AN ANAYLSIS COMPARING BUFFERING VERSUS INTERUPTS ON MOBILE DEVICES

Interactive Qualifying Project Report completed in partial fulfillment
of the Bachelor of Science degree at
Worcester Polytechnic Institute, Worcester, MA

Submitted to:
Professor Mark Claypool

Jared Goldman _____

Yuheng Huo _____

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Mark Claypool _____
Advisor Signature

Abstract

Video streaming is becoming a part of our lives. With the hardware on smartphones getting more and more powerful each day, people can stream videos wherever and whenever they want. While wireless Internet technology is improving download speeds on mobile devices, variety in bandwidth over time can still cause interrupts in play. We hypothesize when people are streaming videos on a mobile device, their reaction toward initial buffering and interrupts is different based on the genres of the video content. Our goal in this project is to determine the preferences for buffering versus interrupts for mobile streaming content through a two phase study. First, we created and sent out survey to students at Worcester Polytechnic Institute. We found people do not expect any interrupts when they stream a one minute video, people expect 1 to 5 seconds buffering time at the beginning of a video streaming session, and music videos and funny videos are two of the most popular genre of video that people like to stream on mobile devices. In phase two, we developed a user study in which we asked participants to watch three sections of a funny video and three sections of a music video that we edited to have artificial buffering in them and recorded their feedback. By analyzing the data, we found people are more sensitive to interrupts when they are watching a music video than a funny video. Comparing our study result with the result of a similar study done on desk tops, people opinions toward buffering and interrupts are similar on both mobile and stationary device. The results of this study will be helpful in improving quality of service for video streaming websites.

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1. Introduction

The world of technology is always evolving. In modern times one is able to access the Internet nearly anywhere. This has led to a growth in video streaming, where one gets video content delivered as it is downloaded. Video streaming has turned into an industry, with Websites such as YouTube and Netflix offering fast high quality streaming services. Yet, streaming is not perfect, and often the content is downloaded slower than it can be played, resulting in the video pausing so it can wait for more content to be downloaded. This can be averted by having an initial pause right at the start that allows for some content to be downloaded. However, unpredictable changes to the Internet download rate, mostly drops in bitrate, can still cause the video to be forced to pause to download more content. A longer initial buffer can be used to reduce the effect of these changes in bandwidth have on playback.

Mobile devices are also growing at a rapid rate. One can access the Internet nearly anywhere, and the most portable tools people have for doing so are cellphones, tablets and other small handheld devices. Often a cell phone is the only device that a person will carry on hand for the entire day. Watching videos on a small device, like a cell phone, is different than doing it to a stationary computer. Technical advancements have led to mobile devices with high resolution screens and fast processors that make streaming video on them seem quite appealing. Yet, the screen of the mobile device is much smaller than a desktop counterpart, and its small screen can affect the user's experience. The fact that the user can hold their video playback device in their hand also changes the experience, since the user has a flexible viewing position. The technical process for streaming on a mobile device is almost identical when compared to a desktop. Video streaming to these small devices are seeing a rise in popularity as people look for convenient ways to consume and share videos.

In recent years there has been a large amount of work on video streaming on both mobile and non-mobile platforms. Video streaming has become a well-studied field. There have been large amount of research in the best way to stream video. Most of the research on video streaming relies on the speculation that all videos are equal regardless of the content when dealing with buffering. Past research has been focused on trying to develop this perfect buffer size, where there are no interrupts in the video no matter what, not on how to make the viewing experience with the current hardware the best possible. The mobile industry has also done a large amount of studies on mobile phones. However there has not been a large amount of work regarding video streaming on exclusively mobile devices. There is even less work done directly comparing the tradeoffs of buffering and interrupts on the mobile platform.

This research is a continuation of Allard and Roskuski's [3] work on streaming, where buffering and interrupts were compared on a stationary platform. The technology has evolved to allow for video streaming on mobile devices. Yet, one is still unable to eliminate the possibility of the stream being interrupted. Therefore, there currently exist a tradeoff between the initial buffer and the amount of interrupts that will occur. This tradeoff exists on both the stationary and mobile platform. This study will compare its results to the work of Allard and Roskuski to discern if there is a difference between watching videos on stationary platform versus watching it on a mobile platform. Another goal of this project is to compare how opinions on initial buffering versus interrupts while streaming videos on a mobile platform is affected by the genre of video watched. The study looked to see what opinions are when presented with different amounts of interrupts to the video that they are viewing.

This study includes a user survey and a comparative study. The survey was sent across campus to gather people's opinions on mobile video streaming. There were fifty-seven responses to the survey. The study had people watch videos of different genres and with different styles of artificial pauses added to them. After each video, participants answered a survey which asked them to rate their viewing experience, video content, and their overall experience. Thirty-one people participated in the study.

Analysis of the data suggests that there is a difference in people's opinions on buffering and interrupts when viewing different content on the mobile platform. It also makes it clear there are differences between streaming on a mobile platform versus a stationary one. The result of this research could be useful to future research in the field of mobile video streaming.

Chapter 2 provides summaries of related work in the field of networking and video streaming. Chapter 3 describes the tools and strategies used in our study. Chapter 4 analyzes the data collected from the study. Chapter 5 concludes the results found by the study, and discusses what can be done in the future to improve and extend this research.

2. Related Work

Online video streaming has contributed to an enormous amount in the Internet traffic. Unsurprisingly, there is plenty of research that studies how buffer size (how long a viewer has to wait for video to load) and interruptions (video pausing in the middle of viewing session) can affect users' quality of experience. In this chapter, the methods and technology used in mobile streaming are provided. Studies that have been done on users' streaming experience related to buffer size and interrupts are also presented.

There are many different ways to deliver video content over the Internet. These options include streaming, progressive download, and adaptive streaming. Most on-demand video streaming websites use streaming technology that is a combination of progressive download and adaptive streaming, to achieve the best quality of experience possible for their users. Progressive download is delivered by a regular HTTP web server, instead of directly sending video data for user to "stream". The data is first downloaded and saved in user's' hard drive, then played from the hard drive. Most video streaming websites also incorporate adaptive streaming technology in which a video is encoded in different qualities and switched adaptively based on users' Internet condition [7]. Adaptive streaming helps reduce the effects of changing bandwidth by switching to lower quality video when the bandwidth drops.

Another technology that plays an important role in video streaming on the Internet is video compression. With the help of compression, the amount of data digital media required is reduced. The degree of compression has an inverse relationship to the storage and transmission requirements for video clips. There are two video compression standards that are commonly used in mobile streaming, H.263 developed by the ITU-T and MPEG-4 developed by ISO [9].

Interruption happens in video streaming when the stream buffer runs out of content to play. This happens when the download speed of video is slower than its playback speed. During the interruption, video will pause until the buffer is downloaded with enough content to resume play again [10]. This is most often caused by a drop in Internet quality. This drop causes the download to no longer be able to keep up with the playback at the quality that the video was streaming at. Initial buffering happens at the beginning of the streaming session, the waiting time for the initial buffer is often related to the buffering size of the video player and user's Internet bandwidth. The buffer size is designed to be just big enough so that if there are no changes in bandwidth the video will not be required to interrupt at all.

Last year's study that was focused on video streaming experience on stationary devices gave inspiration for this study. In their research, Allard and Roskuski[3] had three hypotheses: the first one is, as the buffer size increases, the annoyance level increases slowly at first, but grows exponentially after a certain point. The second hypothesis is that, as the number of interrupts increases, the user's annoyance levels increase logarithmically. The third one is the rate of users annoyance from interrupts is amplified by the level of motion in the video. To perform this study, they used artificially induced interrupts and initial buffering time. They categorized videos based on how much motion the video had in it. They then had one group of people watching videos that only contained interrupts and had the other group watch videos that only contained an initial buffer. They then collected data on how the study groups reacted by giving each group a survey. Eventually, they found out that in the videos with same amount of interrupts, motion is independent from the user's annoyance. They concluded that there is a third degree polynomial relationship between buffer size and user's annoyance level. They also showed there exists a logarithmic relationship between number of interrupts and users'

annoyance. During their user study, Allard and Roskuski accidently found that their participants felt more annoyed when interrupts occurred in the middle of speech. This discovery was an inspiration for this particular study, and it brought up the question that maybe users will react differently to interrupts occurring in videos with different genres of content.

Mok, Ricky KP, et al [5] studied the correlation between the quality of service of network and quality of service of applications. In their research, they set up a server to implement HTTP video streaming over TCP and used a click router to emulate different bandwidth, packet loss and round trip time. They used a set of application performance matrices to study the application's quality of service and a passive measurement technique to measure network's quality of service. They also did a subjective survey test to evaluate users' quality of experience. The result of the study represents, that on the network phase, throughputs are lowered by round trip time and packet loss, thus increasing video streaming interrupts, and on the application phase, the number of interrupts in streamed video has major influence on a user's quality of experience.

Despite the fact that the research projects above were all done on a stationary platform, their works still provides inspiration for mobile platforms. The research highlights that, due to the unpredictable nature of data transfer over the Internet, it is important for the study to artificially induce buffering and interrupts to videos. Unlike in the previous research, mobile devices are always streaming video in a wireless environment, which makes it hard to directly manipulate round trip time and packet loss in order to change number of interrupts.

Nowadays, people who want to stream video on their mobile device have two choices, one is streaming videos in a browser, and the other is watch the video from a variety of

applications. During the research, we found a study done on quality of experience of YouTube application on mobile devices.

Wamser, Florian, et al. [10] developed an application that runs on the android platform and can be used to passively monitor the performance of HTTP based streaming applications. Their application could measure network throughput, resolution of the video, interruption times, and length of the video on the client side. The authors used their application to conduct a subjective test to analyze the YouTube application's quality of experience on mobile devices. In the study, they let their subjects watch different YouTube videos under three different controlled bandwidths. The results show that because the interruption event rarely happened during the test, interruptions are considered not disturbing. In addition to that, they did not find that the changes in resolution, because of YouTube's adaptive streaming techniques, had any impact on user's rating for quality of experience.

The research above shows a prominent method that one can use to study the quality of experience of streaming applications on mobile devices. However, for this study, instead of finding the quality of experience of a certain application, we are trying find the impact on users' opinions when they encounter differing amounts of interrupts and buffer sizes in video streaming. It will require that the test videos to be longer in duration than in the previous research, and to be higher quality to collect enough data to show the impact of interrupts and buffer size in this study.

3. Method

To complete this project's intended goals, two separate stages were required. The first stage was a survey on video streaming. This survey provided information on how people use their mobile device when streaming video. Information gained from the survey was also used to fine tune the second stage of the project. The second stage involved having people watch six sections of videos on a mobile device and provide insight on how their viewing experience was affected by the stalling times they encountered during video playback.

The first stage called for the creation of a survey that would be distributed amongst the students at WPI. A total of fifty-seven different responses to the survey were recorded. The purpose of this survey was to gather knowledge on the video streaming habits of the population. Questions for the survey were written in a way to provide informed data would for the rest of the project. The survey was created with the using Qualtrics software and included two sections. The first section asked the participant about basic demographic information. This included gender, age and current major. The second section contained twelve multiple choice questions that determined important knowledge about participants' streaming habits. These questions included things like, what genre of video do you like watching on mobile devices and how long do you expect a one minute video to buffer before it begins to play. These surveys were then sent out through the use of the WPI mailing lists. The full survey can be seen in appendix. Participants were able to access and answer the survey from any device that had the ability to connect to the Internet. The survey remained open and available for people to answer for a period of two weeks. After the survey was closed basic analysis was done so that the second

stage of the project could begin. According to the survey, the two most popular video genres were funny videos and music videos.

The second stage consisted of the major part of this project. First, we needed to find videos that represented different genres of content. The genres of the video were chosen based on the results of the survey from the first stage. The two most popular genres, funny videos and music videos, were selected for the study. A video from each genre was selected, making sure to avoid any content that could be deemed offensive. The funny video chosen was the East/West Bowl sketch from the popular television show Key and Peele. The music video chosen was the hard rock classic Highway to Hell by AC/DC. We found and downloaded these videos from YouTube, which based the survey conducted is the most popular streaming website for streaming video onto mobile device.

The chosen videos had to be edited so they could serve the purposes of the project. First each video was divided into three sections. These sections were chosen by finding the most natural breaking point in the video, while still keeping each section roughly a third of the entire videos length. Artificial buffers and interrupts were added into the video. This was done by adding pauses to the video, along with adding a "loading wheel" to the paused sections. Each video section had about ten percent of additional stalling time added to it. Ten percent was chosen so that the buffering patterns would be noticeable, but not too overbearing. These stalls were added into each section in one of three different patterns. These patterns included, initial buffer only, interrupts only and a combination of the two. These buffer patterns were implemented to each section in the video, so that each video had one of each pattern across it sections. The video was then edited a second time, with different buffer patterns being applied to

the sections. In the end, we had two different versions of each section with different buffer pattern.

The study was conducted at the Rubin Campus Center Building. This was a busy area, however that is not an uncommon environment for mobile video watchers. A second survey was created, using Qualtrics, so that data could be gathered during the study. The full survey for the study can be seen in the appendix. The team signed out a table for a week and asked the passing students to participate in the study. Passersby were asked if they had fifteen minutes to spend on a quick study. When participants agreed to participate in the study, they would be directed towards one of the two separate administrators of the study. They were then read a prepared script that detailed what the study was about and what was required of them. A copy of the script is available in the appendix. The participant would first sign an informed consent form and answer some demographic questions, including gender, age and major. Participants were then given a pair of headphone and one of two different android based smartphones. Phone 1 was a Motorola Moto G (5 inch screen, 1280 by 720 pixels) and phone 2 was a Samsung Galaxy GT (4in screen 800 by 480 pixels). Each smartphone had different versions of the edited videos. The administrator would load up the video section before handing the phone to the participant. The participant would watch the video sections and then hand the phone back to the administrator. Each participant would watch a total of six video sections, three from the first video and three from the second video. They would then be asked to answer the survey, which asked the participants to rate the section. The section was rated on viewing experience (how they felt about the pauses that had been added to the video), content and overall quality. While the participants were answering questions the administrator would load the next section of the video. After all the sections of the first video were finished, the participants were then asked to

rate each section in order of preference. It also asked the participant had already seen this video. This process was then repeated for the second video. After both videos had been played the participant was asked some additional questions that compared the two videos against each other. The data for this study was then compiled and analyzed.

4 Result and Analysis

The data and results of the study are analyzed in this section. The study consisted of two parts, which were the “survey study” and the “main study”. Although the result of the survey were used as a guide to design the main study, the survey and the main study are independent, as the people who participated in the survey study might not have been participants in the main study. Therefore, the result of the survey and the study were analyzed separately.

4.1 Survey Study Result

For the survey study, we received total 57 responses, and we considered 46 of them are valid response. The discarded response are because the participants either did not finish the survey or did not give valid response.

4.1.1 Demographic

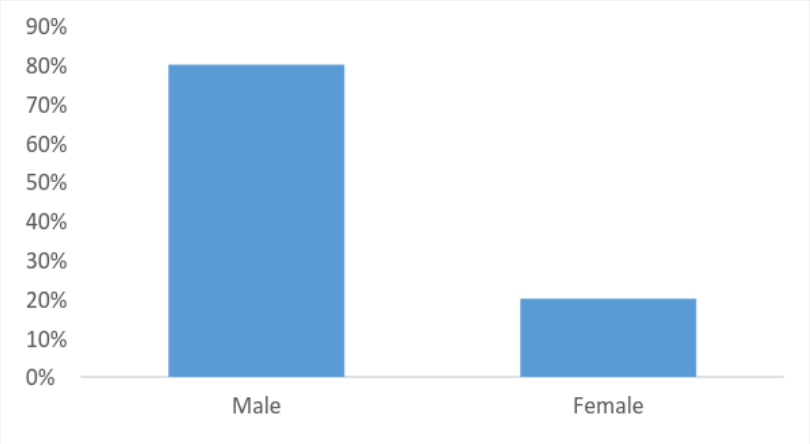

Figure 1a: Gender Distribution (survey)

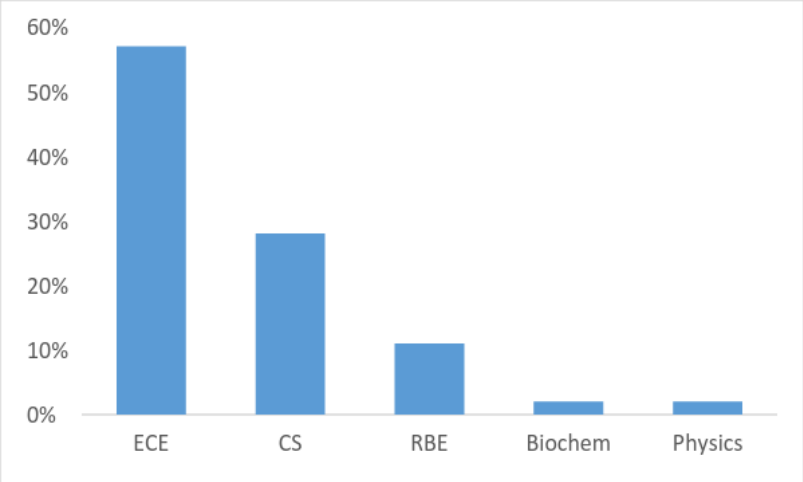

Figure 1b: Major Distribution (survey)

Figure 1a shows a comparison of gender against percent of responses. Gender is on the x axis, while percent of people is shown on the y axis. The ratio between male and female of the valid participants is 4:1.

Figure 1b shows the distribution of participants' major. The x-axis is the major category, and y-axis shows the percentage of people. The survey link was sent through WPI mailing lists with only ECE and CS majors. Hence, most of our participants are WPI students who major in those fields. It is reasonable for our survey to have an extremely unbalanced male to female ratio, considering the dominant gender of those two majors is male and the dominant gender of the school is male.

4.1.2 Survey Response Analysis

In this section, the results of the vital questions in the survey are displayed. These results are important and set guidelines for the main study. These questions show the popularity ranking of different video genres chosen by participants, and the behaviors and expectations of participants when they streaming video on mobile devices.

In the survey, the participants were asked to choose multiple genres of the video they like to stream on a mobile device. Figure 2a demonstrate the results, where the y-axis shows the name of the genre, and the x-axis shows the percentage of participants choosing that genre:

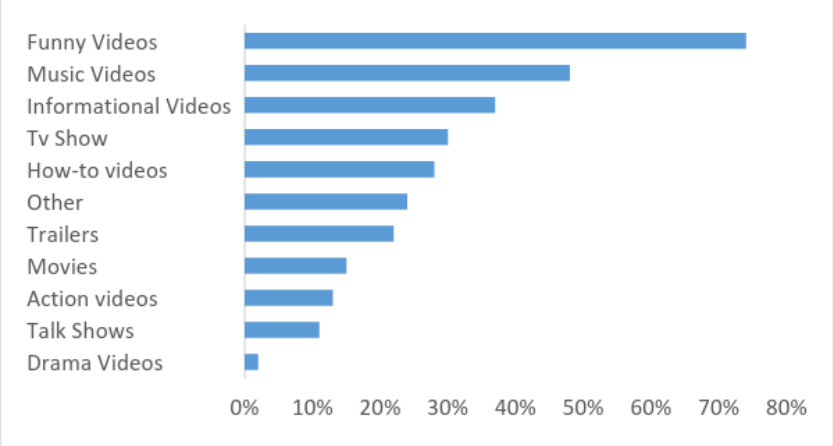

Figure 2a: Most Popular Genre Ranking (survey)

The genres represented in Figure 2a were chosen from a list of the most popular categories for video content from YouTube and Netflix. According to the figure, funny videos is the most popular response, and 74% of the study population chose this as one of their favorite genre. 48% of participants chose music videos which makes it the second most popular

category. Most of participants who chose the “Other” category on the ranking list wrote gaming related content, which should have been a category in the ranking list.

Figure 2b demonstrates what the participants’ expectations were on how many interrupts a video would have when watching a one minute video. The x-axis of the figure shows the options of the number of times of interrupt participants expect in a one minute video, and the y-axis shows the percentage of people choosing that option. Figure 2b shows that 61% of the participants answered they do not expect any interrupts in a one minute video. Only 37% of participants think there should be 1-2 interrupts, and 2% participants say they expect 3-5 interrupts.

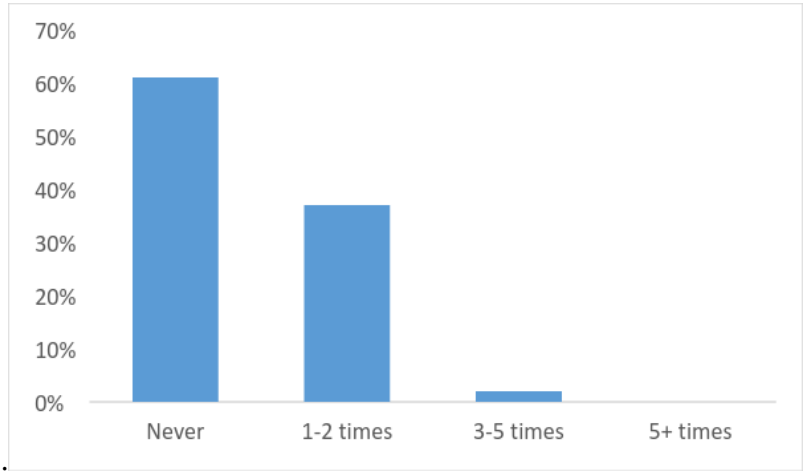

Figure 2b: Distribution of the expectation of interrupt times in a one minute video

The survey also showed what the participants’ expectations on the length of the initial buffer at the start of the video. Figure 2c shows the results of this question. The x-axis shows the options how many seconds of buffering time is expected at the beginning of the video, and the y-axis shows the percentage of people choosing that option.

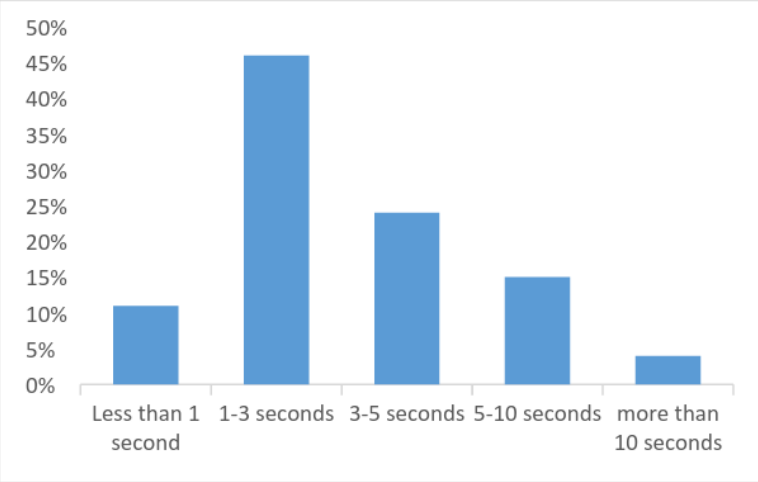

Figure 2c: Distribution of the expectation of initial buffering time

According to Figure 2c, 70% of the participants expect 1-5 seconds of initial buffering time, in which 46% of the participants expect 1-3 seconds and 24% of participants expect 3-5 seconds. There are about 2% of participants who expected more than 10 seconds of initial buffering time, which makes that the least expected buffering time. The result of this question shows that majority of people expect a noticeable initial buffering time in an interval of 1-5 seconds, and only a small portion of the participants will assume it is normal to wait more than 10 seconds for a video start.

Last but not least, the study identifies the main source for streaming videos on a mobile device, and the results are shown in Figure 2d. The x-axis in this figure shows different options of video streaming website, and the y-axis shows the percentage of people selecting that option.

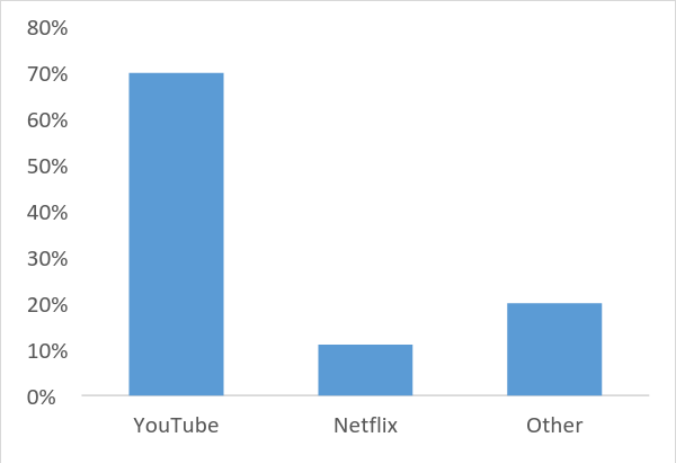

Figure 2d: Distribution of the main streaming source on mobile device

Around 70% of our participants chose YouTube as the main streaming source on mobile device, while only 10% of our participants chose Netflix. Most people who selected "Other" wrote they like to stream video on Twitch.tv, which is a live streaming video platform that focuses on video game streaming. It appears that YouTube as a free streaming Website, which contains far more variety of video contents than a pay to access Netflix does, is the most popular choice when people stream video on mobile devices. The decision to choose video sources from YouTube is made due to this result of this survey question.

Based on survey results we decided to use funny video and music video, not only because they are the top 2 most popular video genres, but also in funny videos people tend to focus more on the visual content, while in the music video people tend to focus more on the audio content.

4.2 Main Study Results

We had a total 37 WPI students participate in our study. Four of them attended the pilot study, and their result were dropped at the beginning of the main study. Two additional results were removed from the listing due to an error in the data collection. Only 31 results were considered valid for analysis.

4.2.1 Demographic

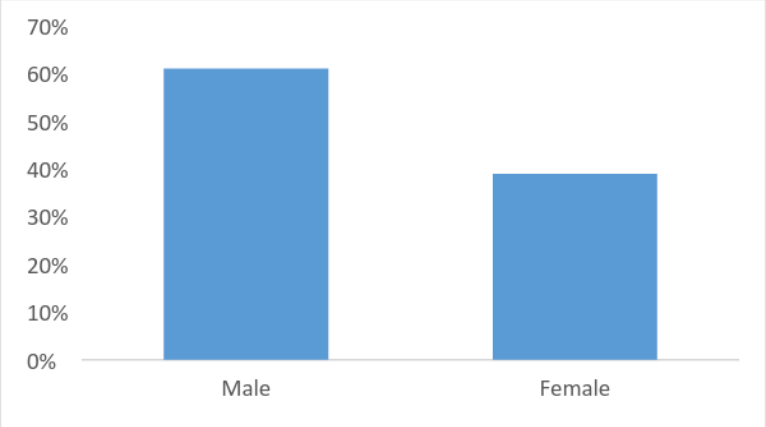

Figure 3a: Gender Distribution (study)

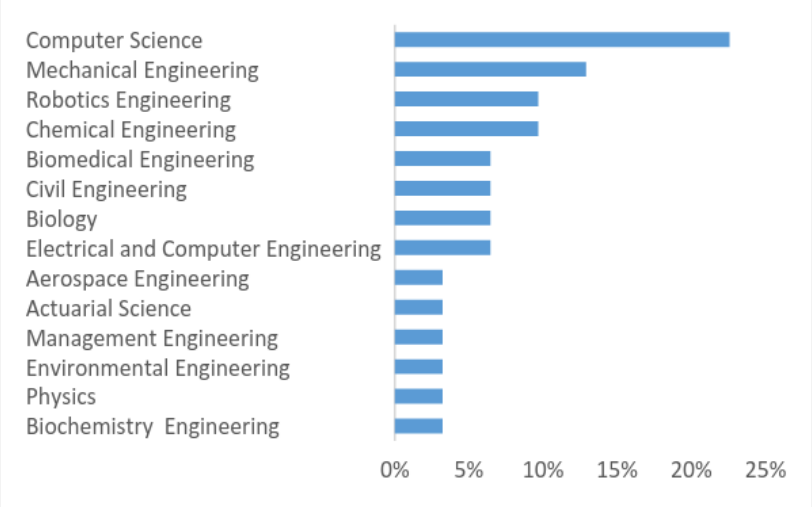

Figure 3b: Major Distribution (study)

In Figure 3a, the x-axis shows the gender categories, which contains male and female, and the y-axis shows the percentage. As Figure 3a displays, 61% of participants are male, and 39% are female. There were zero responses for the third category of "Other".

In Figure 3b, the x-axis shows the percentages of the participants who study in the major, and y-axis shows majors. According to the Figure, the top 2 majors are Computer Science, which is 23%, and Mechanical Engineering, which is 13%.

Because the study was held in the Rubin Campus Center, which is one of the most popular building in WPI for students, the study population was more diverse than the survey study. The gender distribution is close to the overall WPI gender distribution, which according to WPI Factbook 2015 is 67% male and 33% female.

4.2.2 Video Content and Buffering Pattern

Two videos were chosen for this study. Video 1 was a music video, featuring the AC/DC song “Highway To Hell” (https://www.youtube.com/watch?v=l482T0yNkeo). Video 2 was the East/West Bowl sketch from the TV show Key and Peele (https://www.youtube.com/watch?v=gODZzSOelss), which is considered a funny video. The genres of the videos were chosen from the result of “most popular video genre people stream on their mobile device” question from the survey study. The videos were each edited into three different sections, and each section was shown as an individual video to the participants. The duration of each section ranges from 1 minute to 1 minute 40 seconds. The video sections were designed and edited with three different video buffering patterns, which includes initial buffering only, interrupts only, and the combination of both initial buffering and interrupts. Each section was edited to be 10% longer, with the newly added time being stalls to the video playback. In the video sections with initial buffering only, all the time stalled occurred at the beginning of the video section. In the video with interrupts only, stalls were inserted in the middle of the video content, each 1 second long. The video with combination of both initial buffering and interrupts had half of the stalls at the initial buffering screen, and half the stalls as randomly occurring 1 second interrupts during the content of the video. Each section of video has two versions, both versions have the same video content, but different buffering pattern. Different versions of the videos were uploaded to different phones. The table below displays the relation between video sections and buffering pattern on each phone:

	Music Video			Funny Video		
	Section 1	Section 2	Section 3	Section 1	Section 2	Section 3
Moto G (Phone1)	Initial buffering only	Combine	Interrupts only	Combine	Initial buffering only	Interrupts only
Samsung Galaxy GT (Phone 2)	Interrupts only	Initial buffering only	Combine	Interrupts only	Combine	Initial buffering only

Table 1: Video content and buffering pattern

4.2.3 Data analysis

During the study, participants were asked to rate their viewing experience, which is how the buffering and interrupts affect their viewing experience in the video section. Participants were also asked to rate the content of the video and their overall experience with the video.

In this section, first the correlations between viewing experience ratings and content ratings were analyzed. The result from the correlation between overall rating and content ratings, and correction between overall ratings and viewing experience ratings are also discussed in detail. We also demonstrate the relation between buffering pattern and video genre through the collected ratings of viewing experience. Finally, we compare the data from a related study with our results.

4.2.3.1 Correlations

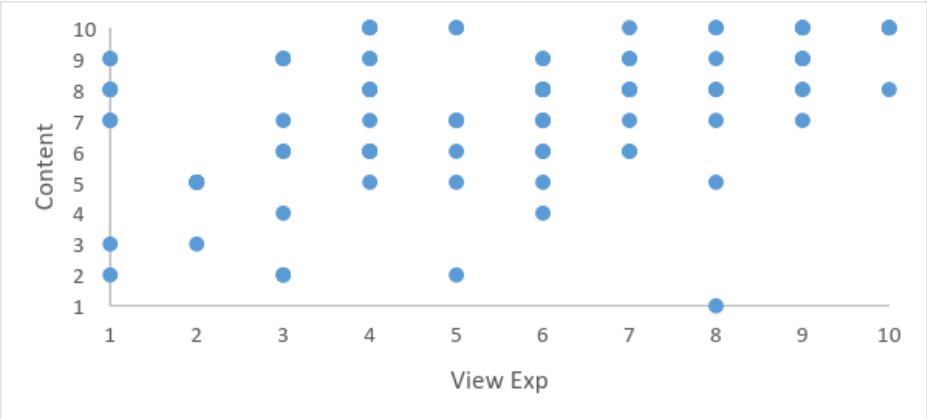

Figure 4a: Music Video: correlation between content rating and viewing experience rating

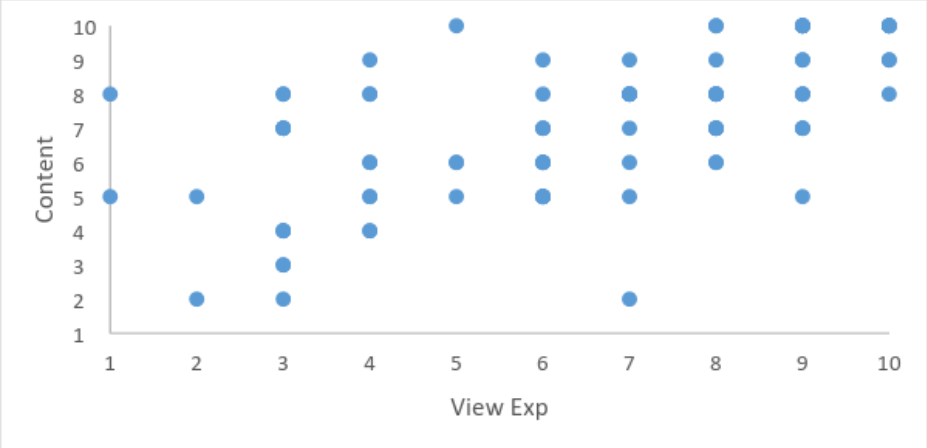

Figure 4b: Funny Video: correlation between content rating and viewing experience rating

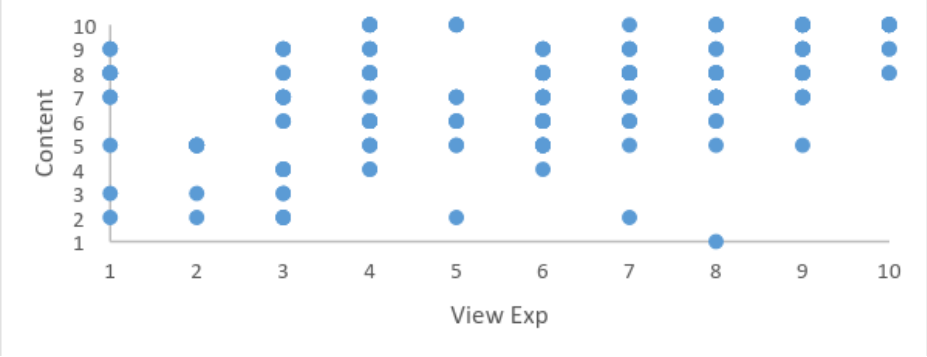

Figure 4c: Overall correlation between content rating and viewing experience rating

	Music Video	Funny Video	Combine
Content vs Viewing Experience	0.37	0.6	0.45

Table 2: list of all r values for Figures 4a – 4c

Figures 4a-4c are the graphs that depict the correlation between the content ratings and viewing experience ratings for music video only, funny video only, and combination of both videos. The x-axis in the graphs show content ratings, and the y-axis in the graphs show viewing experience ratings. Each dot on the graphs represents one answer from one participant. There are some overlapping dots.

Table 2 list the r values for each graph. The r value for overall correlation in graph 4c is 0.45, which represents a weak correlation. The r value for the music video is 0.37, which also represents a weak correlation. However, the r value for the funny video correlation is 0.6, which is a moderate correlation. This suggest that there could exist a stronger relation between content and how people feel about buffering and interrupts in funny videos than music videos.

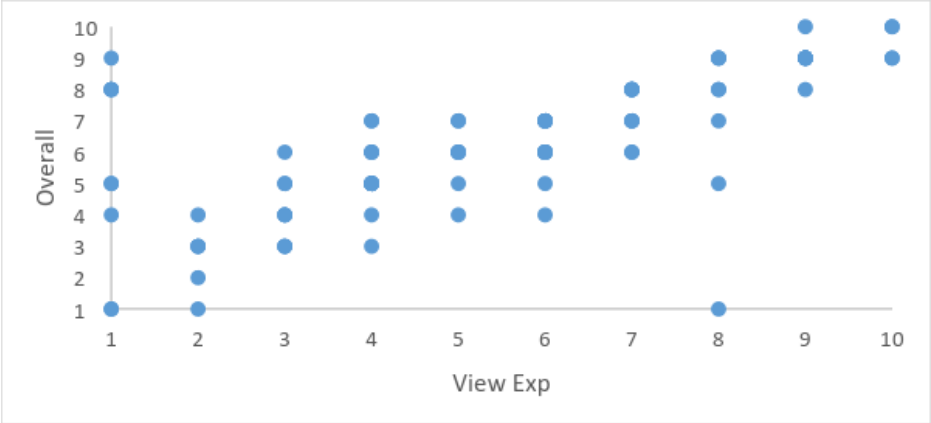

Figure 5a: Music video correlation between viewing experience rating and overall rating

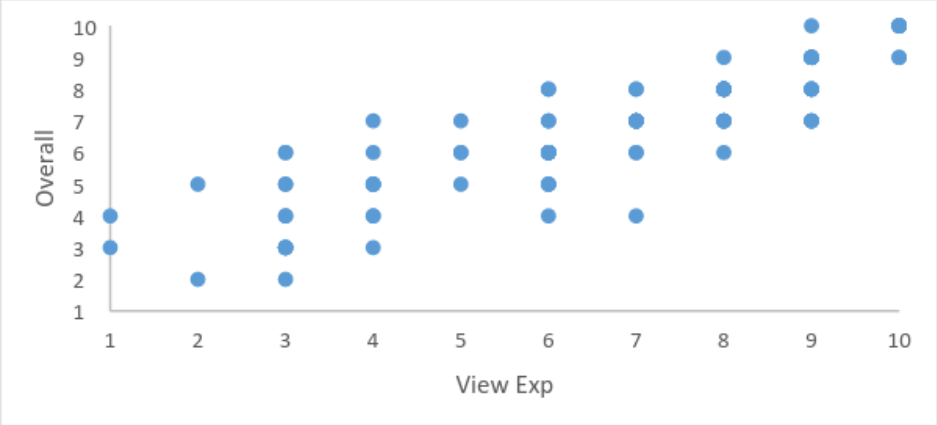

Figure 5b: funny video correlation between viewing experience rating and overall rating

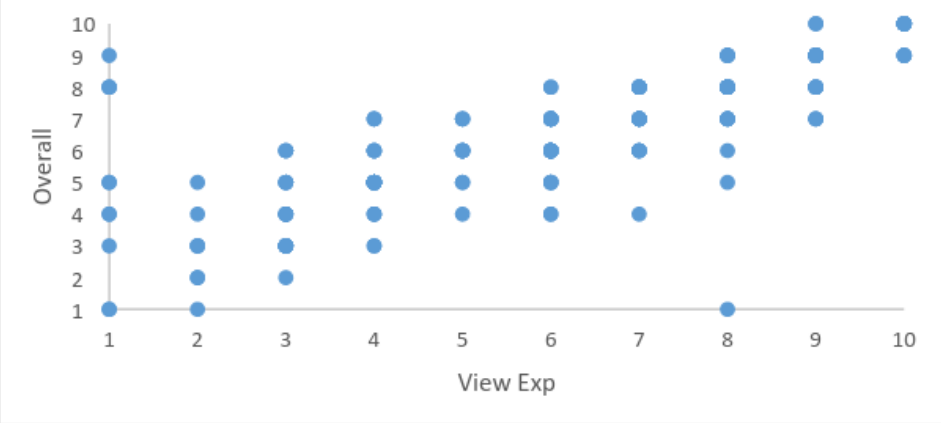

Figure 5c: Overall video correlation between viewing experience rating and overall rating

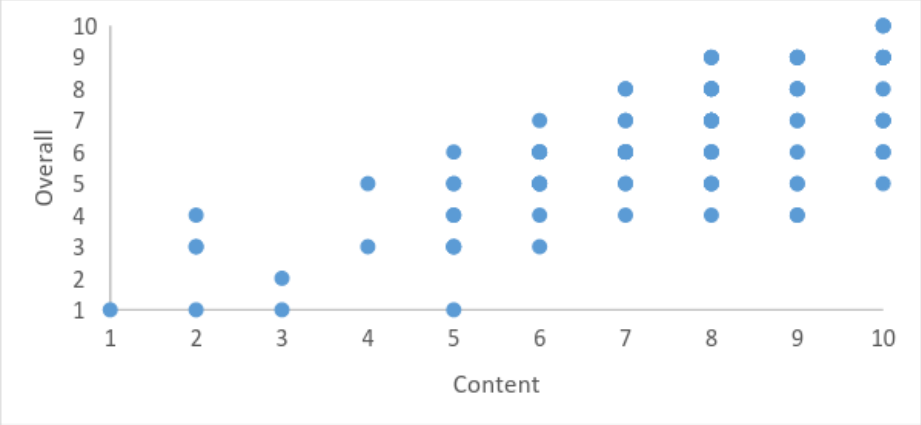

Figure 6a: Music video correlation between content rating and overall rating

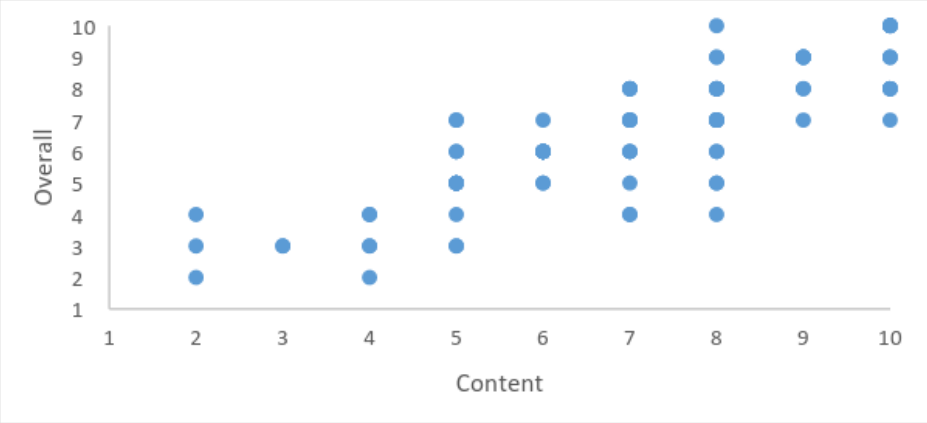

Figure 6b: Funny video correlation between content rating and overall rating

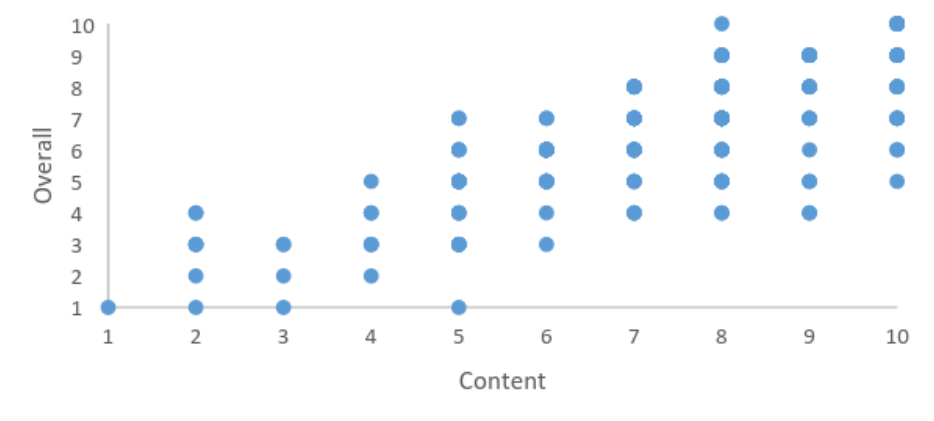

Figure 6c: Overall video correlation between content rating and overall rating

	Music Video	Funny Video	Combination
Overall vs Viewing Experience	0.67	0.87	0.77
Overall vs Content	0.75	0.83	0.78

Table 3: list of all r values for Figures 5a – 6c

Figure 5a-5c are the graphs that demonstrate the correlation between the viewing experience ratings and overall ratings for music video only, funny video only, and combination of both videos. The x-axes in the graphs show viewing experience ratings, and the y-axes in the graphs show overall ratings. Figure 6a-6c are the graphs that shows the correlation between the content ratings and overall ratings for music video only, funny video only, and combination of both videos. The x-axes in the graphs show viewing experience ratings, and the y-axes in the graphs show overall ratings. Each dot on the graphs represents an answer from one participant. It is possible for dots to overlap.

Table 3 lists all the r values for graphic 5a – 6c. According to table 2, there exists a strong correlation in all of the graphs. For music video, the correlation between overall ratings and content ratings is slightly stronger than the correlation between overall ratings and viewing experience ratings. However, for funny videos, the correlation for overall vs. viewing experience is stronger.

4.2.3.2 Viewing Experience Ratings

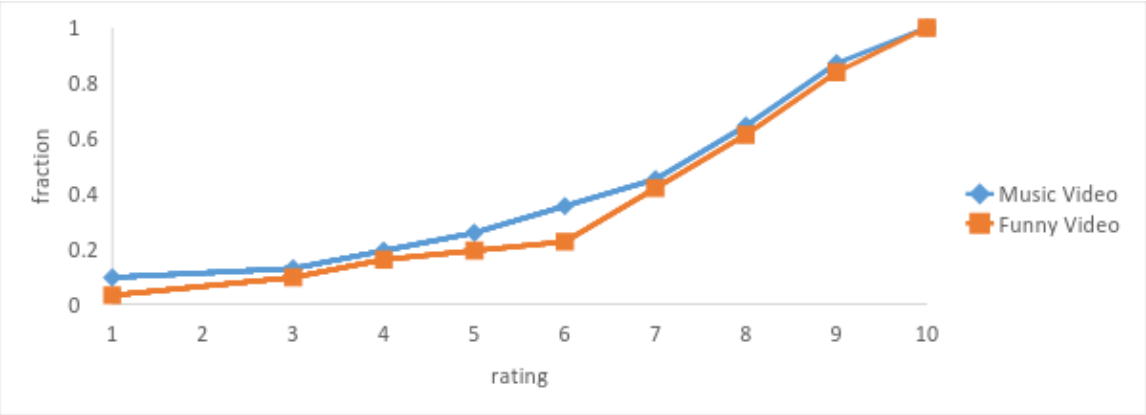

Figure 7a: Cumulative Distributed Function for Viewing Experience Rating on initial buffering only for music and funny video.

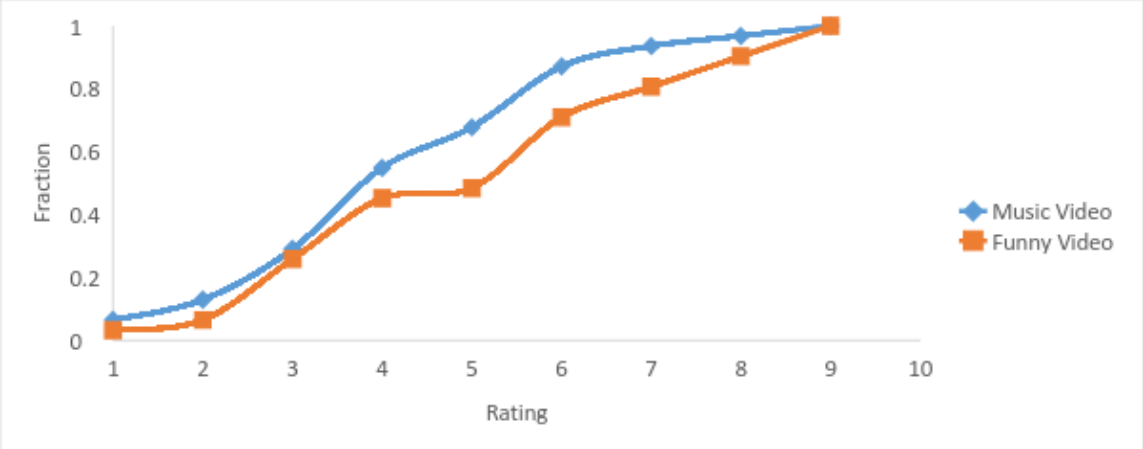

Figure 7b: Cumulative Distributed Function for Viewing Experience Rating on interrupts only for music and funny video.

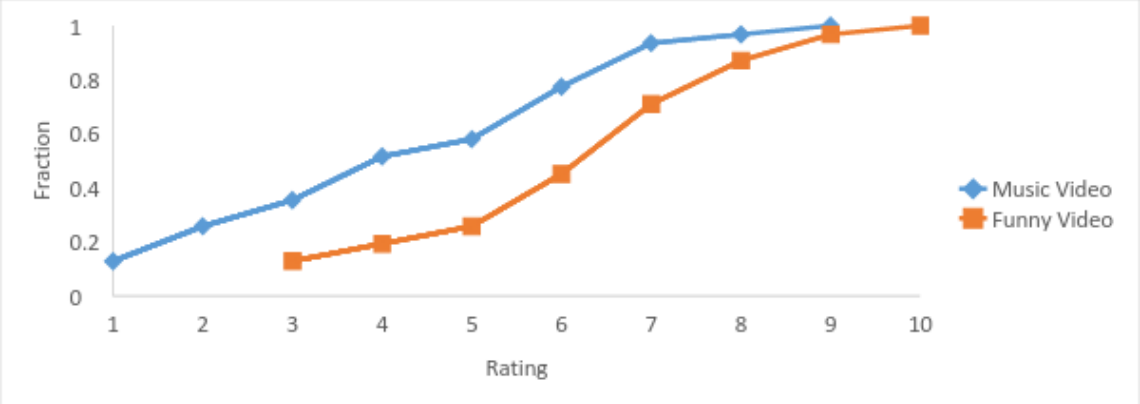

Figure 7c: Cumulative Distributed Function for Viewing Experience Rating on combination of initial buffering and interrupts for music and funny video.

Figure 7a-7c represent the cumulative distribution function of viewing experience rating on different buffering patterns for the funny video and music video. The y-axes on the graphs show the ratings, and the x-axes show the fraction of participants, who evaluated their viewing experience with rating x or below. As the graphs depicts, participants tend to tolerate the initial buffering more, and give higher ratings. However, they tend to be affected strongly by the interrupts in the video, and give lower ratings. By comparing the ratings between funny video and music video, we find that for interrupts and initial buffering only patterns, the rating trends tend to overlap, showing there is not a large difference between the opinions. However, when there are both interrupts and initial buffering in the video, the viewing experience of music video was rated much lower than that of funny video.

By comparing the ratings given to all 3 sections of each video, each participant's favorite and least favorite buffering pattern was determined. Table 3 shows the results of this analysis. Note, if a participant gave the same viewing experience rating to two different buffering patterns, it was counted as both having either the best rating or the worst rating. Thus, the sum of numbers in the table are greater than 1.

	Music Video		Funny Video	
	Best Rating	Worst Rating	Best Rating	Worst Rating
Initial Buffering Only	81%	13%	71%	13%
Interrupts Only	16%	58%	10%	81%
Combination	10%	45%	39%	32%

Table 4: Best and worst viewing experience ratings each participants gave to different buffering pattern in both videos

As data on the table 4 shows, for both genres, participants tended to give their best viewing experience rating to video sections that only have initial buffering, and tended to give the worst rating to video sections that have lots of interrupts. These results match the CDF

graphs 7a-7c. For the funny video genre, most participants gave worst rating to video with only interrupts. For the music video genre, people who gave worst rating to the video with only interrupts is only slightly more than people who gave worst rating to the video with both initial buffering and interrupts. This suggests that people tend to give worst rating to music video as long as it contains interrupts.

4.2.3.3 Comparison to Previous Work

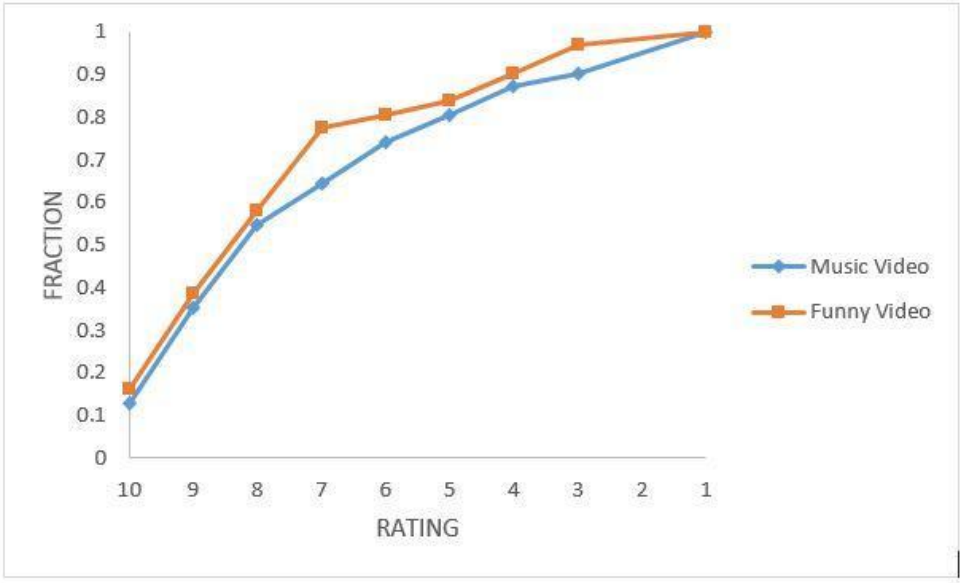

Figure 8a: Cumulative Distribution Function for Viewing Experience Rating on initial buffering from 2016 study

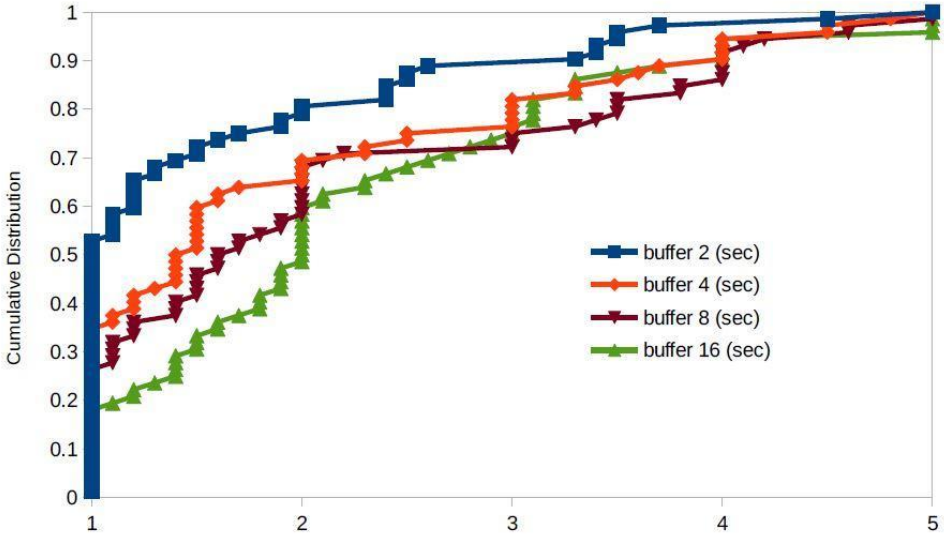

Figure 8b: Cumulative Distribution Function for Annoyance level, with respect to buffer time for video for 2015 study.

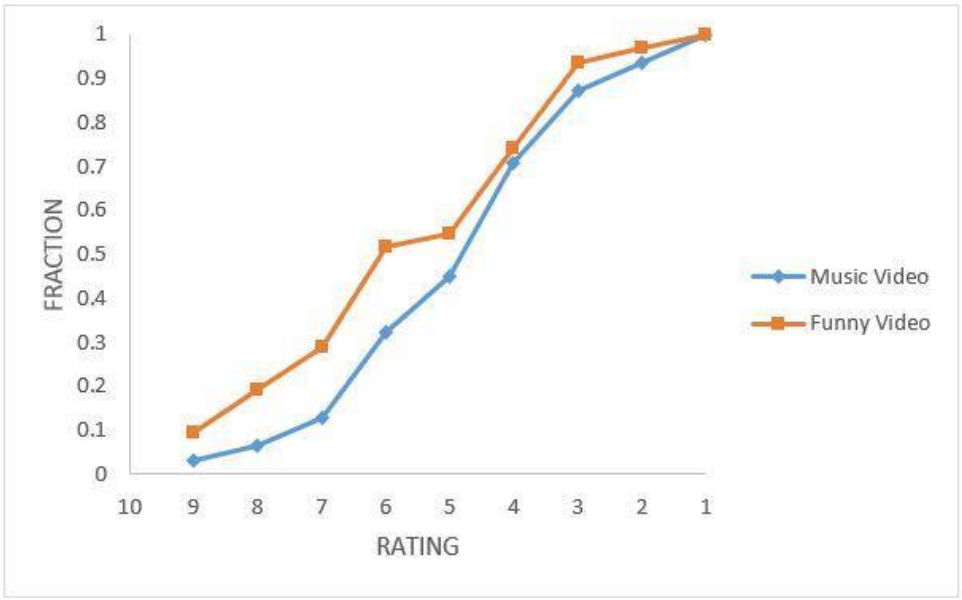

Figure 8c: Cumulative Distributed Function for Viewing Experience Rating on Interrupts only for music and funny video

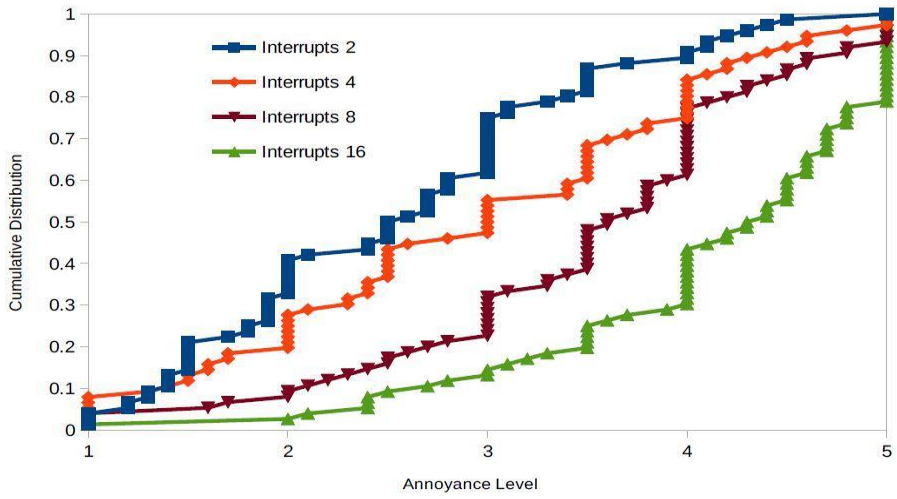

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Figure 8d: Cumulative Distribution Function for Annoyance level with respect to interrupt count for video.

The results of this study is also compared to the results from last year's study by Allard and Roskuski [3], which is mentioned in the related work section. Figure 8b and Figure 8d, illustrate the cumulative distribution function of annoyance with respect to initial buffer time and

interrupt times, with the x-axis represents the annoyance level and the y-axis representing the percent of user annoyance scores with a rating of x or less. The different trend lines represent the CDF for each buffer time and interrupt times. In their study, Allard and Roskuski measured annoyance level. To make our results easier to compare with, we reversed rating order in Figure 7a and Figure 7c, which results shows in Figure 8a and Figure 8c. According to Figures, despite the previous study is done on desktops, our results share similar trends in both the initial buffering only and interrupts only with their results. This suggests interrupts and initial buffers have similar effect on user's quality of experience on both mobile devices and stationary devices.

5. Conclusion & Future Work

With mobile devices becoming ubiquitous and powerful, streaming video on mobile devices has become one of the fastest and most convenient way to obtain news and entertainments. However, due to the unstable nature of the Internet connection, initial buffering and interrupts are two unavoidable drawbacks in video streaming that will reduce quality of experience. Therefore, to improve users' viewing experience on video streaming, a better video buffering algorithm is needed. To achieve this goal, it is essential to study how people react to buffering and interrupts.

This project identified the different effects of buffering and interrupts when streaming mobile videos, by setting up a two stage study. In the first stage, a survey was created and distributed it to WPI students. The purpose of the survey is to learn the behavior of college students when they stream videos on a mobile device. In the second stage, a user study was developed based on the results of the survey in the first stage. Each participant in the user study watched two videos of different genres that were each broken up into three sections. Each section of a video had a different buffering pattern artificially added to it. Participants rated viewing experience, content, and overall experience for each video and each section of video.

From the survey in stage one, many different users behaviors and preferences were revealed. First, music videos and funny videos were the top two most popular video genres that people liked to watch when streaming video on mobile devices. Second, when watching a one minute video on a mobile device, most of people would not expect any interrupts. Third, most people, when streaming on a mobile device are expecting 1 to 5 seconds of initial buffering time before their video begins. Finally, most people choose YouTube to be their main source for video streaming on mobile devices.

Based on the data we collected from the user study, several conclusions were made. First, by analyzing correlations between ratings it was discovered that the correlation between content rating and viewing experience rating, the correlation between overall rating and content rating, and the correlation between overall rating and viewing experience rating are all stronger in music videos than in funny videos. Second, by drawing a CDF graph for the viewing experience rating on videos with different buffering patterns, it was found that while there is not too much of a difference in ratings for music videos and funny videos with initial buffering only, the ratings for music videos are always worse in videos with interrupts only, and in videos with combination of both initial buffering and interrupts. This suggests people are more sensitive to interrupts in music videos then they are in funny videos. Finally, by comparing our results with the results from last year's project, it was found that generally, the effect of buffering and interrupts is similar for video streaming on both mobile devices and stationary devices.

Even though our research finds that there exists a difference in how buffering and interrupts affect users when there are different genres, there are still ways this research can be improved. For future work, performing the user study with more mobile devices can make data collection more efficient. A mobile application that can control video download speed and record length of initial buffering time and interrupt times is also desirable for researching a similar topic. From our survey, we also found gaming videos could be a potential candidate for popular videos people stream on mobile device, and it would be interesting to see how buffering and interrupts can have effect when people are streaming videos on websites such as Twitch.tv.

There also exists many new avenues for research based on this study. A more in depth analysis is always possible, especially if it directly compares more video genres. Future research can also compare how the audio component affects people's perceptions on the interrupts. A

study could directly compare video streaming on a stationary device to streaming on a mobile device. It is also possible to test if people are more tolerant of buffering when they perceive the device as using mobile data instead of Wi-Fi to stream video.

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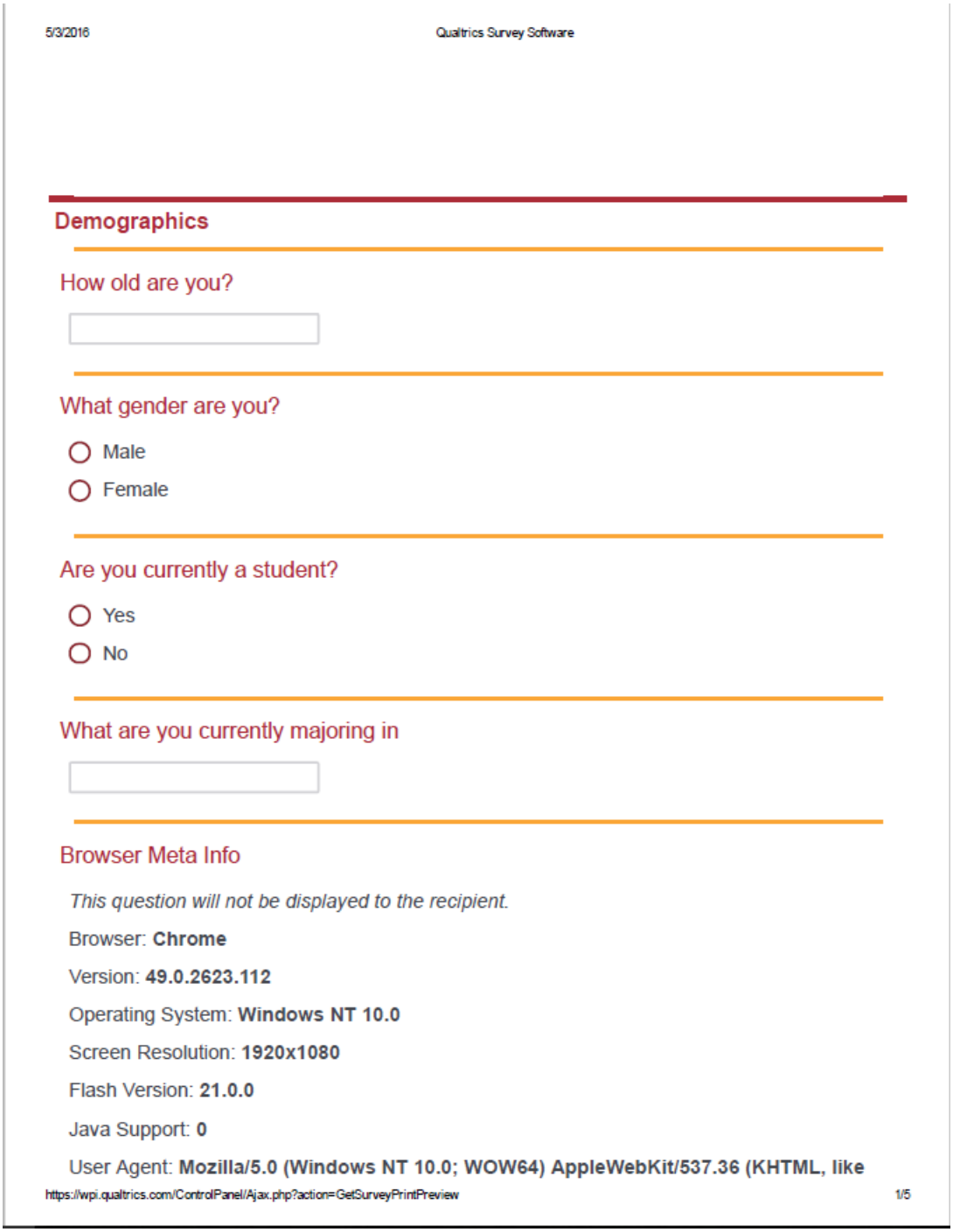
7. Appendix

7.1 Survey Study Survey



5/3/2016 Qualtrics Survey Software

Demographics

How old are you?

What gender are you?

- Male
- Female

Are you currently a student?

- Yes
- No

What are you currently majoring in

Browser Meta Info

This question will not be displayed to the recipient.

Browser: **Chrome**

Version: **49.0.2623.112**

Operating System: **Windows NT 10.0**

Screen Resolution: **1920x1080**

Flash Version: **21.0.0**

Java Support: **0**

User Agent: **Mozilla/5.0 (Windows NT 10.0; WOW64) AppleWebKit/537.36 (KHTML, like**

https://wpi.qualtrics.com/ControlPanel/Ajax.php?action=GetSurveyPrintPreview 1/5

Gecko) Chrome/49.0.2623.112 Safari/537.36

Should skip?

The following survey is about mobile video streaming

Do you use your mobile device to stream video?

- ◯ Yes
- ◯ No

Default Question Block

Please answer as many questions as you can. If you are unsure of an answer you can skip that question

Which mobile platform do you use to stream video most often?

- ◯ Phone
- ◯ Tablet
- ◯ Other

If other, please specify what

What operating system does your mobile device run?

- ◯ IOS (iPhone, iPad)
- ◯ Android (Samsung, Google, Motorola)
- ◯ Windows Mobile
- ◯ Other

If other, please specify what

On what kind of network do you stream videos on most often?

- 3G
- 4G
- Wifi

Where do you use your mobile device to watch videos most often?

- Home
- In transit (car, train, bus, etc)
- Other

If other, please specify what

What is your most commonly used source for mobile video streaming?

- Netflix
- Youtube
- Other

If other, please specify what

What do you use to stream video to your mobile device most often?

- Application
- Browser

What time of day do you stream videos most often?

- ○ Morning
- ○ Early Afternoon
- ○ Late Afternoon
- ○ Evening
- ○ Night

How much time do you spend on your mobile device streaming videos?

- ○ 0-10 minutes a week
- ○ 10-30 minutes a week
- ○ 30-60 minutes a week
- ○ More than 60 minutes a week

On average how long are the videos that you watch on your mobile device?

- ○ Less than 30 seconds
- ○ 30 seconds to 2 minutes
- ○ 2-5 minutes
- ○ 5-10 minutes
- ○ 10+ minutes

What genres of video do you watch on your mobile device most often? (you may select as many as you like)

- ☐ Funny Videos
- ☐ Music Videos
- ☐ Horror videos
- ☐ Action videos
- ☐ Drama Videos
- ☐ Informational Videos
- ☐ How-to videos
- ☐ Talk Shows

- [ ] Trailers
- [ ] Movies
- [ ] Tv Show
- [ ] Other

If other, please specify what

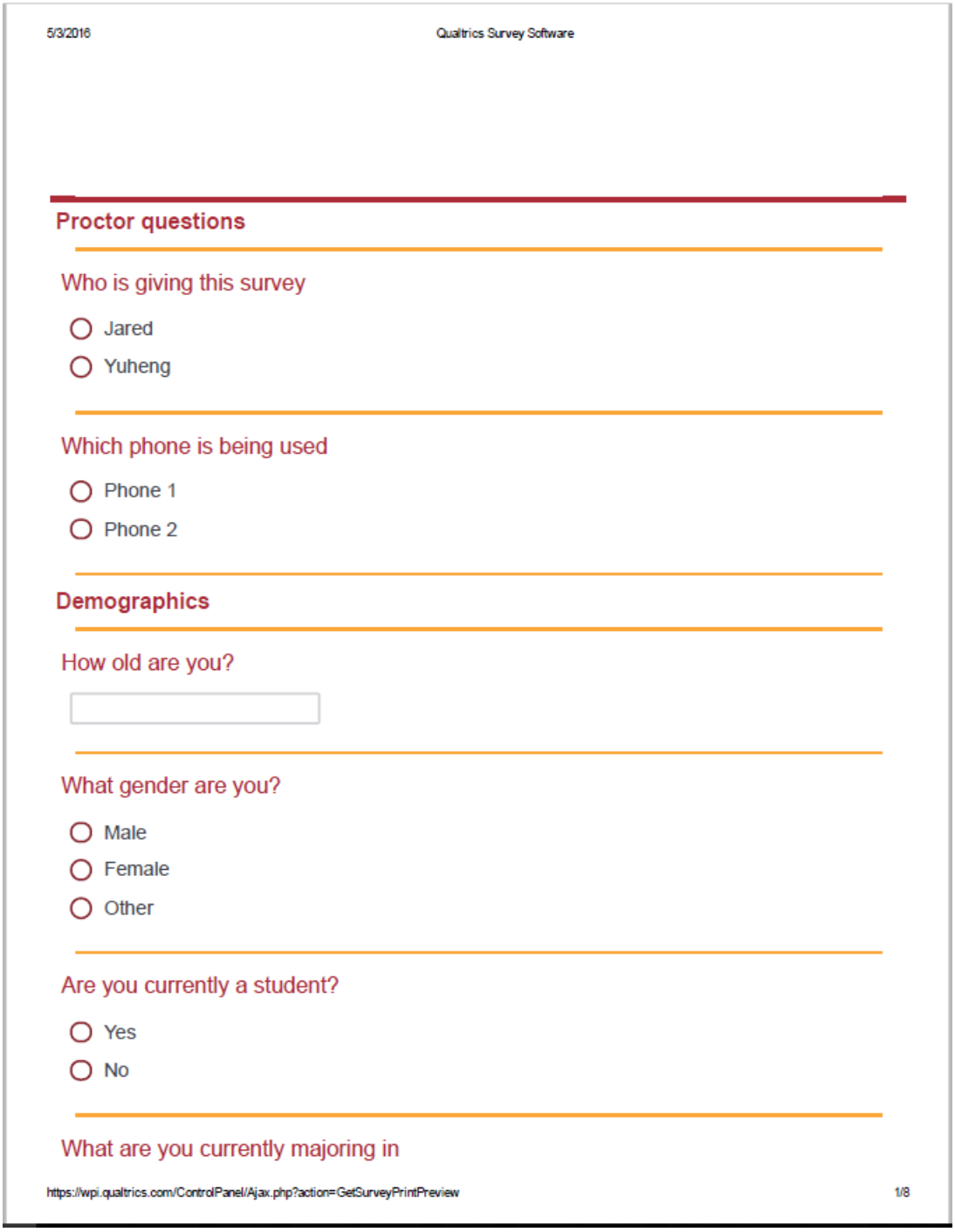
On average how long does it take for a streamed video to start playing on your mobile device?

- ○ Less than 1 second
- ○ 1-3 seconds
- ○ 3-5 seconds
- ○ 5-10 seconds
- ○ more than 10 seconds

When streaming a 1 minute video on your phone, how often do you expect it to stop and rebuffer?

- ○ Never
- ○ 1-2 times
- ○ 3-5 times
- ○ 5+ times

7.2 Main Study Survey



5/3/2016 Qualtrics Survey Software

Proctor questions

Who is giving this survey

- ○ Jared
- ○ Yuheng

Which phone is being used

- ○ Phone 1
- ○ Phone 2

Demographics

How old are you?

What gender are you?

- ○ Male
- ○ Female
- ○ Other

Are you currently a student?

- ○ Yes
- ○ No

What are you currently majoring in

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video 1 section 1

Questions For video 1 section 1

Drag the slider to rate your experience.
0 is poor. 5 is average. 10 is excellent

Please rate your viewing experience for this section

0 1 2 3 4 5 6 7 8 9 10

Rate Experience on a scale of 0 to 10

Please rate the content for this section

0 1 2 3 4 5 6 7 8 9 10

Rate Experience on a scale of 0 to 10

Please rate your overall experience

0 1 2 3 4 5 6 7 8 9 10

Rate Experience on a scale of 0 to 10

video 1 section 2

Questions for Video 1 section 2

Drag the slider to rate your experience.
0 is poor. 5 is average. 10 is excellent

Please rate your viewing experience for this section

0 1 2 3 4 5 6 7 8 9 10

Rate Experience on a scale of 0 to 10

Please rate the content for this section

0 1 2 3 4 5 6 7 8 9 10

Rate Experience on a scale of 0 to 10

Please rate your overall experience

0 1 2 3 4 5 6 7 8 9 10

Rate Experience on a scale of 0 to 10

video 1 section 3

Questions for Video 1 section 3

Drag the slider to rate your experience.
0 is poor. 5 is average. 10 is excellent

Please rate your viewing experience for this section

0 1 2 3 4 5 6 7 8 9 10

Rate Experience on a scale of 0 to 10

Please rate the content for this section

0 1 2 3 4 5 6 7 8 9 10

Rate Experience on a scale of 0 to 10

Please rate your overall experience

0 1 2 3 4 5 6 7 8 9 10

Rate Experience on a scale of 0 to 10

Video 1 questions

Please rank the sections of the first video

Based on viewing experience, please rate the sections of the first video.

Section 1

Section 2

Section 3

Based on content, please rank the sections of the first video.

Section 1

Section 2

Section 3

Based on overall experience, please rank the sections of the first video.

Section 1

Section 2

Section 3

Have You seen this video before?

- ◯ Yes
- ◯ No

video 2 section 1

Questions for Video 2 section 1

Drag the slider to rate your experience.
0 is poor. 5 is average. 10 is excellent

Please rate your viewing experience for this section

	0	1	2	3	4	5	6	7	8	9	10
Rate Experience on a scale of 0 to 10											

Please rate the content for this section

	0	1	2	3	4	5	6	7	8	9	10
Rate Experience on a scale of 0 to 10											

Please rate your overall experience

	0	1	2	3	4	5	6	7	8	9	10
Rate Experience on a scale of 0 to 10											

video 2 section 2

Questions for Video 2 Section 2

Drag the slider to rate your experience.
0 is poor. 5 is average. 10 is excellent

Please rate your viewing experience for this section

	0	1	2	3	4	5	6	7	8	9	10
Rate Experience on a scale of 0 to 10											

Please rate the content for this section

	0	1	2	3	4	5	6	7	8	9	10
Rate Experience on a scale of 0 to 10											

Please rate your overall experience

	0	1	2	3	4	5	6	7	8	9	10
Rate Experience on a scale of 0 to 10											

video 2 section 3

Questions for Video 2 Section 3

Drag the slider to rate your experience.
0 is poor. 5 is average. 10 is excellent

Please rate your viewing experience for this section

	0	1	2	3	4	5	6	7	8	9	10

Rate Experience on a scale of 0 to 10

Please rate the content for this section

0 1 2 3 4 5 6 7 8 9 10

Rate Experience on a scale of 0 to 10

Please rate your overall experience

0 1 2 3 4 5 6 7 8 9 10

Rate Experience on a scale of 0 to 10

video 2 questions

Please rank the sections of the second video

Based on viewing experience, please rate the sections of the first video.

Section 1

Section 2

Section 3

Based on content, please rank the sections of the first video.

Section 1

Section 2

Section 3

Based on overall experience, please rank the sections of the first video.

Section 1

Section 2

Section 3

Have you seen this video before?

- ○ Yes
- ○ No

Block 10

Which video had a better user experience?

- ○ Video 1
- ○ Video 2

Which video had the better content?

- ○ Video 1
- ○ Video 2

Overall, which video did you enjoy watching more

- ○ Video 1
- ○ Video 2

Powered by Qualtrics

7.3 Script

Script

When the participants sit down

“Hi, we are doing a study on people’s preferences while watching streamed videos on a mobile devices. The focus of the study is on how buffering and interrupts effect the user experience. If you have 10 minutes of time and we would love it if you would watch some videos and fill out a survey. If you would be willing to participate there are some forms you need to sign first.”

Hand the participants consent form

“Alright then. We will ask you to fill out a short demographics survey. After that you will watch 2, 3 minute videos. The videos will each be broken up into 3 separate sections. After each section you will answer a few short questions. At the end of each video we will ask a few additional questions. Be aware that all your survey responses will be kept anonymous and confidential. Any questions before we begin?”

Answer any questions the participants have

Begin survey

After video 1

“Please hand me the phone so that I can prepare the second video for you.”

After video 2

“Thank you for participating in our survey.”