use by other broadcasters, not having the restriction of having to wait for a clear channel, will aid in making a more robust streaming system and is necessary for further experimentation and research. [1,5]

The IEEE 802.11 standard is an easy solution for the transmission of wireless data between computers. Its

[11] The figure of 7.5 frames per second was calculated using an MPEG displaying 29.95 frames per second, and dividing 29.95 by 4, as the 4:1 undersampling was the lowest undersampling ratio that proved to be acceptable to the majority of reviewers.

[12] Television in the United States refreshes video frames at approximately 60Hz, or 30Hz in the case of interlaced video.

widespread acceptance makes implementing such a system inexpensive and simple to set up. Modifications to the standard might be able to retain its advantages while strengthening its weaknesses in strong interference. The 2.4 GHz band is available for unlicensed broadcast which makes it ideal for testing modified broadcast standards, but for a truly robust, and realistic, system for wireless video transmission, further research should first concern itself with seeking FCC approval so that varying power levels can be used and researchers can ignore channel occupancy restrictions. [1]

REFERENCES

[1] 47 CFR §15. United States Code of Federal Regulations, Title 47: FCC Rules and Regulations, Part 15. 2006.

[2] Carlson, Crilly and Rutledge, Communication Systems, 4th Edition. New York: McGraw Hill, 2001.

[3] Chiarglione, Leonardo, http://www.chiariglione.org/mpeg/. Moving Pictures Expert Group (MPEG) Homepage. Retrieved: February, 2007.

[4] Fitzek et al, *Traffic Analysis and Video Quality Evaluation of Multiple Description Coded Video Services for Fourth Generation Wireless IP Networks*. Center for TeleInFrastructure (CTIF). Aalborg University, Aalborg Øst, Denmark. 2005.

[5] Institute of Electrical and Electronics Engineers, IEEE 802.11 Standard. 1999.

[6] Institute of Electrical and Electronics Engineers, IEEE 802.11b-1999 Addendum. 1999.

[7] Institute of Electrical and Electronics Engineers, IEEE 802.11b-1999 Addendum, Corrigenduml. 2001.

[8] Institute of Electrical and Electronics Engineers, IEEE 802.11g-2003 Addendum. 2003.

[9] Kristoff, John, *The Trouble with UDP Scanning*. De Paul University, Chicago, Illinois, USA. March 11, 2002.

[10] Schulzrinne, Henning, http://www.cs.columbia.edu/~hgs/rtp/. Real-time Transport Protocol Page. Columbia University, New York City, New York, USA. Retrieved April, 2007.

[11] Van Leeuven, Tom et al, *Preserving Streaming Video Quality in Mobile Wireless LAN Networks*. Department of Information Technology, Ghent University, Ghent, Belgium. 2006.

[12] Wavelength Media, http://www.mediacollege.com/video/streaming/overview.html. How to Make Streaming Video. New Zealand. Retrieved April, 2007.

Appendix A – Tabulated Results

Test Number			Date	Video File	Video Quality	Sound Quality	Skipping	Lagging	Synchronization
0001	01	02	4/11/07	FHLQRN_1	1	1	1	1	1
0002	01	02	4/11/07	FHLQRY_3	1	2	1	4	1
0003	01	02	4/11/07	FHLQHY_1	5	5	5	5	5
0004	01	02	4/11/07	FHLQON_3	2	1	1	2	1
0005	01	02	4/11/07	FHLQRN_2	1	1	1	1	1
0006	01	02	4/11/07	FHLQHN_1	1	1	1	1	1
0007	01	02	4/11/07	FHLQON_2	5	5	5	5	5
0008	01	02	4/11/07	FHHQRN_3	3	3	2	3	1
0009	01	02	4/11/07	FHHQHY_2	5	5	5	5	5
0010	01	02	4/11/07	FHHQOY_1	5	5	5	5	5
0011	01	02	4/11/07	Falling_Hare_Clip_HQ	1	1	1	1	1
0012	01	02	4/11/07	FHHQHN_3	4	1	4	2	2
0013	01	02	4/11/07	FHHQRY_1	4	5	4	4	4
0014	01	02	4/11/07	FHHQON_2	5	5	5	5	5
0015	01	02	4/11/07	LVLQON_3	2	2	3	3	1
0016	01	02	4/11/07	LVLQOY_3	5	5	5	5	5
0017	01	02	4/11/07	LVLQOY_2	5	5	5	5	5
0018	01	02	4/11/07	LVLQRN_1	1	1	1	1	1
0019	01	02	4/11/07	LVLQHN_2	1	1	1	1	1
0020	01	02	4/11/07	LVLQRN_3	1	1	1	1	1
0021	01	02	4/11/07	LVLQHY_1	5	5	5	5	5
0022	02	02	4/11/07	FHLQRN_1	1	1	1	1	1
0023	02	02	4/11/07	FHLQRY_3	2	2	3	4	2
0024	02	02	4/11/07	FHLQHY_1	5	5	5	5	5
0025	02	02	4/11/07	FHLQON_3	1	1	2	1	1
0026	02	02	4/11/07	FHLQRN_2	1	1	1	1	1
0027	02	02	4/11/07	FHLQHN_1	1	1	1	1	1
0028	02	02	4/11/07	FHLQON_2	5	5	5	5	5
0029	02	02	4/11/07	FHHQRN_3	3	3	4	3	2
0030	02	02	4/11/07	FHHQHY_2	5	5	5	5	5
0031	02	02	4/11/07	FHHQOY_1	5	5	5	5	5
0032	02	02	4/11/07	Falling_Hare_Clip_HQ	1	1	1	1	1
0033	02	02	4/11/07	FHHQHN_3	3	3	4	4	4
0034	02	02	4/11/07	FHHQRY_1	4	5	4	5	3
0035	02	02	4/11/07	FHHQON_2	5	5	5	5	5
0036	02	02	4/11/07	LVLQON_3	1	2	3	3	1
0037	02	02	4/11/07	LVLQOY_3	5	5	5	5	5
0038	02	02	4/11/07	LVLQOY_2	5	5	5	5	5
0039	02	02	4/11/07	LVLQRN_1	1	1	1	1	1
0040	02	02	4/11/07	LVLQHN_2	1	1	1	1	1
0041	02	02	4/11/07	LVLQRN_3	1	1	1	1	1
0042	02	02	4/11/07	LVLQHY_1	5	5	5	5	5
0043	03	02	4/11/07	FHLQRN_1	1	1	1	1	1
0044	03	02	4/11/07	FHLQRY_3	2	2	2	4	3
0045	03	02	4/11/07	FHLQHY_1	2	2	1	3	2
0046	03	02	4/11/07	FHLQON_3	1	1	1	1	1
0047	03	02	4/11/07	FHLQRN_2	1	1	1	1	1
0048	03	02	4/11/07	FHLQHN_1	1	1	1	1	1
0049	03	02	4/11/07	FHLQON_2	5	5	5	5	5
0050	03	02	4/11/07	FHHQRN_3	3	3	2	4	3
0051	03	02	4/11/07	FHHQHY_2	5	5	5	5	5
0052	03	02	4/11/07	FHHQOY_1	5	5	5	5	5
Test Number			Date	Video File	Video Quality	Sound Quality	Skipping	Lagging	Synchronization

0053	03	02	4/11/07	Falling_Hare_Clip_HQ	1	1	1	1	1
0054	03	02	4/11/07	FHHQHN_3	4	4	3	4	3
0055	03	02	4/11/07	FHHQRY_1	5	5	5	5	5
0056	03	02	4/11/07	FHHQON_2	5	5	5	5	5
0057	03	02	4/11/07	LVLQON_3	2	4	2	3	3
0058	03	02	4/11/07	LVLQOY_3	5	5	5	5	5
0059	03	02	4/11/07	LVLQOY_2	5	5	5	5	5
0060	03	02	4/11/07	LVLQRN_1	1	1	1	1	1
0061	03	02	4/11/07	LVLQHN_2	1	1	1	1	1
0062	03	02	4/11/07	LVLQRN_3	1	1	1	1	1
0063	03	02	4/11/07	LVLQHY_1	5	5	5	5	5
0064	04	02	4/13/2007	Falling_Hare_Clip_LQ	1	1	1	1	1
0065	04	02	4/13/2007	FHLQRN_3	2	1	1	1	1
0066	04	02	4/13/2007	FHLQHY_3	5	5	5	5	5
0067	04	02	4/13/2007	FHLQOY_3	5	5	5	5	5
0068	04	02	4/13/2007	FHLQRY_2	4	2	2	4	2
0069	04	02	4/13/2007	FHLQHN_3	1	1	1	3	1
0070	04	02	4/13/2007	FHLQHN_1	1	1	1	3	1
0071	04	02	4/13/2007	FHHQRN_1	3	4	4	4	2
0072	04	02	4/13/2007	FHHQON_3	4	4	4	4	4
0073	04	02	4/13/2007	FHHQHY_1	5	5	5	5	5
0074	04	02	4/13/2007	FHHQOY_2	5	5	5	5	5
0075	04	02	4/13/2007	FHHQRN_2	4	4	4	4	3
0076	04	02	4/13/2007	FHHQRY_3	4	5	4	5	4
0077	04	02	4/13/2007	FHHQOY_3	5	5	5	5	5
0078	04	02	4/13/2007	LVLQRN_2	2	1	1	1	1
0079	04	02	4/13/2007	LVLQRY_2	5	5	5	5	5
0080	04	02	4/13/2007	LVLQHY_3	5	5	5	5	5
0081	04	02	4/13/2007	LVLQRN_2	2	2	1	1	1
0082	04	02	4/13/2007	LVLQHN_1	3	4	4	4	4
0083	04	02	4/13/2007	LVLQON_2	3	4	2	3	3
0084	04	02	4/13/2007	LVLQON_1	4	4	4	3	4
0085	05	02	4/13/2007	Falling_Hare_Clip_LQ	2	1	1	1	1
0086	05	02	4/13/2007	FHLQRN_3	3	1	1	1	1
0087	05	02	4/13/2007	FHLQHY_3	5	5	5	5	5
0088	05	02	4/13/2007	FHLQOY_3	5	5	5	5	5
0089	05	02	4/13/2007	FHLQRY_2	4	2	2	4	4
0090	05	02	4/13/2007	FHLQHN_3	2	2	2	4	1
0091	05	02	4/13/2007	FHLQHN_1	2	1	1	1	1
0092	05	02	4/13/2007	FHHQRN_1	3	4	4	4	4
0093	05	02	4/13/2007	FHHQON_3	3	5	5	5	5
0094	05	02	4/13/2007	FHHQHY_1	5	5	5	5	5
0095	05	02	4/13/2007	FHHQOY_2	5	5	5	5	5
0096	05	02	4/13/2007	FHHQRN_2	3	5	5	5	4
0097	05	02	4/13/2007	FHHQRY_3	5	5	5	5	5
0098	05	02	4/13/2007	FHHQOY_3	5	5	5	5	5
0099	05	02	4/13/2007	LVLQRN_2	1	1	1	1	1
0100	05	02	4/13/2007	LVLQRY_2	5	5	5	5	5
0101	05	02	4/13/2007	LVLQHY_3	5	5	5	5	5
0102	05	02	4/13/2007	LVLQRN_2	2	1	1	1	1
0103	05	02	4/13/2007	LVLQHN_1	2	4	5	5	5
0104	05	02	4/13/2007	LVLQON_2	1	3	4	4	3
0105	05	02	4/13/2007	LVLQON_1	3	4	4	4	4
0106	06	02	4/13/2007	FHLQRY_1	2	1	3	1	1

Test Number			Date	Video File	Video Quality	Sound Quality	Skipping	Lagging	Synchronization
0107	06	02	4/13/2007	FHLQHN_2	1	1	1	1	1
0108	06	02	4/13/2007	Falling_Hare_Clip_LQ	1	1	1	1	1
0109	06	02	4/13/2007	FHLQHY_2	5	5	5	5	5
0110	06	02	4/13/2007	FHLQOY_2	5	5	5	5	5
0111	06	02	4/13/2007	FHLQON_1	1	1	1	1	1
0112	06	02	4/13/2007	FHLQOY_1	5	5	5	5	5
0113	06	02	4/13/2007	FHHQRY_2	4	5	4	4	4
0114	06	02	4/13/2007	FHHQHY_3	5	5	5	5	5
0115	06	02	4/13/2007	FHHQON_1	5	5	5	5	5
0116	06	02	4/13/2007	FHHQHN_1	3	2	1	4	2
0117	06	02	4/13/2007	FHHQHN_2	2	2	4	4	4
0118	06	02	4/13/2007	Falling_Hare_Clip_HQ	1	1	1	1	1
0119	06	02	4/13/2007	FHHQRN_3	2	1	1	4	3
0120	06	02	4/13/2007	LVLQRY_1	1	1	1	4	1
0121	06	02	4/13/2007	LVLQOY_1	5	5	5	5	5
0122	06	02	4/13/2007	LVLQHY_2	5	5	5	5	5
0123	06	02	4/13/2007	LVLQHN_3	1	1	3	1	4
0124	06	02	4/13/2007	LVLQRN_1	1	1	1	1	1
0125	06	02	4/13/2007	HS_Football_Clip_LQ	1	1	1	1	1
0126	06	02	4/13/2007	LVLQRY_3	1	2	4	4	1
0127	07	02	4/13/2007	FHLQRY_1	1	1	4	5	2
0128	07	02	4/13/2007	FHLQHN_2	1	1	1	1	1
0129	07	02	4/13/2007	Falling_Hare_Clip_LQ	2	1	1	1	1
0130	07	02	4/13/2007	FHLQHY_2	5	5	5	5	5
0131	07	02	4/13/2007	FHLQOY_2	5	5	5	5	5
0132	07	02	4/13/2007	FHLQON_1	2	1	1	1	1
0133	07	02	4/13/2007	FHLQOY_1	5	5	5	5	5
0134	07	02	4/13/2007	FHHQRY_2	3	4	5	5	5
0135	07	02	4/13/2007	FHHQHY_3	5	5	5	5	5
0136	07	02	4/13/2007	FHHQON_1	5	5	5	5	5
0137	07	02	4/13/2007	FHHQHN_1	4	4	4	3	4
0138	07	02	4/13/2007	FHHQHN_2	3	3	4	4	5
0139	07	02	4/13/2007	Falling_Hare_Clip_HQ	2	1	1	1	1
0140	07	02	4/13/2007	FHHQRN_3	4	3	1	4	2
0141	07	02	4/13/2007	LVLQRY_1	3	2	4	2	3
0142	07	02	4/13/2007	LVLQOY_1	5	5	5	5	5
0143	07	02	4/13/2007	LVLQHY_2	5	5	5	5	5
0144	07	02	4/13/2007	LVLQHN_3	2	3	2	3	4
0145	07	02	4/13/2007	LVLQRN_1	1	1	1	1	1
0146	07	02	4/13/2007	HS_Football_Clip_LQ	1	1	1	1	1
0147	07	02	4/13/2007	LVLQRY_3	1	2	3	3	2
0148	08	02	4/16/2007	FHLQRN_1	1	1	1	1	1
0149	08	02	4/16/2007	FHLQON_3	1	1	2	1	1
0150	08	02	4/16/2007	FHLQHN_3	1	1	2	2	1
0151	08	02	4/16/2007	FHLQRN_3	1	1	1	1	1
0152	08	02	4/16/2007	FHLQOY_1	5	5	5	5	5
0153	08	02	4/16/2007	Falling_Hare_Clip_LQ	2	1	1	1	1
0154	08	02	4/16/2007	FHLQHY_1	5	5	5	5	5
0155	08	02	4/16/2007	FHHQRN_1	2	1	5	5	1
0156	08	02	4/16/2007	FHHQON_3	5	5	5	5	5
0157	08	02	4/16/2007	FHHQHN_1	5	4	4	5	5
0158	08	02	4/16/2007	FHHQOY_1	5	5	5	5	5
0159	08	02	4/16/2007	Falling_Hare_Clip_HQ	2	1	1	1	1
0160	08	02	4/16/2007	FHHQHY_2	5	5	5	5	5

Test Number			Date	Video File	Video Quality	Sound Quality	Skipping	Lagging	Synchronization
0161	08	02	4/16/2007	FHHQRN_2	4	4	4	4	4
0162	08	02	4/16/2007	LVLQON_3	1	4	4	4	4
0163	08	02	4/16/2007	LVLQHN_3	1	2	2	2	1
0164	08	02	4/16/2007	LVLQRY_1	5	5	5	5	5
0165	08	02	4/16/2007	LVLQHN_1	1	2	2	3	1
0166	08	02	4/16/2007	HS_Football_Clip_LQ	1	1	1	1	1
0167	08	02	4/16/2007	LVLQRN_2	1	1	1	1	1
0168	08	02	4/16/2007	LVLQON_2	1	3	2	1	1
0169	09	02	4/16/2007	FHLQRN_1	1	1	1	1	1
0170	09	02	4/16/2007	FHLQON_3	1	1	1	3	1
0171	09	02	4/16/2007	FHLQHN_3	1	3	2	3	2
0172	09	02	4/16/2007	FHLQRN_3	1	1	1	1	1
0173	09	02	4/16/2007	FHLQOY_1	5	5	5	5	5
0174	09	02	4/16/2007	Falling_Hare_Clip_LQ	1	1	1	1	2
0175	09	02	4/16/2007	FHLQHY_1	4	5	3	4	4
0176	09	02	4/16/2007	FHHQRN_1	4	5	3	4	3
0177	09	02	4/16/2007	FHHQON_3	4	5	5	5	5
0178	09	02	4/16/2007	FHHQHN_1	3	4	3	4	2
0179	09	02	4/16/2007	FHHQOY_1	5	5	5	5	5
0180	09	02	4/16/2007	Falling_Hare_Clip_HQ	1	1	1	1	1
0181	09	02	4/16/2007	FHHQHY_2	5	5	5	5	5
0182	09	02	4/16/2007	FHHQRN_2	3	4	3	4	2
0183	09	02	4/16/2007	LVLQON_3	2	3	3	2	3
0184	09	02	4/16/2007	LVLQHN_3	2	2	3	3	2
0185	09	02	4/16/2007	LVLQRY_1	4	4	4	4	4
0186	09	02	4/16/2007	LVLQHN_1	2	2	3	2	1
0187	09	02	4/16/2007	HS_Football_Clip_LQ	1	1	1	1	1
0188	09	02	4/16/2007	LVLQRN_2	3	2	2	2	2
0189	09	02	4/16/2007	LVLQON_2	1	1	2	3	3
0190	10	02	4/16/2007	FHLQRN_2	1	1	1	2	1
0191	10	02	4/16/2007	FHLQRY_2	4	1	3	4	2
0192	10	02	4/16/2007	FHLQON_2	5	5	5	5	5
0193	10	02	4/16/2007	FHLQHY_2	5	5	5	5	5
0194	10	02	4/16/2007	FHLQRY_1	4	5	4	4	4
0195	10	02	4/16/2007	FHLQOY_3	5	5	5	5	5
0196	10	02	4/16/2007	FHLQRY_3	3	3	3	4	3
0197	10	02	4/16/2007	FHHQRY_1	3	5	4	4	4
0198	10	02	4/16/2007	FHHQON_2	4	5	5	5	5
0199	10	02	4/16/2007	FHHQRY_3	4	5	5	5	5
0200	10	02	4/16/2007	FHHQHY_3	5	5	5	5	5
0201	10	02	4/16/2007	FHHQHY_1	5	5	5	5	5
0202	10	02	4/16/2007	Falling_Hare_Clip_HQ	1	1	1	1	1
0203	10	02	4/16/2007	FHHQOY_2	5	5	5	5	5
0204	10	02	4/16/2007	LVLQRN_3	1	1	1	1	1
0205	10	02	4/16/2007	LVLQRY_3	2	3	4	3	3
0206	10	02	4/16/2007	LVLQHY_3	5	5	5	5	5
0207	10	02	4/16/2007	LVLQOY_3	5	5	5	5	5
0208	10	02	4/16/2007	LVLQRY_2	4	5	5	5	5
0209	10	02	4/16/2007	LVLQOY_1	5	5	5	5	5
0210	10	02	4/16/2007	HS_Football_Clip_LQ	1	1	1	1	1
0211	11	02	4/16/2007	FHLQRN_2	1	1	1	2	1
0212	11	02	4/16/2007	FHLQRY_2	4	1	4	4	3
0213	11	02	4/16/2007	FHLQON_2	5	5	5	5	5
0214	11	02	4/16/2007	FHLQHY_2	5	5	5	5	5

Test Number			Date	Video File	Video Quality	Sound Quality	Skipping	Lagging	Synchronization
0215	11	02	4/16/2007	FHLQRY_1	4	5	4	4	5
0216	11	02	4/16/2007	FHLQOY_3	5	5	5	5	5
0217	11	02	4/16/2007	FHLQRY_3	2	3	4	4	3
0218	11	02	4/16/2007	FHHQRY_1	3	5	4	4	5
0219	11	02	4/16/2007	FHHQON_2	3	5	4	4	5
0220	11	02	4/16/2007	FHHQRY_3	3	5	5	5	5
0221	11	02	4/16/2007	FHHQHY_3	5	5	5	5	5
0222	11	02	4/16/2007	FHHQHY_1	5	5	5	5	5
0223	11	02	4/16/2007	Falling_Hare_Clip_HQ	1	1	1	1	1
0224	11	02	4/16/2007	FHHQOY_2	5	5	5	5	5
0225	11	02	4/16/2007	LVLQRN_3	1	1	1	1	1
0226	11	02	4/16/2007	LVLQRY_3	1	1	2	2	3
0227	11	02	4/16/2007	LVLQHY_3	5	5	5	5	5
0228	11	02	4/16/2007	LVLQOY_3	5	5	5	5	5
0229	11	02	4/16/2007	LVLQRY_2	5	4	5	5	5
0230	11	02	4/16/2007	LVLQOY_1	5	5	5	5	5
0231	11	02	4/16/2007	HS_Football_Clip_LQ	1	1	1	1	1
0232	12	02	4/18/2007	FHLQHY_3	5	5	5	5	5
0233	12	02	4/18/2007	FHLQOY_2	5	5	5	5	5
0234	12	02	4/18/2007	Falling_Hare_Clip_LQ	1	1	1	2	1
0235	12	02	4/18/2007	FHLQON_1	2	1	1	1	1
0236	12	02	4/18/2007	FHLQHN_2	1	1	1	1	1
0237	12	02	4/18/2007	FHLQRY_3	2	2	4	4	2
0238	12	02	4/18/2007	FHLQRN_1	1	1	1	1	1
0239	12	02	4/18/2007	FHHQRY_2	5	5	5	5	5
0240	12	02	4/18/2007	FHHQHN_2	1	2	4	4	1
0241	12	02	4/18/2007	FHHQON_1	5	5	5	5	5
0242	12	02	4/18/2007	FHHQHN_3	2	2	5	5	2
0243	12	02	4/18/2007	FHHQOY_3	5	5	5	5	5
0244	12	02	4/18/2007	FHHQRN_2	2	3	5	4	2
0245	12	02	4/18/2007	FHHQOY_1	5	5	5	5	5
0246	12	02	4/18/2007	LVLQHN_2	1	1	2	1	1
0247	12	02	4/18/2007	LVLQHY_1	5	5	5	5	5
0248	12	02	4/18/2007	LVLQOY_2	5	5	5	5	5
0249	12	02	4/18/2007	LVLQHY_2	5	5	5	5	5
0250	12	02	4/18/2007	LVLQRN_3	1	1	1	1	1
0251	12	02	4/18/2007	LVLQOY_1	5	5	5	5	5
0252	12	02	4/18/2007	LVLQRN_2	1	1	1	1	1
0253	13	02	4/18/2007	FHLQHY_3	5	5	5	5	5
0254	13	02	4/18/2007	FHLQOY_2	5	5	5	5	5
0255	13	02	4/18/2007	Falling_Hare_Clip_LQ	1	1	1	1	1
0256	13	02	4/18/2007	FHLQON_1	1	1	1	1	1
0257	13	02	4/18/2007	FHLQHN_2	1	1	1	1	1
0258	13	02	4/18/2007	FHLQRY_3	4	4	4	4	4
0259	13	02	4/18/2007	FHLQRN_1	1	1	1	1	1
0260	13	02	4/18/2007	FHHQRY_2	4	4	4	4	4
0261	13	02	4/18/2007	FHHQHN_2	4	4	4	4	4
0262	13	02	4/18/2007	FHHQON_1	5	5	5	5	5
0263	13	02	4/18/2007	FHHQHN_3	4	4	4	4	3
0264	13	02	4/18/2007	FHHQOY_3	5	5	5	5	5
0265	13	02	4/18/2007	FHHQRN_2	4	4	4	4	4
0266	13	02	4/18/2007	FHHQOY_1	5	5	5	5	5
0267	13	02	4/18/2007	LVLQHN_2	1	1	1	1	1
0268	13	02	4/18/2007	LVLQHY_1	5	5	5	5	5

Test Number			Date	Video File	Video Quality	Sound Quality	Skipping	Lagging	Synchronization
0269	13	02	4/18/2007	LVLQOY_2	5	5	5	5	5
0270	13	02	4/18/2007	LVLQHY_2	5	5	5	5	5
0271	13	02	4/18/2007	LVLQRN_3	1	1	1	1	1
0272	13	02	4/18/2007	LVLQOY_1	5	5	5	5	5
0273	13	02	4/18/2007	LVLQRN_2	1	1	1	1	1
0274	14	02	4/18/2007	FHLQHY_3	5	5	5	5	5
0275	14	02	4/18/2007	FHLQOY_2	5	5	5	5	5
0276	14	02	4/18/2007	Falling_Hare_Clip_LQ	1	1	1	1	1
0277	14	02	4/18/2007	FHLQON_1	1	1	1	2	1
0278	14	02	4/18/2007	FHLQHN_2	1	1	2	1	1
0279	14	02	4/18/2007	FHLQRY_3	4	4	4	4	4
0280	14	02	4/18/2007	FHLQRN_1	1	1	1	1	1
0281	14	02	4/18/2007	FHHQRY_2	5	5	4	4	4
0282	14	02	4/18/2007	FHHQHN_2	4	4	4	4	4
0283	14	02	4/18/2007	FHHQON_1	5	5	5	5	5
0284	14	02	4/18/2007	FHHQHN_3	5	5	5	4	5
0285	14	02	4/18/2007	FHHQOY_3	5	5	5	5	5
0286	14	02	4/18/2007	FHHQRN_2	4	3	5	4	3
0287	14	02	4/18/2007	FHHQOY_1	5	5	5	5	5
0288	14	02	4/18/2007	LVLQHN_2	1	1	2	1	1
0289	14	02	4/18/2007	LVLQHY_1	5	5	5	5	5
0290	14	02	4/18/2007	LVLQOY_2	5	5	5	5	5
0291	14	02	4/18/2007	LVLQHY_2	5	5	5	5	5
0292	14	02	4/18/2007	LVLQRN_3	1	2	1	1	1
0293	14	02	4/18/2007	LVLQOY_1	5	5	5	5	5
0294	14	02	4/18/2007	LVLQRN_2	1	1	1	1	1
0295	15	02	4/20/2007	FHLQRN_1	1	1	1	1	1
0296	15	02	4/20/2007	FHLQRY_3	5	5	5	4	4
0297	15	02	4/20/2007	FHLQHY_1	5	5	5	5	5
0298	15	02	4/20/2007	FHLQON_3	1	1	1	1	1
0299	15	02	4/20/2007	FHLQRN_2	1	1	1	1	1
0300	15	02	4/20/2007	FHLQHN_1	1	1	1	1	1
0301	15	02	4/20/2007	FHLQON_2	3	3	4	3	4
0302	15	02	4/20/2007	FHHQRN_3	5	5	5	5	5
0303	15	02	4/20/2007	FHHQHY_2	5	5	5	5	5
0304	15	02	4/20/2007	FHHQOY_1	4	4	4	4	4
0305	15	02	4/20/2007	Falling_Hare_Clip_HQ	2	1	2	1	1
0306	15	02	4/20/2007	FHHQHN_3	5	5	5	5	5
0307	15	02	4/20/2007	FHHQRY_1	5	5	5	5	5
0308	15	02	4/20/2007	FHHQON_2	4	4	4	4	4
0309	15	02	4/20/2007	LVLQON_3	3	4	4	4	4
0310	15	02	4/20/2007	LVLQOY_3	5	5	5	5	5
0311	15	02	4/20/2007	LVLQOY_2	5	5	5	5	5
0312	15	02	4/20/2007	LVLQRN_1	1	1	1	1	1
0313	15	02	4/20/2007	LVLQHN_2	2	1	2	1	1
0314	15	02	4/20/2007	LVLQRN_3	1	1	2	2	1
0315	15	02	4/20/2007	LVLQHY_1	5	5	5	5	5
0316	16	02	4/20/2007	FHLQRN_1	1	1	1	1	1
0317	16	02	4/20/2007	FHLQRY_3	4	4	4	4	4
0318	16	02	4/20/2007	FHLQHY_1	5	5	5	5	5
0319	16	02	4/20/2007	FHLQON_3	1	1	2	2	1
0320	16	02	4/20/2007	FHLQRN_2	1	1	1	1	1
0321	16	02	4/20/2007	FHLQHN_1	1	1	1	1	1
0322	16	02	4/20/2007	FHLQON_2	5	5	5	5	5

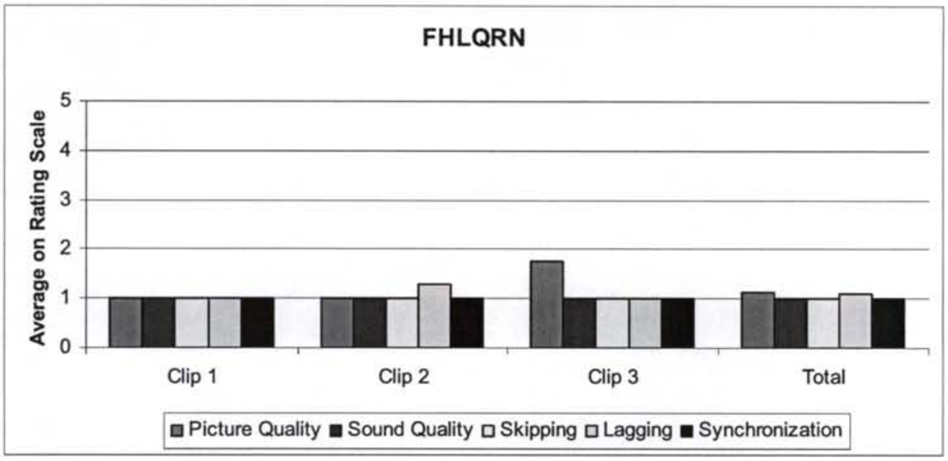
Test Number			Date	Video File	Video Quality	Sound Quality	Skipping	Lagging	Synchronization
0323	16	02	4/20/2007	FHHQRN_3	3	4	3	4	4
0324	16	02	4/20/2007	FHHQHY_2	5	5	5	5	5
0325	16	02	4/20/2007	FHHQOY_1	5	5	5	5	5
0326	16	02	4/20/2007	Falling_Hare_Clip_HQ	1	1	1	1	1
0327	16	02	4/20/2007	FHHQHN_3	2	4	4	4	4
0328	16	02	4/20/2007	FHHQRY_1	3	5	5	5	5
0329	16	02	4/20/2007	FHHQON_2	4	5	5	5	5
0330	16	02	4/20/2007	LVLQON_3	1	3	4	4	4
0331	16	02	4/20/2007	LVLQOY_3	5	5	5	5	5
0332	16	02	4/20/2007	LVLQOY_2	5	5	5	5	5
0333	16	02	4/20/2007	LVLQRN_1	1	2	1	1	2
0334	16	02	4/20/2007	LVLQHN_2	1	1	1	1	1
0335	16	02	4/20/2007	LVLQRN_3	1	1	2	1	1
0336	16	02	4/20/2007	LVLQHY_1	5	5	5	5	5

Appendix B – Graphical Results

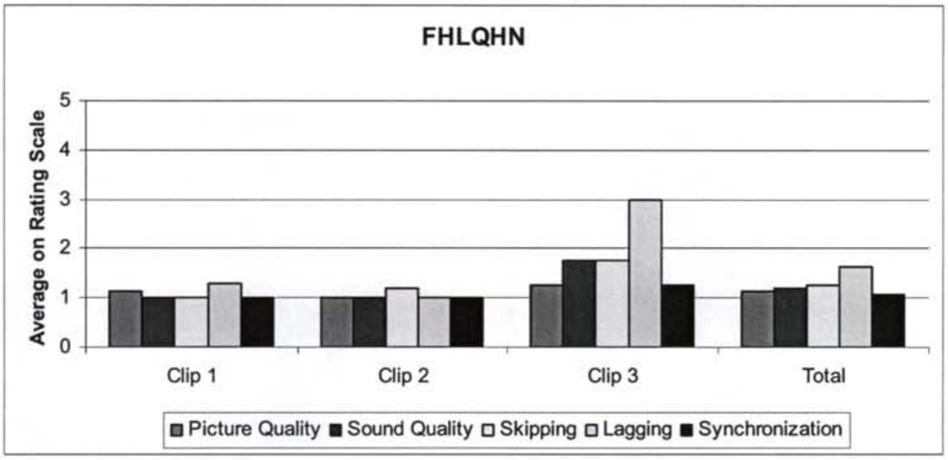
Original Video Clips

Falling Hare Clip Low Quality without Interference

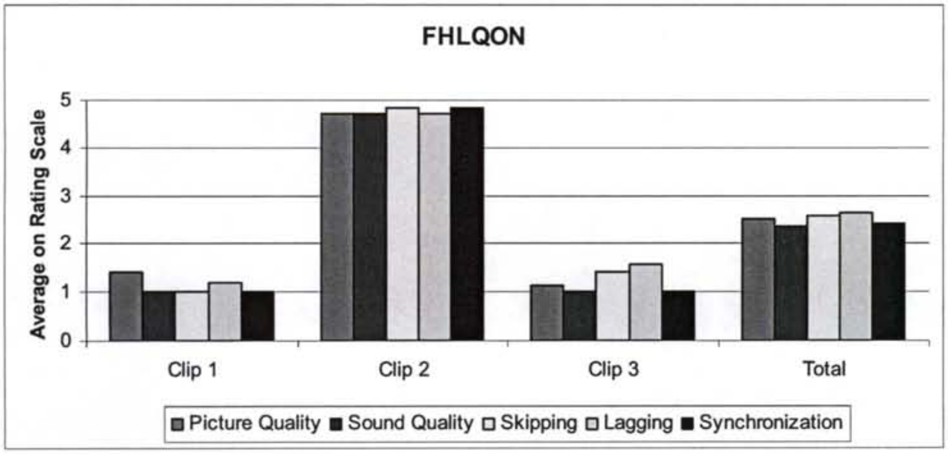
Room: ~13 ft.



Hall: ~54 ft.

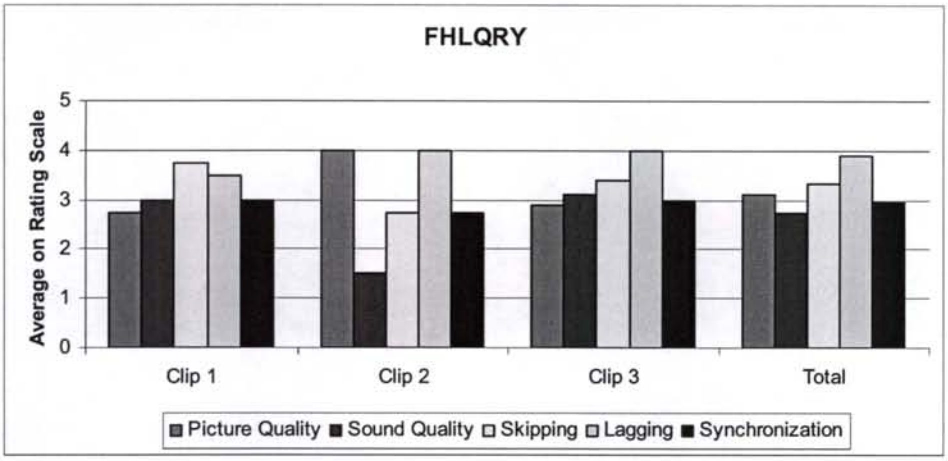


Outside: ~70 ft.

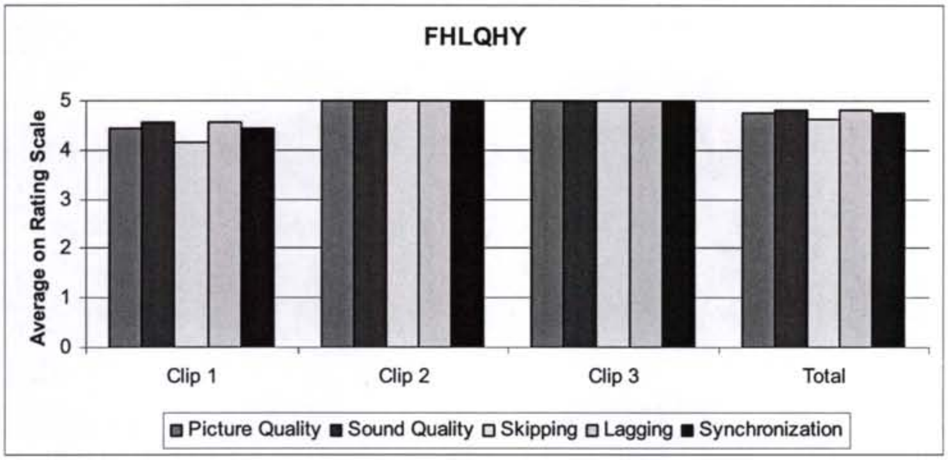


Falling Hare Clip Low Quality with Interference

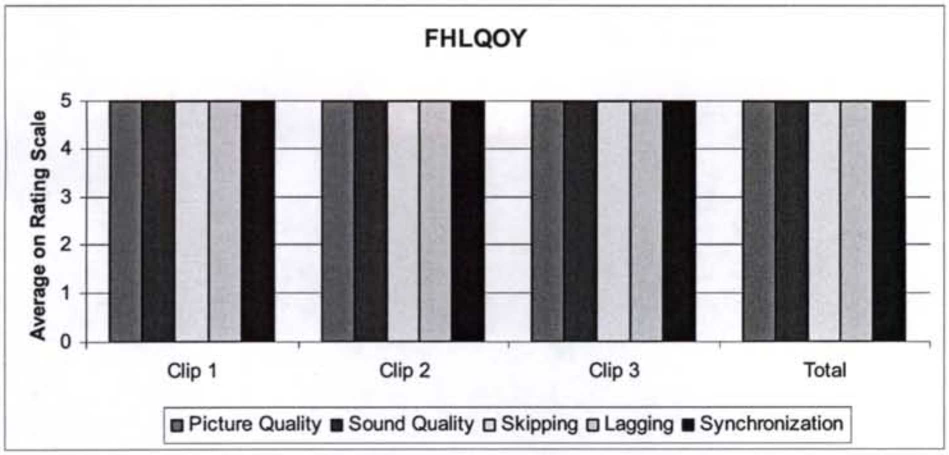
Room: ~13 ft.



Hall: ~54 ft.

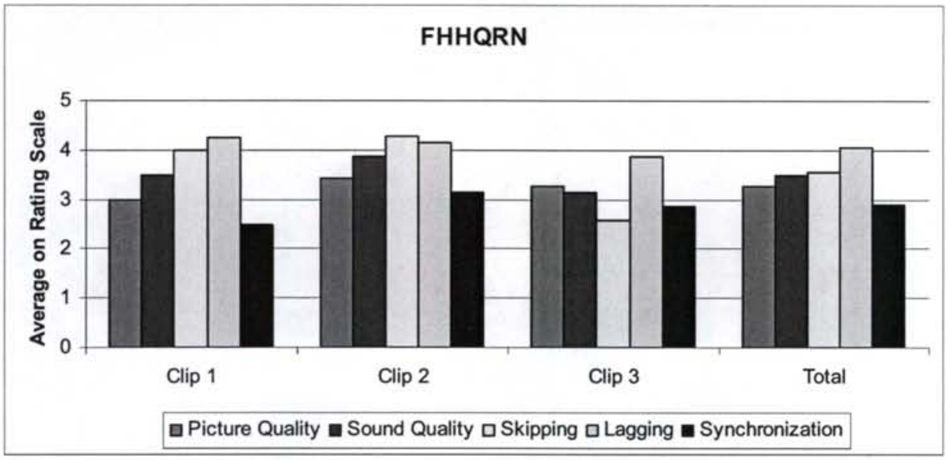


Outside: ~70 ft.

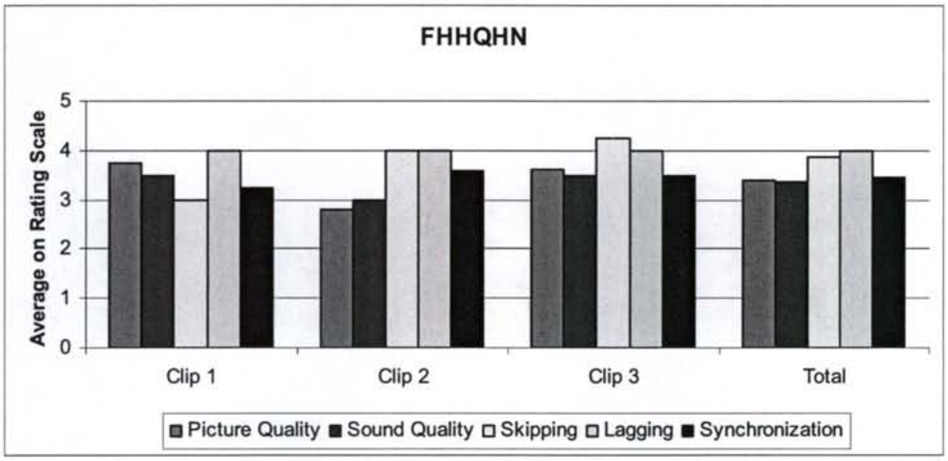


Falling Hare Clip High Quality without Interference

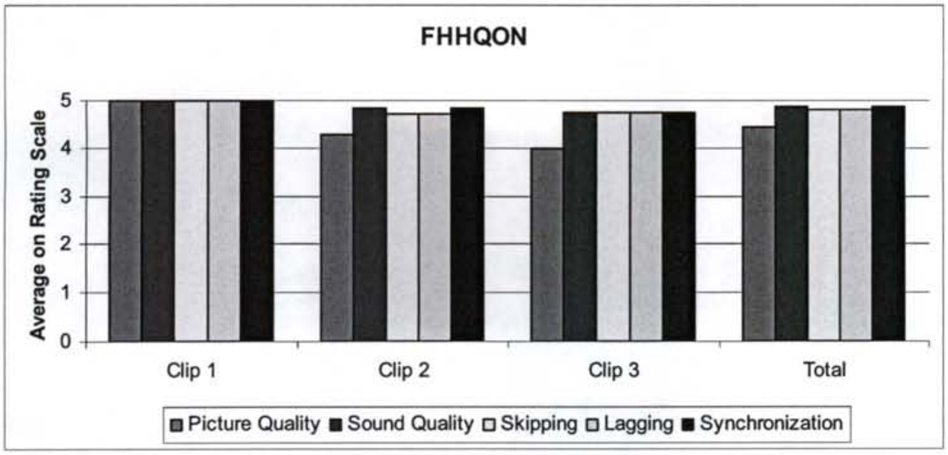
Room: ~13 ft.



Hall: ~54 ft.

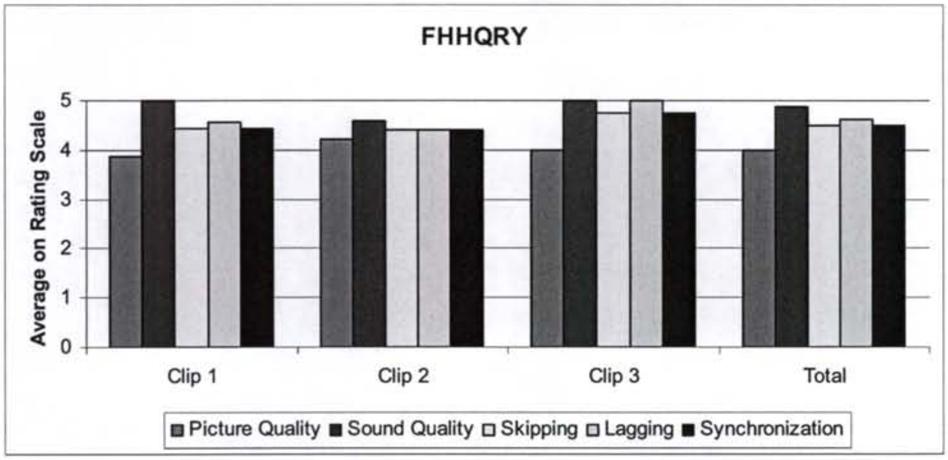


Outside: ~70 ft.

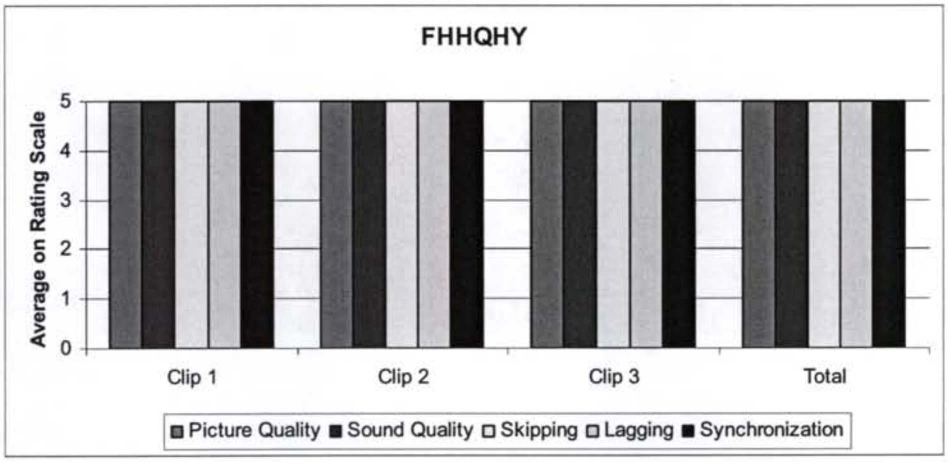


Falling Hare Clip High Quality with Interference

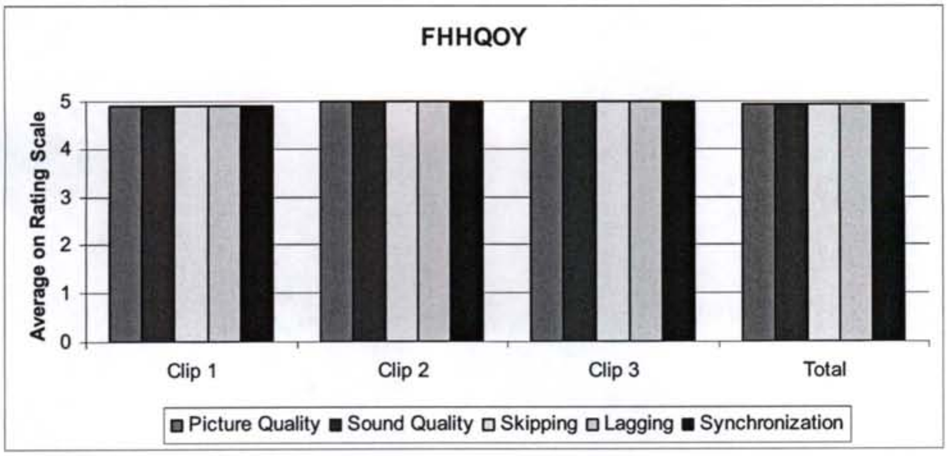
Room: ~13 ft.



Hall: ~54 ft.

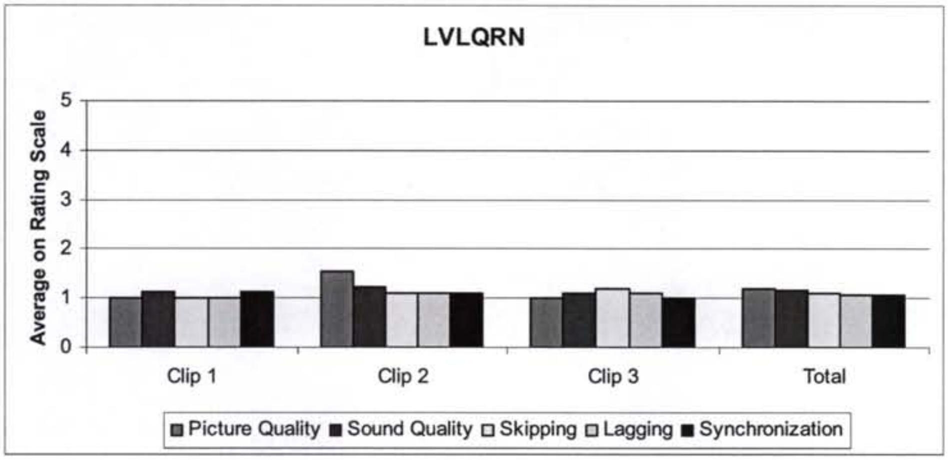


Outside: ~70 ft.

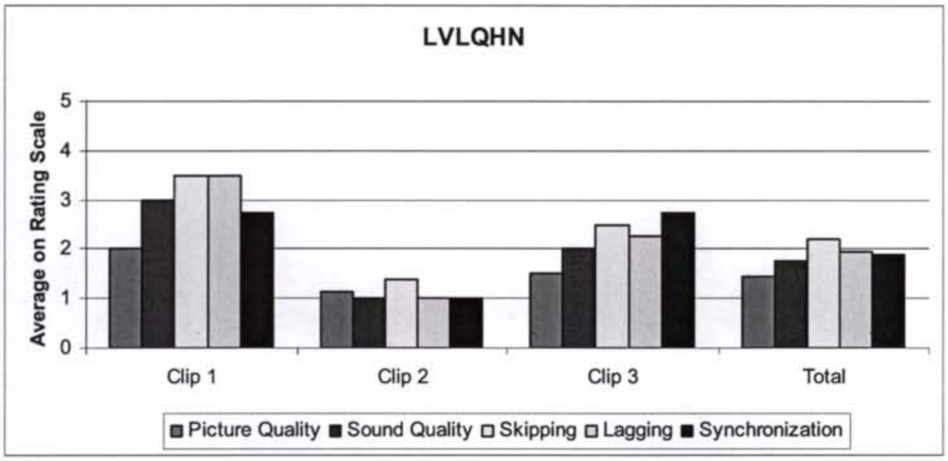


HS Football Clip Low Quality without Interference

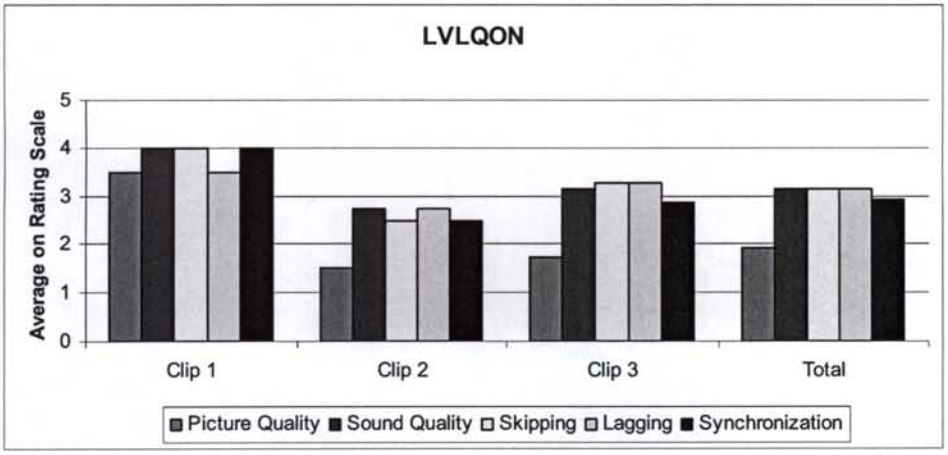
Room: ~13 ft.



Hall: ~54 ft.

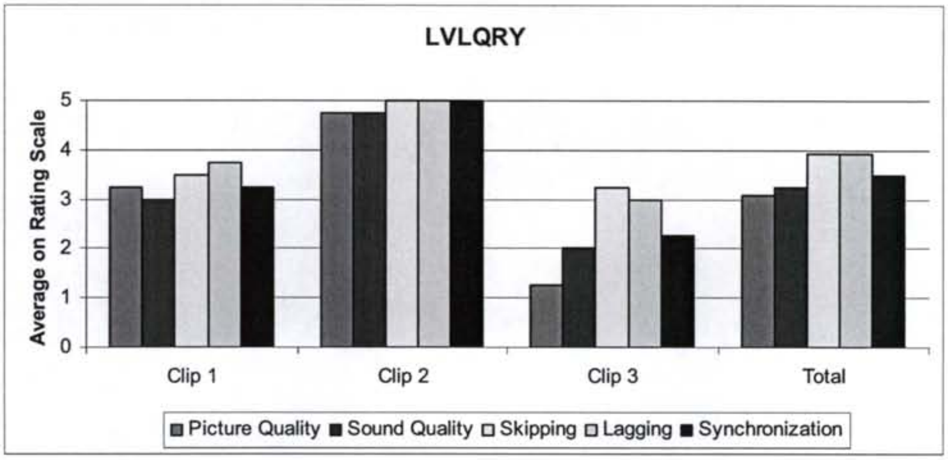


Outside: ~70 ft.

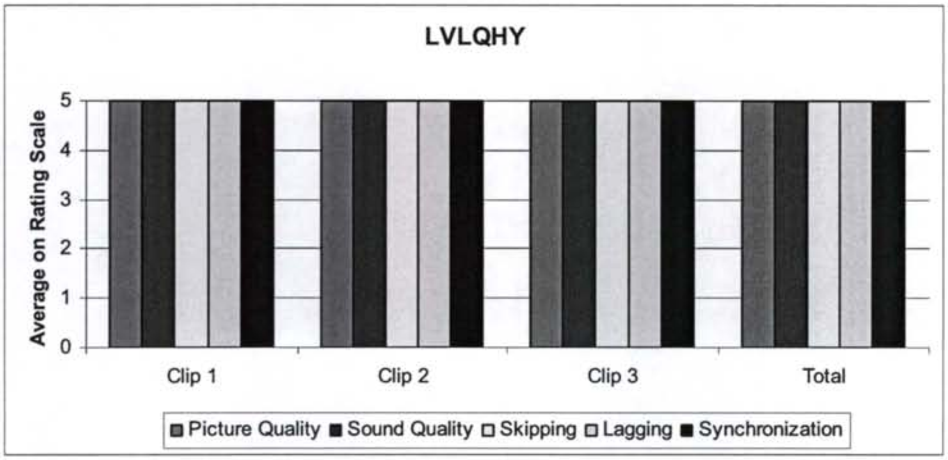


HS Football Clip Low Quality with Interference

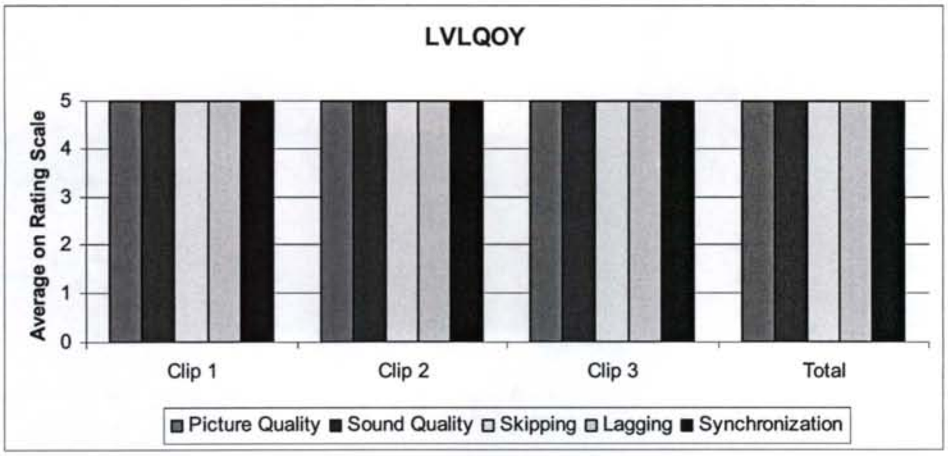
Room: ~13 ft.



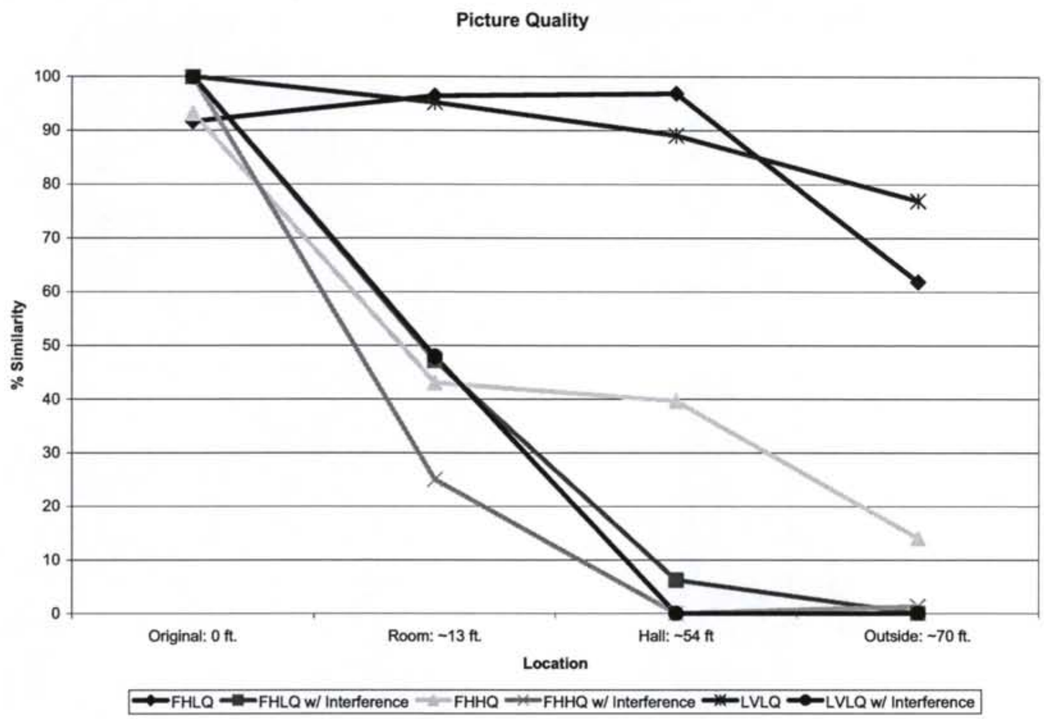
Hall: ~54 ft.

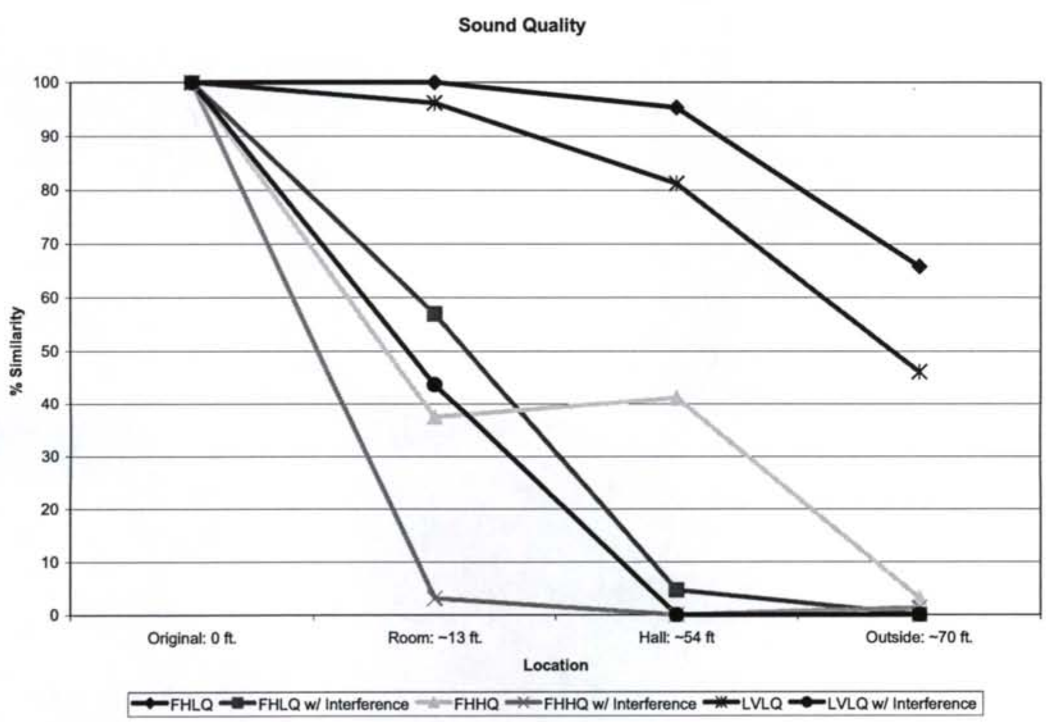


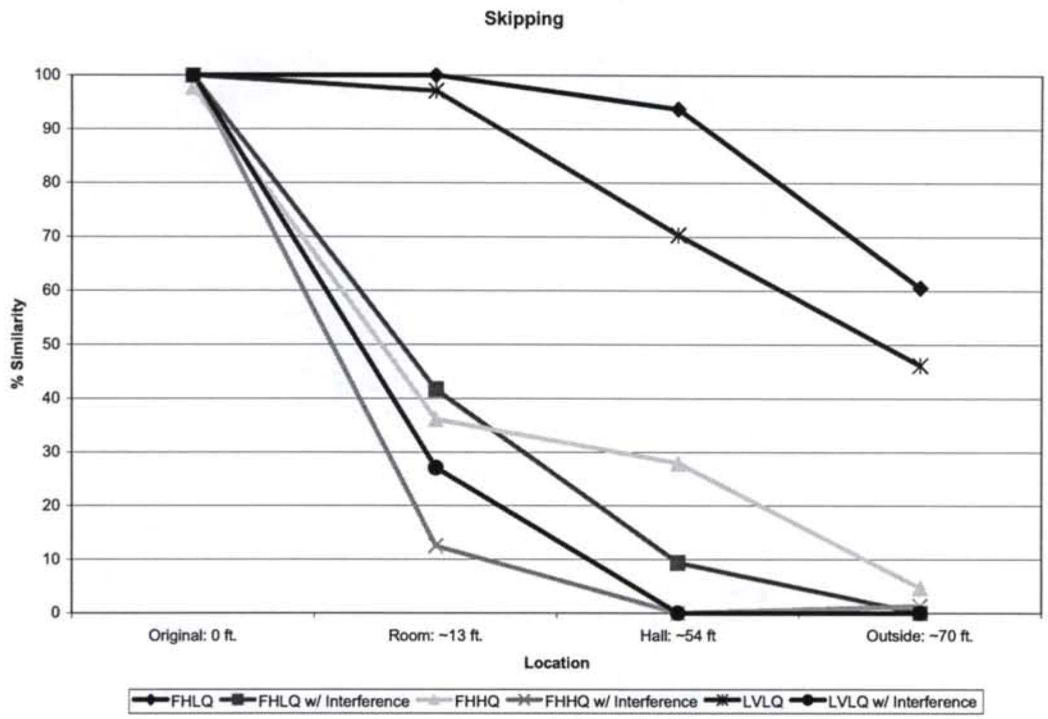
Outside: ~70 ft.

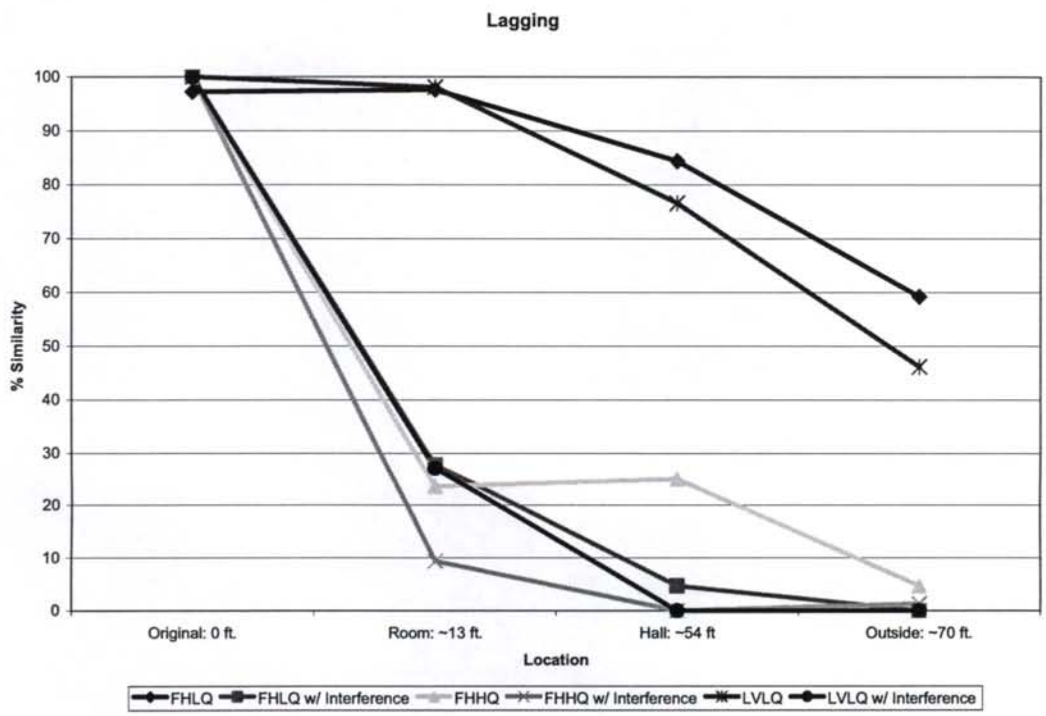


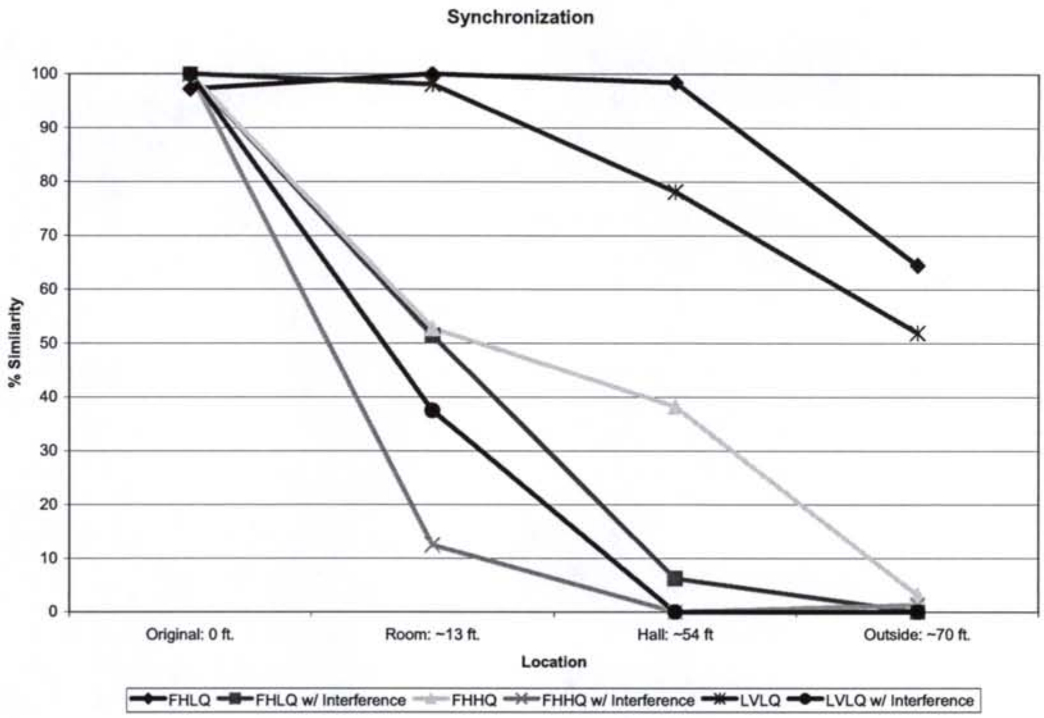
All Video Clips



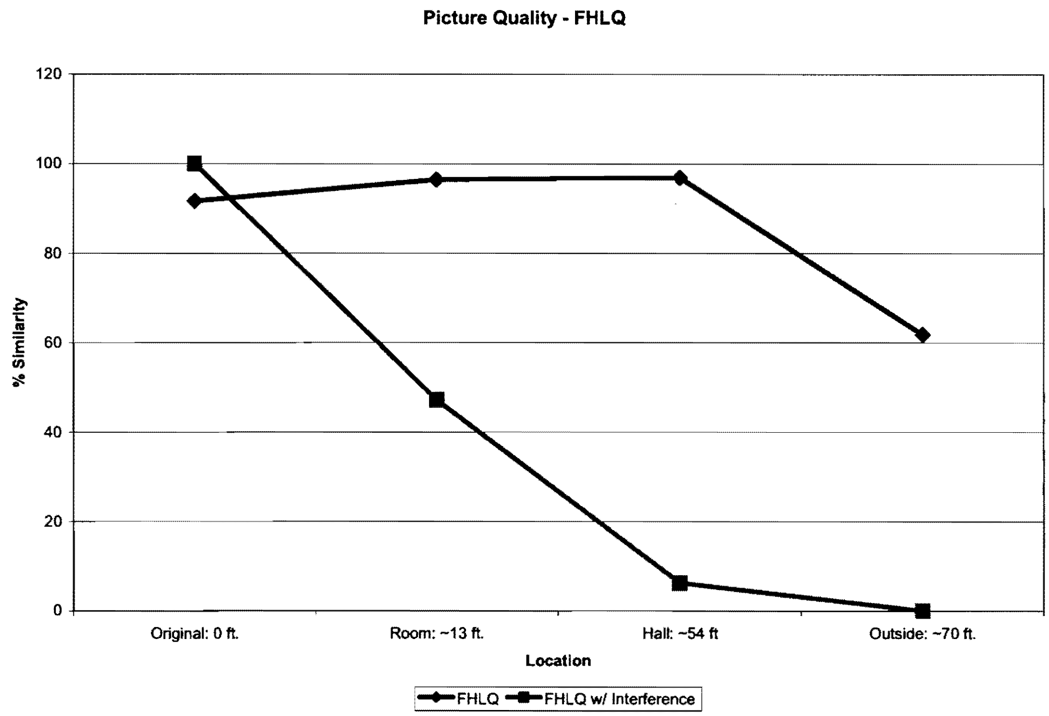


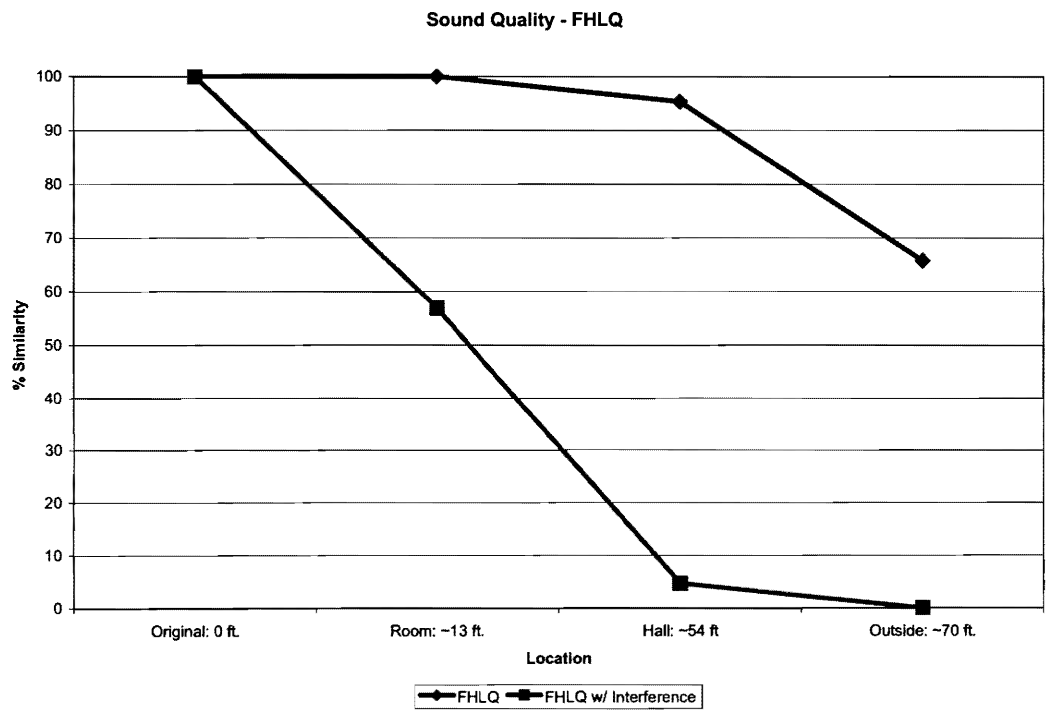

Skipping
100
90
80
70
60
50
40
30
20
10
0
% Similarity
Original: 0 ft.
Room: ~13 ft.
Hall: ~54 ft
Outside: ~70 ft.
Location
FHLQ
FHLQ w/ Interference
FHHQ
FHHQ w/ Interference
LVLQ
LVLQ w/ Interference

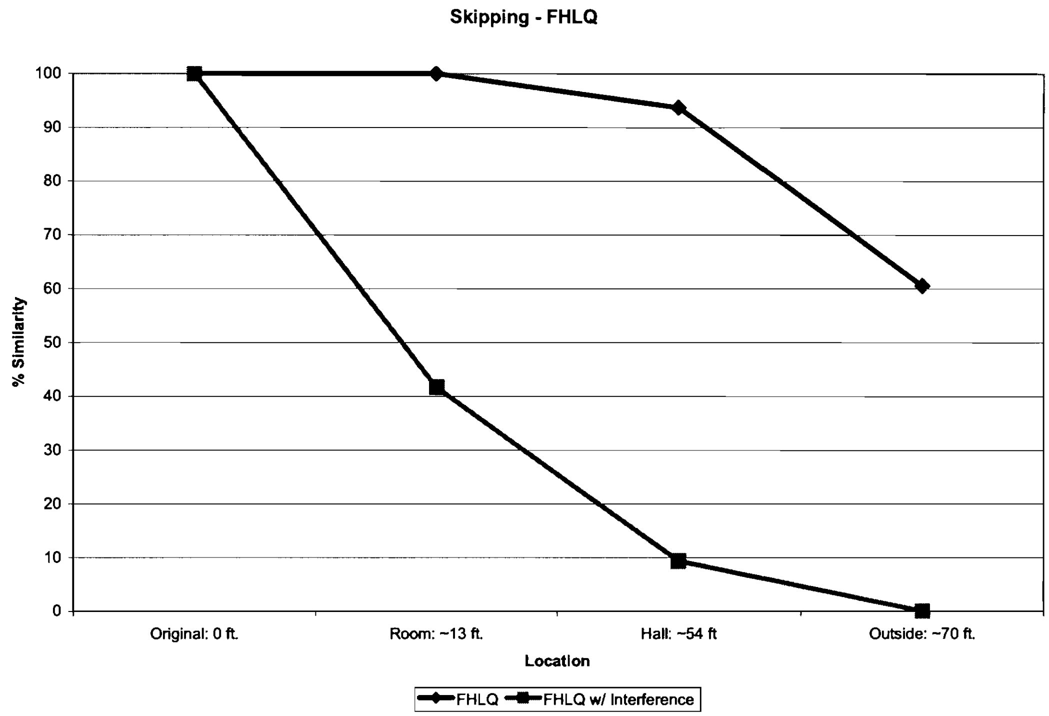

Lagging
100
90
80
70
60
50
40
30
20
10
0
% Similarity
Original: 0 ft.
Room: ~13 ft.
Hall: ~54 ft
Outside: ~70 ft.
Location
FHLQ
FHLQ w/ Interference
FHHQ
FHHQ w/ Interference
LVLQ
LVLQ w/ Interference

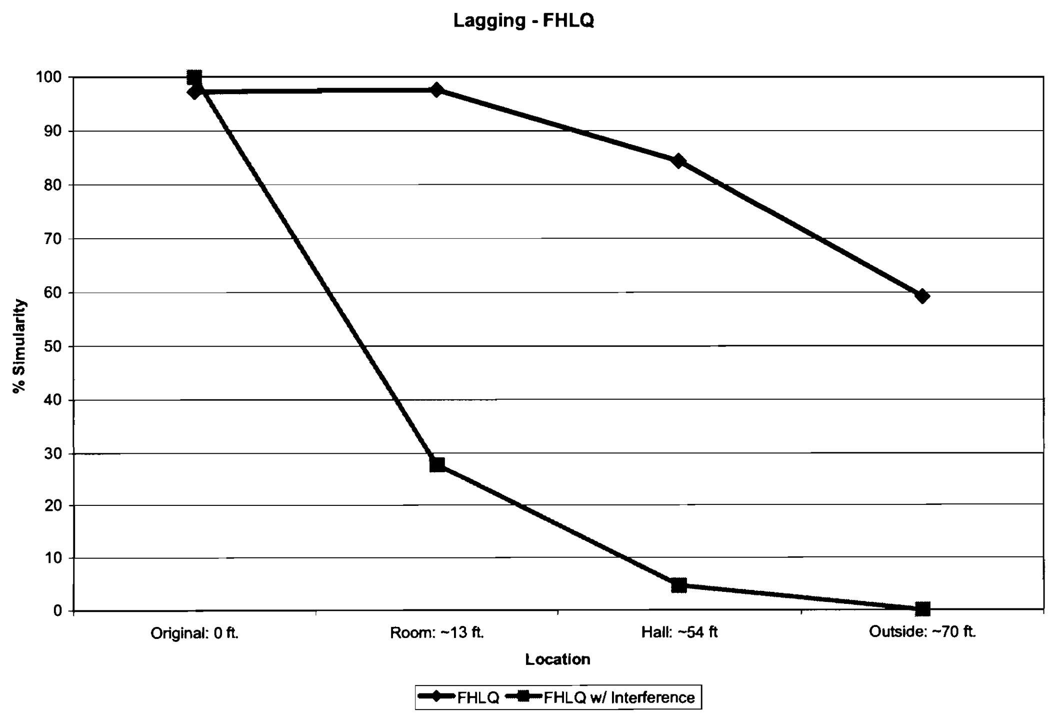

Synchronization
100
90
80
70
60
50
40
30
20
10
0
% Similarity
Original: 0 ft.
Room: ~13 ft.
Hall: ~54 ft
Outside: ~70 ft.
Location
FHLQ
FHLQ w/ Interference
FHHQ
FHHQ w/ Interference
LVLQ
LVLQ w/ Interference

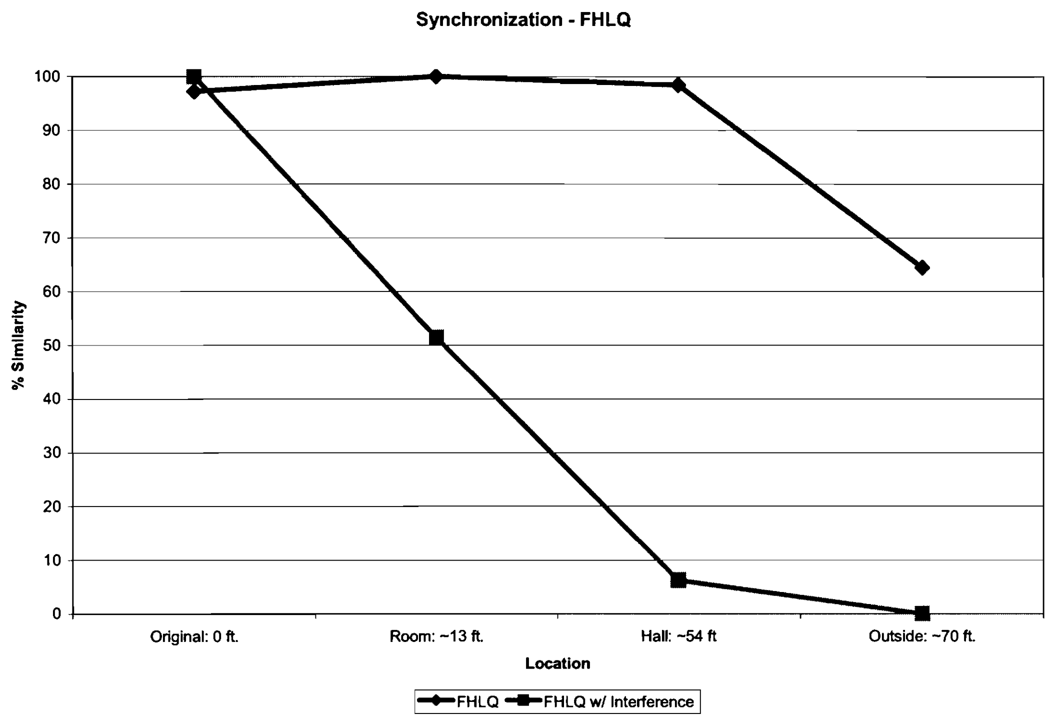
Falling Hare Low Quality Clip



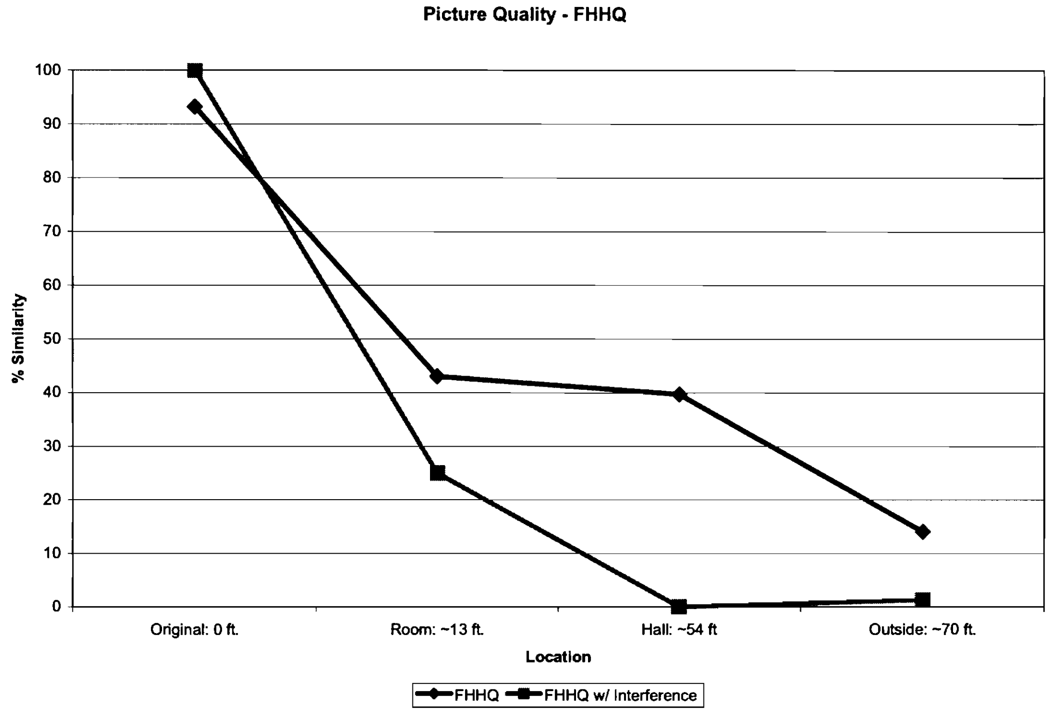


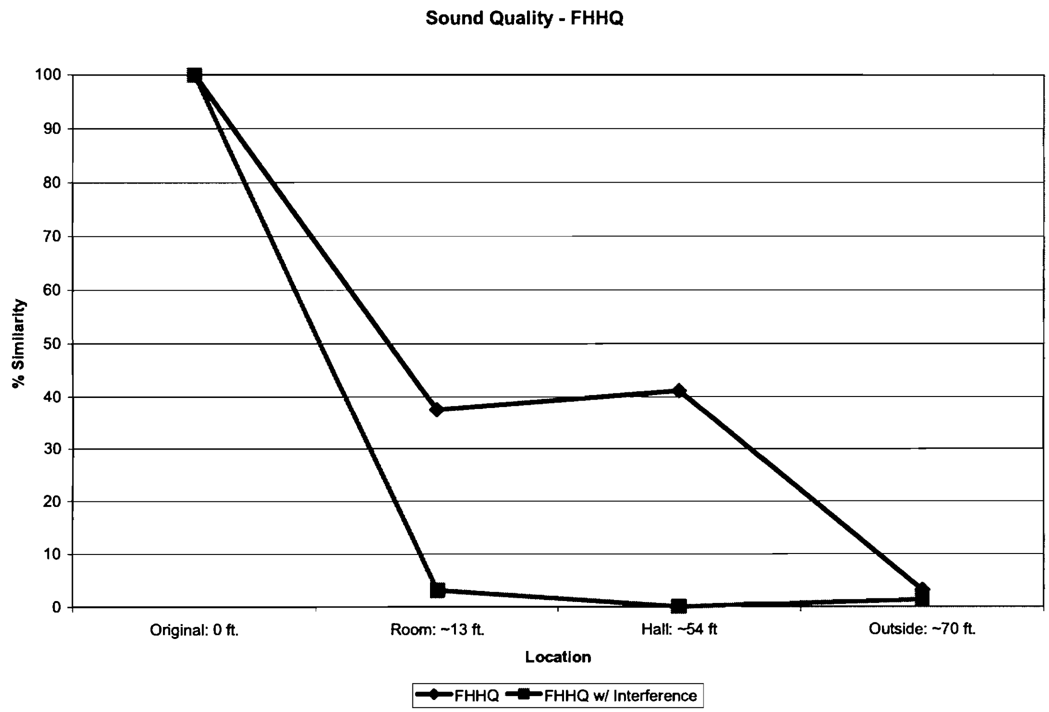

Skipping - FHLQ
% Similarity
100
90
80
70
60
50
40
30
20
10
0
Original: 0 ft.
Room: ~13 ft.
Hall: ~54 ft
Outside: ~70 ft.
Location
FHLQ
FHLQ w/ Interference


Lagging - FHLQ
% Simularity
100
90
80
70
60
50
40
30
20
10
0
Original: 0 ft.
Room: ~13 ft.
Hall: ~54 ft
Outside: ~70 ft.
Location
FHLQ
FHLQ w/ Interference

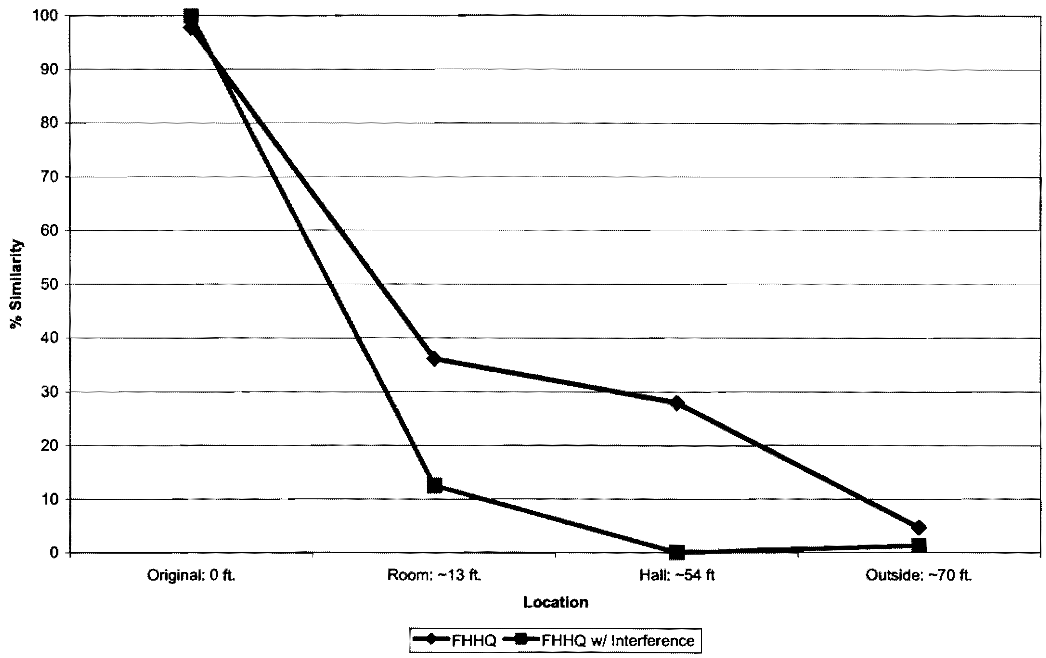

Synchronization - FHLQ
% Similarity
100
90
80
70
60
50
40
30
20
10
0
Original: 0 ft.
Room: ~13 ft.
Hall: ~54 ft
Outside: ~70 ft.
Location
FHLQ
FHLQ w/ Interference

Falling Hare High Quality Clip

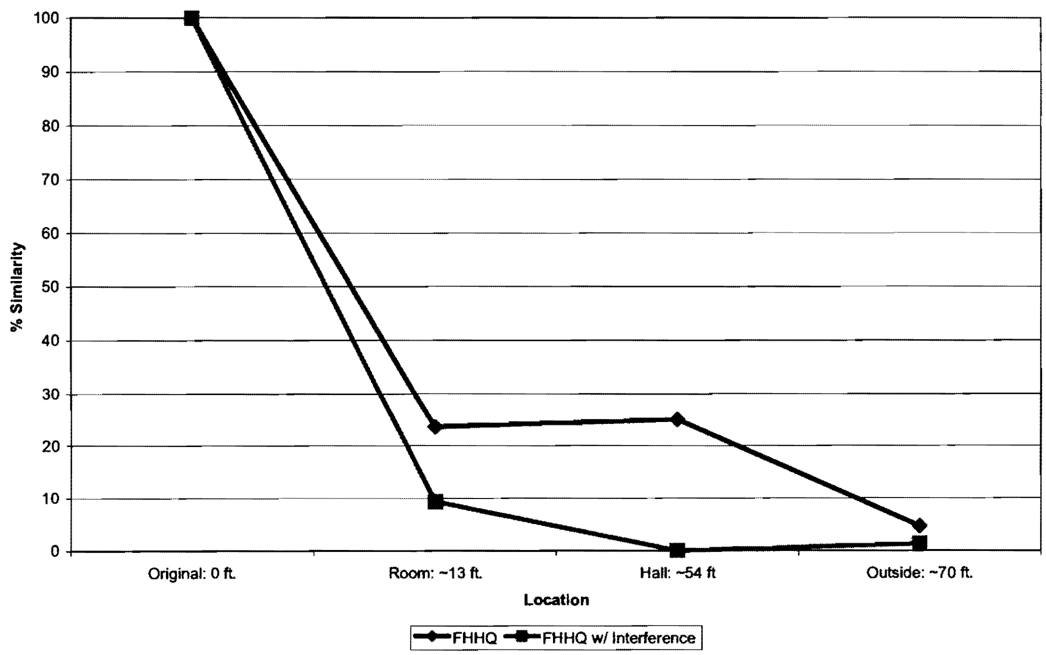


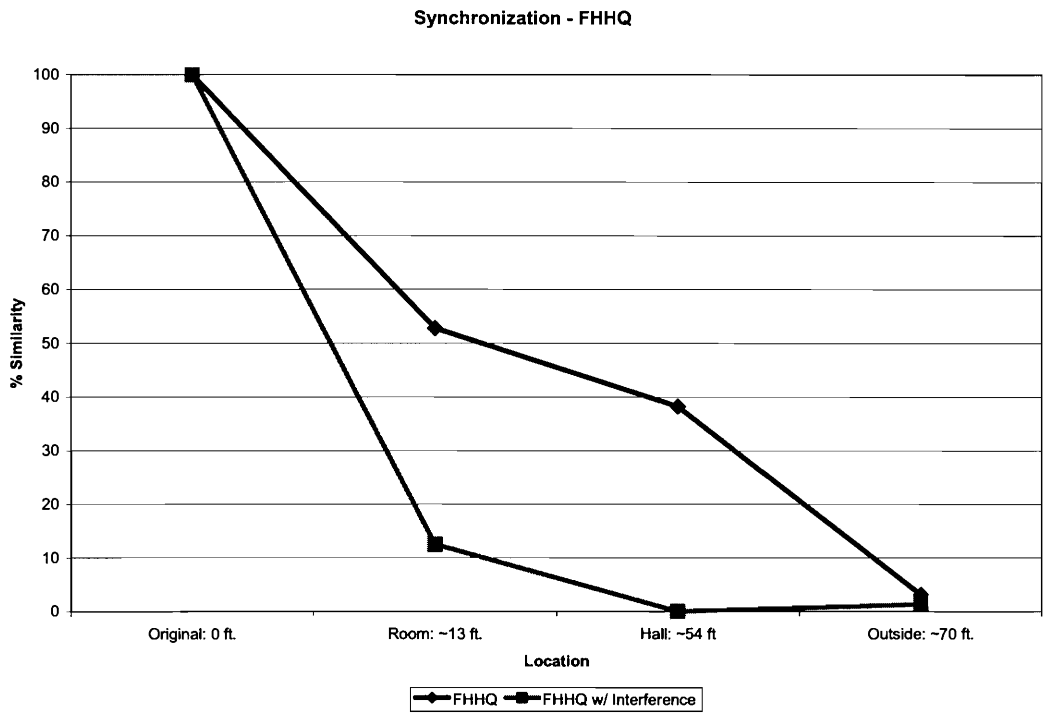


Skipping - FHHQ

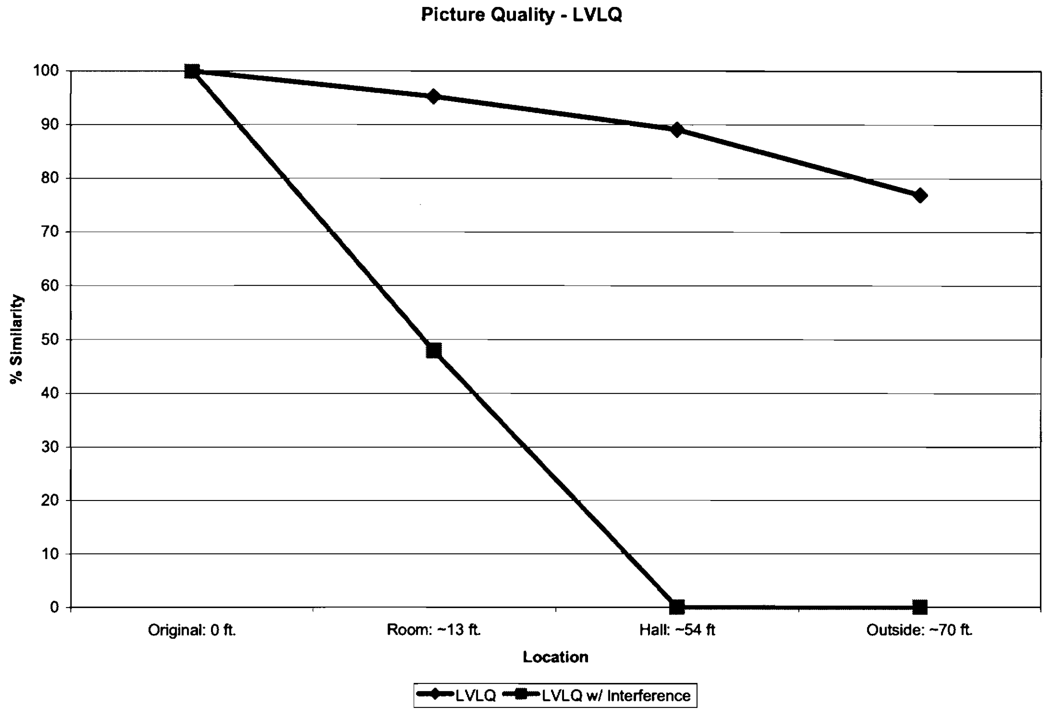


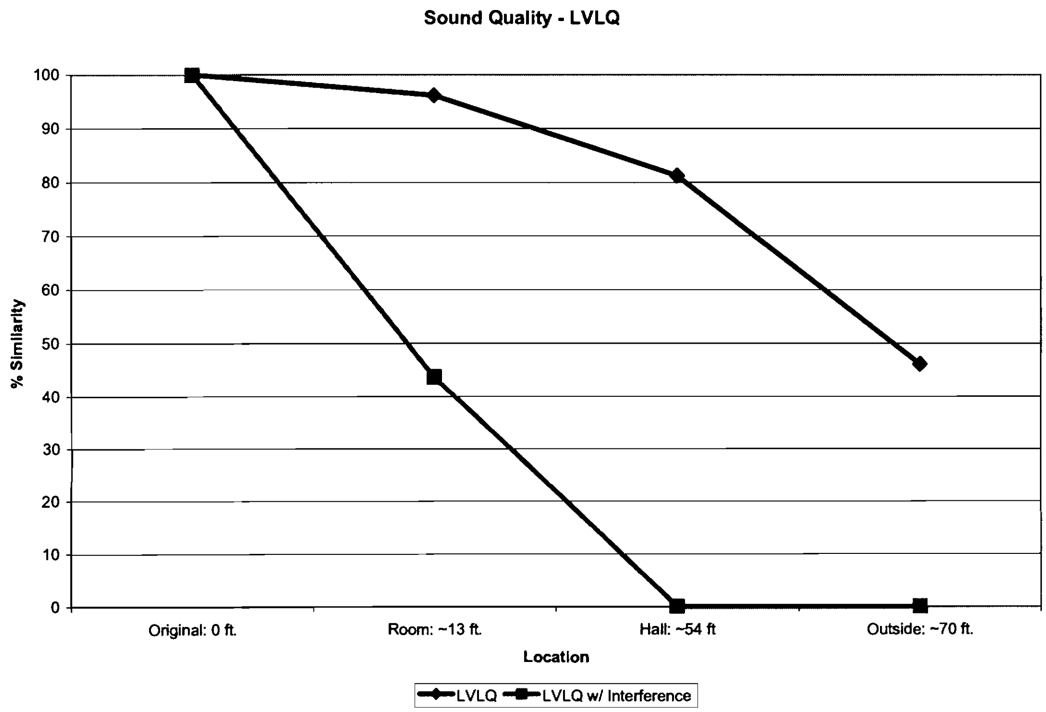
Lagging - FHHQ

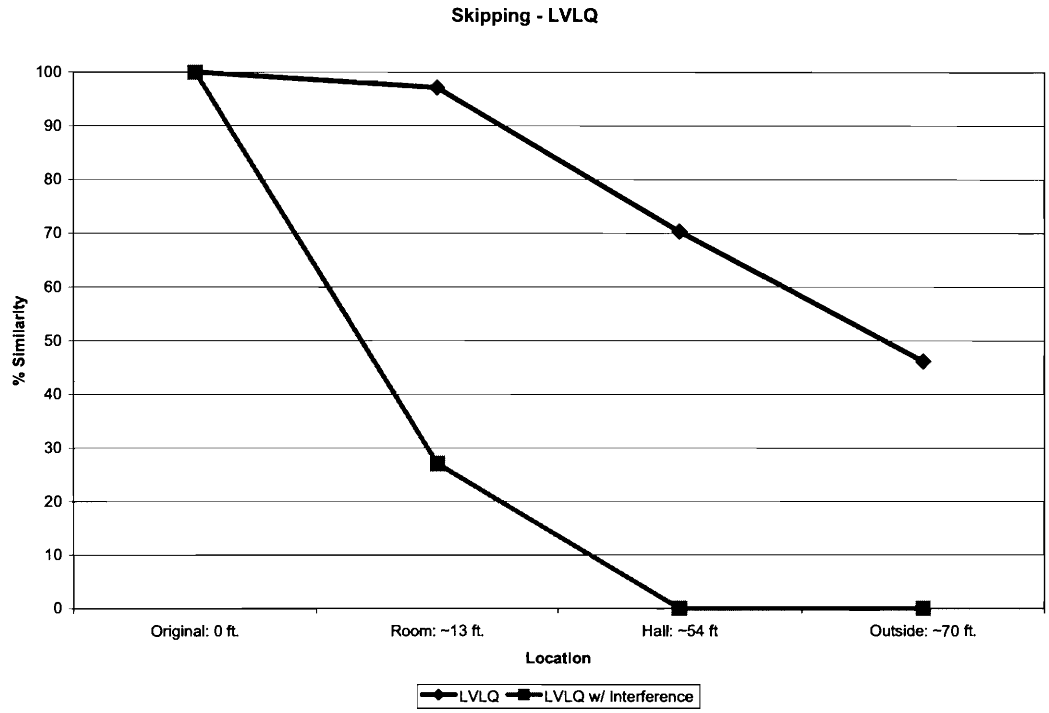


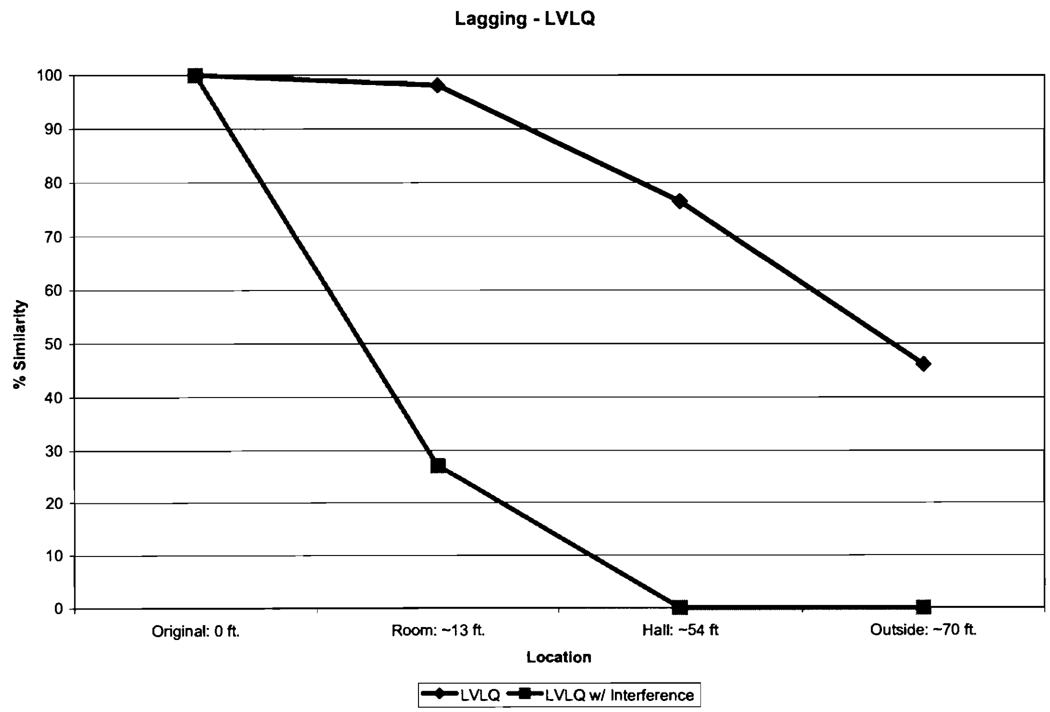

Synchronization - FHHQ
100
90
80
70
60
50
40
30
20
10
0
% Similarity
Original: 0 ft.
Room: ~13 ft.
Hall: ~54 ft
Outside: ~70 ft.
Location
FHHQ
FHHQ w/ Interference

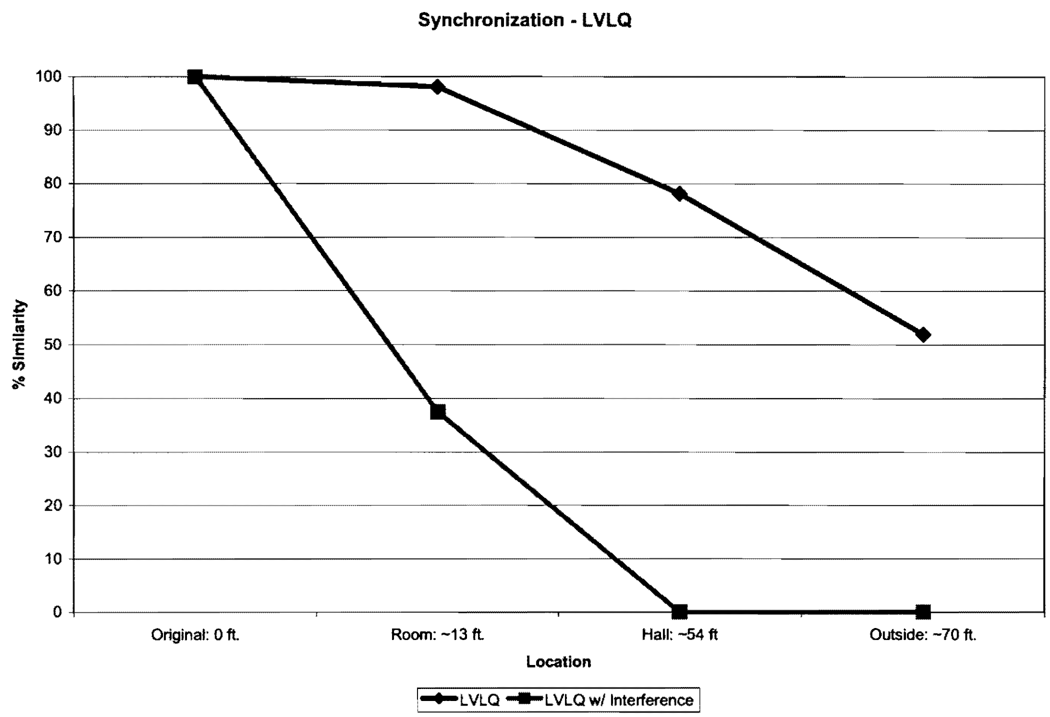
HS Football Low Quality Clip






Skipping - LVLQ
100
90
80
70
60
50
40
30
20
10
0
% Similarity
Original: 0 ft.
Room: ~13 ft.
Hall: ~54 ft
Outside: ~70 ft.
Location
LVLQ
LVLQ w/ Interference


Lagging - LVLQ
100
90
80
70
60
50
40
30
20
10
0
% Similarity
Original: 0 ft.
Room: ~13 ft.
Hall: ~54 ft
Outside: ~70 ft.
Location
LVLQ
LVLQ w/ Interference


Synchronization - LVLQ
100
90
80
70
60
50
40
30
20
10
0
% Similarity
Original: 0 ft.
Room: ~13 ft.
Hall: ~54 ft
Outside: ~70 ft.
Location
LVLQ
LVLQ w/ Interference