Third-Wave Livestreaming: Teens' Long Form Selfie

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ABSTRACT

Mobile livestreaming is now well into its third wave. From early systems such as Bambuser and Qik, to more popular apps Meerkat and Periscope, to today's integrated social streaming features in Facebook and Instagram, both technology and usage have changed dramatically. In this latest phase of livestreaming, cameras turn inward to focus on the streamer, instead of outwards on the surroundings. Teens are increasingly using these platforms to entertain friends, meet new people, and connect with others on shared interests. We studied teens' livestreaming behaviors and motivations on these new platforms through a survey completed by 2,247 American livestreamers and interviews with 20 teens, highlighting changing practices, teens' differences from the broader population, and implications for designing new livestreaming services.

Author Keywords

Mobile; Video; Livestreaming; Teens.

ACM Classification Keywords

H.4.3. Communications Applications: Computer conferencing, teleconferencing, and videoconferencing; H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

INTRODUCTION

Livestreaming video of one's environment to others over a network has been a topic of study in HCI since the early 1990s. From early Media Spaces [3,17], through web-based streaming [1,9,31], to multiple generations of mobile phone apps [5,7,11,23,30] the technology as well as the uses and contexts of streaming have changed dramatically.

What was once a way to connect workspaces together [3] evolved into tools for police accountability [26], broadcasting protests [29], and engaging in other forms of activism [5]. However, this technology is now in widespread use by diverse audiences of everyday users. In particular, as we show, teens have been adopting livestreaming systems in increasing numbers.

Understanding teens' use of livestreaming is important for several reasons. Teens often act as lead users, for example of systems such as Snapchat [2,24], and their behaviors often spread to larger portions of the population over time. Secondly, teens are an often-understudied community, due to limitations in contacting them directly for studies and the needs of obtaining parental consent. Exploring how this population is utilizing the latest generations of livestreaming services can help us understand broader implications for the design of future live video services.

Beyond the users themselves, the design of current mobile video streaming services and how they are being actively marketed are quite different from previous waves of livestreaming services. While Qik was billed as a tool to "capture, instantly share, and preserve great moments on video," [19] new livestreaming tools such as Facebook Live encourage users to go Live "when you're just hanging out with friends or whatever." [20] This shift from livestreaming "great moments" to everyday scenes represents a change in use for livestreaming apps that needs deeper investigation. Whereas previous work focused on characteristics of popular streams [30], in the new livestreaming world, the majority of use involves everyday users streaming with small audiences. It is this type of use we explored in more detail.

To explore how teens are engaging with the most recent generation of livestreaming apps, we set out to answer the following research questions:

1. How often are teenagers livestreaming?
2. What platforms are they using?
3. What activities are they doing on their streams?
4. How is the behavior and motivations of teenagers similar or different compared to adults?

To answer these questions, we employed a mixed methods approach, using a large survey and factor analysis to derive quantitative insights into these questions while leveraging qualitative interviews to help explain the quantitative results and provide a deeper understanding of how these services are fitting into the lives of their users.

In the remainder of this paper, we will explore the background of changing technology for livestreaming, and discuss our study methods, findings, and implications for

design. Our main contribution lies in presenting the first study that qualitatively and quantitatively explores teens' use and motivation for using livestreaming apps, showing how they use livestreaming to connect with friends, to entertain their friends and viewers by chatting, playing verbal games, and engaging in their interests (gaming, making art, singing). We then provide implications for the design of new livestreaming services.

BACKGROUND

Researchers have been exploring the use of live video broadcasting for many years. From dedicated hardware for workplace video streaming, through streaming websites, and now two generations of mobile streaming apps, practices have evolved as well as the reasons for streaming in the first place. We will explore each of these waves of video streaming and discuss the gaps that remain, which we will help answer in the remainder of the paper.

Early Video Streaming Systems

Media Spaces at Xerox PARC [3] used custom hardware to connect workplaces together with video streams of remote users. Later, at Nynex [17], similar systems were built using the web. Studies of these systems explored ways that live video from a workspace could be shared in real time with users in other offices as a way to build awareness and a sense of community in distributed workspaces.

Later, other web-based broadcasting services were released publicly and began to gain popularity, including Chatroulette, where studies [13] showed a desire among users to be connected to people that they did not know through live video. Services such as Skype and Google Hangouts also emerged around this time. While mostly used for person-to-person video calling, the use of these tools was also explored for co-viewing television at a distance [18] and connecting children with relatives over a distance [1, 9]. Google Hangouts in particular, with its ability to host public hangouts with a persistent link, led to a variety of interesting livestreaming behaviors, including around fandoms, writing groups, and cooking classes [31].

First-Generation Mobile Livestreaming

As mobile phones incorporated cameras and initial mobile livestreaming solutions emerged, researchers began to explore the use of this new medium. In 2010, Juhlin et al. [11] explored the first generation of mobile livestreaming apps, Bambuser and Qik. They found that users struggled to find topics to broadcast about and that streamers exhibited poor camera work that detracted from the quality of the experience for viewers. In exploring the content of broadcasts, 40% were "tests" that had no other content or purpose, while another 21% were just videos of screens, often re-broadcasting a program that was already being broadcast on television. The remaining 40% involved views of groups, tours, social events, demonstrations, and other uses which had lower frequency. Notably, the majority of these streams were outwardly focused on the environment.

Dougherty [5] explored the use of Qik in more detail in 2011, digging deeper on the use of these platforms for civic use. She found that 71% of videos were produced by males, and that 11% were created to have some type of larger civic value, such as being journalistic, activistic, or educational. The producers of the video were often in their 20s-40s, with many also in their 50s or 60s. Teens were not as a major source of production with this generation of mobile livestreaming applications, nor were women.

Weilenmann et al. [32] further explored the ability of early livestreamers to understand basic videographic techniques and what it took to create quality broadcasts. Juhlin et al. [10] took this further to create tools for video streamers that provided professional-like editing capabilities and allowed users to work together to create livestreams using multiple cameraphones.

Second Generation Mobile Livestreaming

In the past few years, a new generation of mobile livestreaming apps have emerged. Meerkat, Periscope, and others provide much more user-friendly and consumer-focused solutions compared to previous generations of livestreaming apps. Supporting the latest generation of smartphones, they provided easy ways to post links into social media as well as simple, modern interfaces. As these have come into more widespread use, researchers have explored their use in various ways.

Tang et al. [30] explored the use of Meerkat and Periscope through a content analysis of popular videos as well as interviews with top streamers. As in studies from the first generation of tools [5, 11], the majority of streamers were in their 20s-40s and male. However, the topics of the streams had advanced from tests and screen re-broadcasts to more interactive chats with an audience, showing of an object or place, or demonstrating a specific skill or activity. The focus of this study was on popular streamers, which may have biased the types of streams observed. Interesting to us, only about 7% of their streams were from people aged 10-20, a demographic we were very interested in exploring, given the rapid rise in use of other mobile video tools among this demographic.

Hamilton et al. [7] investigated the interaction between the streamer and the viewer in the context of a live multi-stage jazz event. They explored ways that the audience helped direct the streamer to particular sites of interest and how a community formed among the viewers of a live stream. These interactions occurred in a special-built streaming system that they created for the study.

Reeves et al. [23] explored the tensions involved in live streaming gameplay, and the attention that must be paid to different aspects. Streamers must not only engage with the game and put on a good performance, but they should also engage with the camera to provide compelling footage and engage with the audience members who are watching the

livestream. We will see some of these tensions return when we discuss how teens are using livestreaming today.

Gaps

While existing research has explored a variety of contexts of use of livestreaming, as well as the behavior of some of the most popular streamers, it has not explored the more everyday uses of livestreaming. By focusing on top broadcasters, the experience of more typical users has not been explored in great detail. We expect that only a small percentage of users would achieve a top livestreamer status with audiences in the hundreds, thousands or tens of thousands, whereas the vast majority would have very few live viewers. If we only examine livestreams with a large audience, or only streamers who have achieved a large following, we miss the largest proportion of users.

Our own work set out to explore the everyday use of livestreaming in a population that has been previously understudied: teens. For example, in Dougherty [5] and Tang's [30] work, most livestreamers were older and male. We also sought to explore livestreaming use in the new third generation of live streaming services which are a part of popular social applications such as Facebook and Instagram. Even work published in 2016 [30] focused on Meerkat and Periscope, two platforms that we observed lower amounts use in 2016. New platforms such as Facebook Live and Instagram, as well as a variety of niche apps, have emerged as apps to stream to broad friend networks and the public.

In addition to the population and platform changes, we were interested in answering questions not addressed by the previous literature, including what motivated teens to livestream, how often they engaged in this behavior, and the types of content that teens streamed. As shown below, the answers to all of these questions were quite different from what was observed in previous work focusing on older users or more popular streamers on the previous generations of streaming apps. We will explicitly show areas where teen motivations are significantly different from adult users.

METHOD

To answer our research questions, we used a mixed methods approach. First, we used a survey and factor analysis to find motivations to stream and significantly different characteristics of teen livestreamers. Second, we supplemented those insights with qualitative interviews to explain the behaviors observed in the survey. All methods below were approved by our institution's standard review processes before the study was conducted.

The survey was deployed in a popular online blogging network. American users of the platform randomly encountered the call to participate in an area on the screen normally used for advertisements. In the call, participants were told that they would earn $5 if they completed the survey and that if they were under 18 that they would need their parents to complete a consent form in order to receive this incentive. Participants under 13 were disqualified from participating.

Survey respondents answered questions on age, gender (open text field), and their online activities such as watching videos, creating videos, and livestreaming. Based on those answers, participants were routed to specific parts of the survey with questions related to the activities they indicated. The survey had over 100 questions; however, based on their answers, most participants answered a much smaller number. In this paper, we will focus on the 57 questions related to livestreaming.

In addition to the survey, to more deeply understand livestreaming behaviors, we interviewed 20 teens aged 13-18 who had recently participated in livestreaming as the main streamer or as an active or background participant in a friend's livestream. Teens visited our lab in friendship pairs and were interviewed together. Participants were recruited via Craigslist and through a posting to members of our broader organization for relatives who might meet our criteria. Teens were explicitly recruited to cover a wide range of socioeconomic and ethnic backgrounds as well as a city/suburban mix from a large US metropolitan area. More than half came from racial minority groups, in line with the population of our region. Teen participants and the parent who brought them to the session were offered an incentive and parental consent was obtained before each interview. Sessions lasted approximately one hour.

Analysis

The survey included behavioral questions on how often participants engaged in a variety of activities over the past two weeks using a six point ordinal scale (from "never" to "several times per day") and questions related to motivation that fell on a 7 point scale from "strongly disagree" to "strongly agree." To assess patterns in responses, we grouped questions based on factor analysis and compared differences between three age groups: 13-17, 18-25, and 26-40 year olds.

Factor Analysis

We were interested in understanding the motivations that our participants had for livestreaming and in understanding any barriers or anxieties that users had while livestreaming. In order to find statistical patterns across participants, and then to find significant differences in these patterns by age, we employed factor analysis to cluster sets of questions.

	13	14-15	16-17	18-21	22-25	26-29	30-35	36-40
All respondents	247	1006	1522	3155	1007	385	217	104
Streamers	43 (17%)	183 (18%)	323 (21%)	618 (20%)	242 (24%)	104 (27%)	52 (24%)	27 (26%)
Watchers	170 (69%)	714 (71%)	1048 (69%)	2021 (64%)	653 (65%)	246 (64%)	128 (59%)	64 (61%)

Table 1: Ages of survey respondents and livestreamers within our sample.

As is standard for factor analysis of survey data, factor loadings were determined through principal component analysis and then rotated using the varimax procedure. Both methods are well established in survey-related research [6] and have been used in other heavily cited HCI work such as [16,15,27,14]. Following a Uses and Gratifications approach [12], researchers have explored motivations to contribute to a variety of online communities [16] as well as the extent to which various desires are met by the use of social media [21]. We used this approach to explore motivations and desires met by livestreaming.

For each factor in our analysis, the average factor score was computed for each age group. Average factor scores were then scaled such that, for each factor, the age group with the largest score value was set to 1 and the others were set to the appropriate fraction of the largest value. If factor scores were found to deviate between age groups, we investigated those deviations with Pearson correlations. We will present the results of this analysis below, using quotes from the interviews to help explain the motivations in greater detail.

Qualitative Analysis
A number of survey questions were open text boxes for qualitative responses, such as asking for self-reported activities during livestreams. Two co-authors coded the first 5% of responses and met to gain consensus on categories. Then one researcher coded the remaining responses, and met with the second coder to reach consensus.

Interviews from the in-lab studies were video recorded and quotes relevant to particular factors from the survey analysis were captured from the video recordings to help explain the themes that emerged through the factor analysis. Both quotes from the open-ended responses in the survey and the interviews will be used below to provide rich examples and deeper insight into the motivations that emerged from the quantitative analysis.

RESULTS
7,990 respondents began the survey and 4,527 completed it. Of those that began the survey, 2,247 of 7,990 (28%) respondents checked that they "Livestreamed (streaming live videos of myself on Facebook LIVE, Live.ly, YouNow, etc)." Of the 2,247 streamers, 1592 completed the survey and are included in the analysis below.

Frequency of Use
One of our main research questions was around understanding the frequency of livestreaming and watching the livestreams of others. Of participants who livestreamed, 31% livestreamed once in the previous two-week period,

33% livestreamed twice and 29% livestreamed a few times per week. Only 5% of respondents indicated that they livestreamed daily or more. Beyond actively livestreaming themselves, 68% had watched a livestream from someone else in the past two weeks.

When exploring the ages of livestreamers, we saw similar rates of participants across age groups, with between 17-27% of respondents in each age group reporting that they livestreamed. Younger participants, aged 13-21 were slightly less likely to stream compared to participants over 21. Note that we are not reporting the percent of the general population who livestream, rather the percent of those who responded to our survey which was placed on a popular blogging platform. The interesting finding from this data is that participation is not vastly different depending on age.

There were minimal differences between genders when exploring teens who watched livestreaming. Those who identified as male, 69% had watched a livestream in the past two weeks. Of those identifying as female, 65% had watched a stream. 36% of males had streamed in the past two weeks compared to 25% of females.

Apps Used
We were also interested in the apps that teens were using to livestream. 58% of livestreaming teens reported using only 1 app for livestreaming, while 28% reported using two, and 10% reported using three. Only 4% of teen respondents used more than three different livestreaming apps.

App Name	Number of Teens Using It
Instagram (Live Streaming feature)	165
Twitch	98
YouNow	85
Facebook LIVE	71
Periscope	56
Lively	31
House Party	26
Picarto	17
YouTube	12
Join.me	7
Hype	2
Beam.pro	2
Friendlife	2

Table 2: Use of Livestreaming Apps

Most teens were using Instagram, Twitch, YouNow, and Facebook LIVE to stream, as shown in Table 2. Apps from the last generation of livestreaming, such as Periscope had lower usage, with a long tail of other apps. We note that two out of the top four apps are integrated within social networking applications. This is a core aspect of 3rd wave livestreaming, as livestreaming becomes more personal and social. We would also like to note that after our study was conducted, Facebook began a large advertising campaign for Facebook LIVE, and we expect the use of this feature to have increased since late 2016 when our data was collected.

Activities

In total, 505 teens responded to the open-ended question on activities performed during livestreaming. As mentioned above, these activities were coded by the research team. There were an average of 1.4 codes, or activities, per teen. We will describe each category of livestreaming activity and the codes that were placed under it.

Chatting and Verbal Games (157 responses - 31% of teens)
"Talk" had 71 responses, which includes discussing miscellaneous topics, talking about oneself, telling stories, and reading aloud. The category "verbal games" included 86 responses regarding games like Truth or Dare, Never Have I Ever, and Would You Rather.

P4 plays games with others from her school over livestreaming: "We do Truth or Dare or Q&A and they know more about me and I know more about them." For her, livestreaming is a way to learn more about classmates and friends, much like how teens would play these types of games when face to face at parties. And she learns more about her friend based on the questions that they ask. P5 talked about watching a friend from school livestream who was "talking about stuff. Nothing really. Just really random stuff." In these cases, friends were able to hang out with those that they knew through livestreaming.

Doing/Experiencing Art (148 responses - 29% of teens)
The category "art," with 92 responses, includes drawing, painting, and digital art. "Sing/music" had 37 responses and includes the teens singing, playing instruments, and karaoke. "Dance" had 8 responses and includes dance games and dance challenges. "Watching videos" has 6 responses and includes the teens watching videos (presumably on Youtube), suggested videos, and movies. "Reading aloud" had 3 responses and involves the teens reading books aloud to the viewers. "DIYs" had 2 responses. DIY stands for "Do It Yourself" and involves building or remodeling things (often arts and crafts) without the help of professionals.

P15 discussed sharing musical taste through livestreaming: "I would have friends, in their dorms or something, listen to music and record themselves." P16 discussed sharing clothing styles through livestreaming: "I think some people dress up or something and want to show off the way they look. I think that applies to a lot of people. I think it's sort of to show off." In both of these cases, participants wanted to share their own artistic tastes in music or fashion with others, perhaps to build their personal brand, but also to connect with others over shared interests and to receive affirmation from their friends about their tastes.

P14 watches friends who dance on livestreams and has considered doing it herself: "I've thought about doing it because I'm a dancer, so I've thought about doing it as I'm dancing and getting views, but I've never actually put thought into it. I just always watch my friends do it and that was pretty cool." In this case, she wanted to share her artistic talent with others and perhaps generate a following of those who enjoy seeing her dance. P7 watches people create art on livestreaming, however she prefers to create youtube videos of making art rather than livestreaming that activity. P6 watched a livestream of a friend making a dress. Participants enjoyed seeing the talents of their friends on display as well as learning about their skills.

Videogaming (135 responses - 27% of teens)
"Computer/video games" had 135 responses and includes games like Minecraft, Overwatch, Sims, Undertale, and other streamable video games.

P9 and P10 have been friends since grade school, and both play videogames, but not together because P9: "I'm console, he's [P10] PC." P10 watches a lot of live videogaming on Twitch but has only livestreamed about 5 times because the setup of applications that send the game stream to Twitch was challenging. The few times he livestreamed, it was for about an hour and 1-2 friends watched: "My friend was playing with me and watching from my perspective."

S2013 (from the survey) streamed himself playing games frequently: "I always take requests for certain steam games, especially things like The Binding of Isaac, Overwatch, and Minecraft." Interesting is that most streamers who reported streaming video games also reported streaming other activities such as Truth or Dare, card games, artwork, or questions and answers. As S5033 said, he livestreams to: "Play Minecraft, Do art." S5108 plays "Minecraft and Truth or Dare" and S7324 plays Minecraft and participants in "makeup challenges" over livestreaming. Gamers were not a distinct group as we had assumed going into the research.

Question and Answer (118 responses - 23% of teens)
"Q&A" had 82 responses and included the teens answering viewers' questions. "Challenges" had 36 responses and includes the teens carrying out viewers' challenges/requests/tags. The challenges range from eating certain foods to dancing a certain way, to carrying out viral challenges such as the "mannequin" challenge in which people try to stay still for as long as possible. "Tags" are a set of questions about a certain topic (e.g. a significant other) that Youtube users often answer.

P3 and P4 were livestreaming together, doing Q&A with their audience members: "We were trying to get enough

people for a Q&A, you know 'what's your favorite color' and it kinda worked but not really (laughs) cuz there's like 3 people watching." S2892 discussed doing Q&A so that people could "make choices for me (what food to make, what songs to listen to)." In both of these cases, questions were directed to the audience and not at the streamer.

Nothing/Unclear (88 responses - 17% of teens)
"Nothing" has 79 responses; respondents claimed they did no activity on the livestream. "Ambiguous" has 9 responses and involves responses that are confusing and hard to decipher. In qualitative data, this was often seen to include users who started a livestream and then no one joined, so they ended it. P4 related her first experience livestreaming, which was short because no one joined: "I did for 3 minutes because no one was on it. And it was at night, so everyone was sleeping."

Daily Activities (40 responses - 8% of teens)
"Food" has 19 responses and involves the teens eating or cooking food. "Makeup" has 11 responses and includes responders either doing makeup/hair normally, or doing makeup as a part of a "challenge" (e.g. putting on makeup blindfolded). "Livestream daily activities" has 7 responses and involves the teens showing viewers what they do during the day, such as hanging out with friends or playing sports. "Pets" has 3 responses and involves the teens showing off their pets to viewers and playing with them.

P17 talked about a time "last month, we were at school and we were just, like, having fun, doing what we usually do, like messing around, and so we just decided to go live." They wanted to show others what they were seeing at school, just as a part of their daily lives. S38 discussed livestreaming "Food! What I like and think looks aesthetically pleasing" while S380 discussed streaming while "we cooked Christmas food and did a truth or dare." As in previous categories, participants often discussed combining multiple activity types together over the course of a livestream, including showing their everyday activities.

Notably Missing
We find it interesting that activities reported in previous literature on livestreaming, such as broadcasting live events, concerts, protests, and other public situations with many people present did not appear in the list of activities that teens streamed. Teens' livestreams were generally of activities within the home, and focused on themselves instead of on their surroundings. This marks a large change in the regular use of livestreaming services, a point that we will return to in the discussion.

FACTOR ANALYSIS
Data from the 57 survey questions related to livestreaming was used in our factor analysis. As mentioned above, factor analysis finds latent factors that explain variance in observed questionnaire responses.

To determine the number of factors, we use a standard a threshold of 1 on the eigenvalues of the principal component decomposition. This threshold suggested that the optimal number of factors was 12.

In this section, we will discuss factors in decreasing order of agreement scores. Thus, the first few factors are qualities that on average most livestreamers strongly agree with, whereas factors discussed last have more variation. When discussing each factor, we will highlight questions where there is significant difference between teens and the general population as well as provide quotes from our qualitative data to help explore the behaviors represented by each factor in greater detail. Differences in agreement by age can be seen in Figure 1.
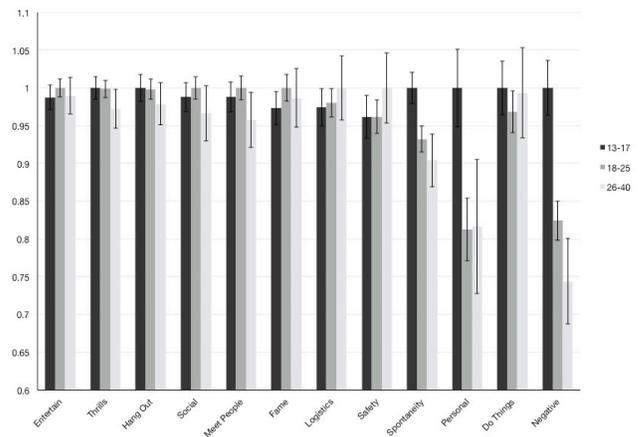

Figure 1: Scaled Factor Scores for Age Groups 13-17, 18-25 and 26-40

Factor 1: Being Entertaining – 5.63

When I livestream, I try to talk about things my viewers care about.	.616
When I livestream, I try to be someone my viewers want to watch.	.653
When I livestream, I try to entertain my viewers.	.685

Livestreamers of all ages were in high agreement that they wanted to please their audience. However, unlike previous studies where the perspective of livestreaming was looking out on something interesting in the world, teen livestreamers aimed to be entertaining themselves: "You can be yourself and have people see you for you. You don't have to hide yourself. You show your face and who you are." (P17) "You want to show what you can do" (P4).

Teens reported wanting their livestreams to be interesting and "impressive" (P3). They want to feature themselves being themselves. When probed about the content of their streams, they would share semi-mundane activities, such as having a friend over or going to the park (P4). In explaining how much she is trying to impress her viewers, P3 shared: "It's also kind of entertaining, not really like you're not trying super hard to make them enjoy. I mean if they're watching and keep watching they're obviously liking watching you so that's like kind of entertaining them." Overall, livestreamers enjoyed trying to entertain their

viewers and kept the viewer's enjoyment in mind while streaming.

Factor 2: Thrill of Livestreaming – 5.27

The most rewarding thing about livestreaming is it's exciting to be live.	.613
The most rewarding thing about livestreaming is it makes me feel better.	.680
The most rewarding thing about livestreaming is I get closer with my audience.	.558
The most rewarding thing about livestreaming is having people interact with me through comments.	.539

In line with the first factor, livestreamers are on the spot to entertain and excited to do it. "It sounds kind of cheesy but you feel kind of special or happy that people want to take the time to watch whatever random thing that you're doing" (P3). P14 shared the same sentiment: "It was fun knowing that people are watching you. It's like, oh, they're commenting while watching you. It was fun."

Our sample included a few participants who had tried livestreaming but weren't motivated to do it again. For example, in one friendship pair, two girls said that they tried it with the third friend who livestreamed regularly. One tried it and found it "uninteresting" (P2) and the other said: "At first I didn't really see the point of it, but people can comment on it and ask questions, like I said before, and so I found it more interesting." (P1)

Getting a reaction from viewers added to the thrill. P1 and P2 agreed that one part of livestreaming that they loved was when viewers tapped the screen and they received "showers of likes." With regard to interacting with comments, P4 shares that it's more fun when there are a few more people to interact with: "If there's a lot of people on it it's pretty fun. If there's only 1 or 2 it's not that fun."

Factor 3: Hanging Out – 5.06

I livestream when I think my friends will be free to watch.	.643
The best part of livestreaming is …Connecting with my friends.	.579
I feel like I'm hanging out with my friends.	.484
Friends are taking time to get to know me.	.519

Participants often used livestream to hang out with their friends, as if they were in the same room or as if they were video-chatting. P3 explained: "It feels like hanging out because you connect to them." P18 was a regular user of Periscope talked about having a Periscope "friend group:" users that would sign on regularly (almost a daily basis), "hang out" and watch, and on different days, take turns streaming. She had never met any of them in person and shared that there was one summer where she regularly "hung out" on Periscope watching others but only livestreamed to the group once herself.

P4 livestreams: "when my friends want to see me, I'll either Facetime or I'll livestream." He stated that he'll decide to Facetime or livestream based on anticipated audience:

"Yeah, it just depends how many people want to go on." P6 discussed a friend who will "message everyone and say hey, you should tune into my livestream." This is similar to past situations where friends might message each other to see who could hang out at a common location after school.

We observed using livestreaming as just another way to hang out with friends when they could not physically be in the same place. As discussed above, much of the chatting, Q&A, and verbal games that teens played while livestreaming match with those that would traditional occur when teens hung out in person.

Factor 4: Prefer to be Social - 4.97

Watching a video with a friend is better than watching it alone.	.706
Hanging out with friends is my favorite way to spend my time.	.469

This factor is a general attitude towards spending time socially rather than related to a specific aspect of livestreaming. P18 shared her experience of wanting to engage with others but feeling shy, and shared that livestreaming felt like a great compromise: "If you're shy and you don't really talk to people in person, livestreaming is the way to go because you don't really see that person in person." Participants wanted to be social and turned to livestreaming to engage socially. The last factor described how livestreaming feels like hanging out, and this factor adds that hanging out socially is preferable to being alone.

When describing what a livestream was, the social aspect was included in the description "and you can share it on instagram and on facebook and on twitter." (P1)

Factor 5: Meeting New People – 4.90

I want to make new friends while livestreaming.	.596
The best part of livestreaming is … Meeting friends of friends.	.607
To find people to hang out with.	.657
To meet cool people.	.648

Livestreamers stream not only to interact with friends, but to connect to new audiences. They hope to connect to new people despite the asymmetrical relationship, where they stream video and rely on comments coming in from audience members.

P4, who discussed playing Truth or Dare above, explained that she livestreams to "get to know" her viewers. She would actively interact with her viewers through the commenting feature: playing truth or dare and generally asking for requests on what to talk about next. "Some people I don't know very well, but we do truth or dare, or they have other ideas than I do [of what to do in the stream] and they just comment down below of what they wanna do, and it's pretty fun." She specifies that with streaming, "these are people are my school. And I might know them better. There's some followers that I don't know. Well I know them because they're at my school, but I don't know them." P4 said she had "20 to 30" people in her school that followed her. She recognized the followers from their

profile pictures, from seeing them around school "playing basketball or in my classes." Part of this is information exchange, but another aspect seems to be about building common ground, as her viewers spend time listening. Livestreaming can be a way to turn weaker ties into stronger ones.

When livestreaming on Periscope, P18 related a story of feeling awkward if there were people on the stream who watched but didn't comment. P17 talked about issues in this asymmetry: "They call it like 'livestreaming friends' so it's not like a gang, but like a group of friends. you all know each other really well. It's really awkward because they all live across the country and it's like, I don't really know you, but you really know me." Being able to successfully engage followers and learn more about them is a key challenge for our participants.

Factor 6: Achieving Fame – 4.76

When I livestream, I try to become famous.	.739
The hardest thing about livestreaming is getting more viewers.	.627
The hardest thing about livestreaming is getting more followers.	.652
I wish I had more people watching when I livestreamed.	.461

With much of the focus of previous work on popular livestreams, this was only a small portion of what motivates livestreamers. When asked about whether they wanted to become famous, many shared that they didn't expect that or even want that. However, one shared that some "YouTube famous" people seemed "normal" and so becoming "internet famous" seemed like it could be within reach.

When asked if they had any strategies to gain more viewers or followers, P1 answered that she labeled the livestream with what the stream would contain (when she had a plan), such as "Q&A." She felt that getting viewers was the hardest part of livestreaming: "Maybe if you wanna have a lot people watching, like do a successful Q&A, getting a lot of people is hard. They may not have notifications turned on, it might not be at the right time for them or be interested in what you're doing." She related how losing followers felt disappointing: "Some people are only on for a minute. You're like 'Oh there's a new person, do you have any questions? because we can see who it is, and then, they might go off because they're not interested and we're like oh.. Ok." Keeping a small audience of friends was the main goal of most of our participants, over attracting mass internet followings.

Factor 7: Logistics and Connection – 4.46

The hardest thing about livestreaming is keeping a good wifi connection.	.669
The hardest thing about livestreaming is keeping up with the comments.	.657

The teens in our sample usually livestreamed from their houses, because of the high quality internet and also if their parents wanted them at home. The teens in the sample didn't have a problem with keeping up with comments because none of them had enough viewers to make the stream of comments too fast to keep track of. In response to an open-ended question on what is hardest about livestreaming, S116 shares a solution related to the problem of keeping up with comments: "Make a livestream service where you can see comments through an app or something that can always be open on the desktop and doesn't erase when it refreshes/ it has a backlog." S908, a video game streamer, said: "Maintaining a high quality video (attempting to run 60fps with not the best wifi)."

Factor 8: Safety Strategies – 4.36

I prefer to use a nickname online rather than my real name.	.722
I prefer not to show my face online to anyone I don't know personally.	.649

Teens voiced concerns about their online safety. Two pairs of participants discussed a recent movie where a teenage heroine was kidnapped after sharing too publicly on social media. Teens shared their parents' rules for participation, such as livestreaming only audio and not showing your face to strangers online. For the most part, teens reported heeding their parents' concerns and tried to be cautious.

Factor 9: Spontaneity – 3.99

I had trouble figuring out what to talk about when I livestreamed.	.486
I feel nervous every time I livestream.	.481
The hardest part of livestreaming is figuring out what to talk about, what to do next.	.755
The most rewarding things about livestreaming is connecting to my audience.	.629
The hardest part of livestreaming is making sure the livestream isn't boring.	.684

Many teens started streaming without a precise plan of what they would do. They approached the livestream like an unplanned conversation where topics would spontaneously come up. When asked how she decides what to talk about, P4 responded: "Sometimes I ask them what they want to do. Some people do truth or dare because they get that from the internet. Or they do the contest emoji thing. And so like I just do it guess. I like those contests." P4 said the hardest part is: "finding a topic. Because it's [the latency in the stream] 10 seconds off, after 10 seconds they hear me. I want it to be at the same time, so they respond a little faster."

The negative correlation between age group and this factor (cor=0.227, p<0.001) indicates that more teens engage in livestreaming without a plan and feel like figuring out what to do next is a difficult problem. Older participants are more likely to come into livestreaming with a particular topic/mission in mind and are less likely to experience problems in finding topics once streaming has begun.

Factor 10: Personally Knowing Audience – 3.34

I don't livestream as much as I want because I'm concerned about my online safety.	.649

I am comfortable with anyone watching me livestream.	-.590
When I livestream, I like to know everyone personally who is watching.	.617
If someone I don't know personally tries to follow my livestream account, I check out their account before accepting.	.684
I only let people follow my livestream account if I know them personally.	.766

Participants shared that they usually recognize the usernames of their handful of audience members -- they are usually friends. When a "stranger" logs on to watch, they notice right away and want to know who they are. P1, when describing what livestreaming is, said: "I mean i think it's cool, it's kinda like a facetime but like to multiple people. I think it's cool but then again all of your followers, if you're public, like anyone can see. You just gotta be careful, with what you say."

P4 was one of our sample's most frequent livestreamers. When asked if anyone she didn't know every tried to follow her, replied: "Yeah but they were like, put your email in here and try to sell stuff, and I didn't want to. I ignored them. They sent a follow request and I disagreed. And then they tried again and I blocked them." And when prompted about others, she replied: "Yeah, there are of them. A lot of fans of musically. I just ignore them." In response to the topic of people you don't know following you, the friendship pair agreed: "I don't want to follow people I don't know and I wouldn't want people I don't know to follow me. Yeah I get why a lot of people are fine with that, but unless I know them, personally, I would say no."

This factor differed significantly across age groups (cor=0.126, p<0.001), where it was much more important for teens to know their viewers personally compared to the older age groups.

Factor 11: Doing Interesting Things – 2.15

I livestreamed because I was somewhere cool or doing something cool.	.720
I livestreamed with an audience.	.752
I was "guested" on livestreaming by a friend (i.e., another streamer invited you to livestream within their livestream).	.679
I "guested" a friend while livestreaming (i.e., you invited someone to livestream within your livestream).	.740

The set of questions related to the more of the outward facing mode of livestreaming. Within the factor, doing something cool was related to having an audience. One participant shared her experience of being "guested" into a livestreaming -- she felt flattered to be asked but also felt on the spot and unsure what to say. She was having dinner with her family when the guest invitation came in and felt nervous that it wasn't a good time to participate.

As discussed above in the activities section, participants found a wide variety of activities to engage in while streaming, including verbal games, engaging in artistic activities, watching video together, or video gaming. Having activities that viewers would find interesting was important to the streamer for keeping the audience engaged.

Factor 12: Alleviating Negative Feelings – 1.94

I livestreamed because I got bored.	.705
I livestreamed because I got lonely.	.707
I started livestreaming but there was no audience so I stopped.	.627

Participants in our interviews talked about wanting to livestream to relieve feelings of boredom or loneliness. They sought audience of friends via livestreaming in these cases. P3 said: "It's fun when there's more people. Then you're not lonely."

We observed a significant difference (cor=-0.145, p<.001) across age groups for this factor, where these situations occurred much more frequently for 13-17 year olds, a moderate amount for 18-25 year olds and much less for those over 25.

LIMITATIONS
There are several important limitations to our methods. Participants for the survey were recruited through advertisements on one particular large blogging network. While this site has over 500 million active users, it may represent a more artistic and creative community than the general internet population. This may affect the types of content that these participants choose to livestream on other platforms. Participants for the survey were also all from the United States, and behaviors elsewhere might be different.

Interviews were conducted in one large American metropolitan city. While we did our best to recruit users of different socioeconomic and ethnic backgrounds, behaviors may be different in other parts of the country or world.

Finally, practices of livestreaming are changing rapidly. With large marketing budgets being used to promote livestreaming within social networks and expanding promotion of these streams within various social apps, we expect new behaviors and practices will emerge. The practices we observed in late 2016 may not be the behaviors observed in late 2017 or into the future. Despite these limitations, to the best of our ability, we have captured the practices of this particular snapshot in time and compared it to previous literature exploring livestreaming practices at other periods of time, and in this process discovered significant differences in use.

DISCUSSION
In studying current everyday practices of livestreaming, on the latest generation of apps, we have discovered a shift in practices from what was observed in previous research. These changes have occurred in a few dimensions: demographics of users, content, and audience.

We found that teens in our sample were livestreaming, and watching livestreams, at a similar rate to older respondents. While only 7% of streamers in Tang et al.'s study [30] were

between 10-20 years old and nearly 50% were 20-30 years old, we found similar rates of participation in livestreaming (both viewing and watching) across age groups. And while Dougherty [5] found that 70% of streamers in Qik were male, we did not see such large differences in gender, with 69% of males having watched a stream in the past few weeks compared to 65% of females, and 36% of males having streamed themselves compared to 25% of females.

The content of livestreams was also different from previous research. Dougherty [5] focused on civic engagement, and Tang et al. [30] saw very little livestreaming around gaming (perhaps due to the focus on Periscope and Meerkat). However, we saw teens engaging with livestreaming to hang out with others online. 29% of streams in our sample involved doing or showcasing art, while 17% involved playing "verbal games" such as Truth or Dare or Never Have I Ever. 27% of teens had streamed themselves playing video games and 21% had streamed Q&A sessions. The teens' streams often happen in the home, and the streaming of popular live events such as protests and concerts that was seen in previous work was not a theme in our findings.

In some ways, these streams were like a long-form selfie, a way to showcase an aspect of one's self and life to others. Akin to selfies, livestreaming may appear highly individual and narcissistic, however our study emphasized a highly social nature. Just how selfies can be understood as a social practice used to calibrate social expectations, probe norms, and garner feedback [28], our participants emphasized livestreaming as a connection to their friends.

Livestreaming for teens was not about reaching a large audience, but engaging with small group of friends online through their livestreams. Our approach of surveying and interviewing everyday users of livestreaming has allowed us to explore some of these more common uses that might not have been as visible when studying the more popular streams in previous work. While perhaps the more popular streamers [30] are in their 20s, teens are streaming to small audiences regularly, with two-thirds of those who had streamed streaming more than once in the past two weeks.

When looking at differences between teens and adults, we found that teens are more likely to stream when they are bored or lonely. They often don't have a plan of what to stream about and are less sure about what to say next. This is inline with videos created by teen girls, where Puikkonen et al. [22] found that one of the five types of videos was "free mode" (unplanned, without structure). Still, users found community through streaming and discovered topics to discuss or games to play as their audience joined.

This third wave of livestreaming is a much more interactive process than previous waves, which were largely seen as "broadcasting" platforms [11]. While the video only goes one way, live text comments connect viewers back to the streamer, enabling the playing of interactive games and directing topics of conversation. Teens explicitly seek this

real time cycle of feedback, similar to the research prototype system designed by Hamilton et al [7], but in the context of the home environment. Compared to previous livestreaming systems, teens are engaging with this current wave, which is more about "hanging out" with friends through the integration of livestreaming with articulated friend networks in Instagram and Facebook. Streamers can maintain social bonds through hanging out with people that they know who happen to join, but unlike video conferencing solutions they do not have to explicitly invite people or plan in advance. A different set of friends could show up each time, and they could adapt the content to what the audience wants to see. This is different from the first wave, where streamers built their personal brand by showing cool places and experiences. Now, personal brand is built through being charismatic and participating in group games and Q&A. This is also different from the second wave as teens now have the ability to engage with their existing broader friend networks.

IMPLICATIONS FOR DESIGN
This research raises several implications for the design of new livestreaming systems. By supporting more of the structured types of activities that we observed, livestreaming clients can make it easier to support hanging out over shared games or content.

Explicit Support for Verbal Games
We observed participants playing a small set of standard games with each other. Participants played typical teen party games such as Truth or Dare, Never Have I Ever or Would You Rather. They also engaged in open-ended question and answer sessions with each other. Adding explicit support for playing these games, including on-screen controls to moderate (up and downvote) questions could help make playing these games more interactive, fun, and natural over trying to maintain state and viewer interest through a comments stream.

Supporting Watching Video Together
When teens streamed video over livestreams, the camera focus was away from the teen themselves. Tools can support simultaneously watching video together in a separate player on the screen, while still using the camera to focus on the streamer. Tools like Zync [25] allowed for streaming video while text chatting, and these new types of systems would take that one step further to also share live video of the person who initiated the streaming. This could be extended to support broader Social-TV situations [8] where video from multiple parties could be shown at once.

Focus on Friends
The teens in our study did not seek to be world-famous through their live streams. While the idea of fame is tantalizing, the fear of strangers is stronger. They wanted to engage with friends and perhaps build their friend network slightly. Building livestreaming systems that focus on connections with friends over public broadcast can better meet the needs of many common streaming purposes.

CONCLUSION

We have presented the results of a large-scale survey on livestreaming behaviors as well as in-depth interviews with 20 teens who livestream in order to better understand practices and motivations with today's generation of livestreaming applications. We have uncovered significant differences from previous work in the demographics of livestreamers, the topics of the stream, and the desired audience and have presented several implications for the design of new livestreaming systems.

Additional work lies in exploring the use of livestreaming outside of the United States and with other age ranges as well as in building and evaluating the use of systems that follow from our design implications. We believe that we are the first to explore teen motivations for livestreaming in this new generation of streaming applications and that this research opens many interesting opportunities for further research and system development.

REFERENCES

1. Frank Bentley and Santosh Basapur. 2012. StoryPlace.Me: the path from studying elder communication to a public location-based video service. In CHI '12 Extended Abstracts on Human Factors in Computing Systems (CHI EA '12). ACM, New York, NY, USA, 777-792. DOI: http://dx.doi.org/10.1145/2212776.2212851

2. Frank Bentley, Karen Church, Beverly Harrison, Kent Lyons, Matthew Rafalow. 2015. Three Hours a Day: Understanding Current Teen Practices of Smartphone Application Use. arXiv. https://arxiv.org/ftp/arxiv/papers/1510/1510.05192.pdf

3. Sara A. Bly, Steve R. Harrison, and Susan Irwin. 1993. Media spaces: bringing people together in a video, audio, and computing environment. Commun. ACM 36, 1 (January 1993), 28-46. DOI=http://dx.doi.org/10.1145/151233.151235

4. Catherine E. Shoichet. 2016. Facebook Live video offers new perspective on police shootings. CNN. http://www.cnn.com/2016/07/07/us/facebook-live-video-minnesota-police-shooting/ Accessed 2/7/17.

5. Audubon Dougherty. 2011. Live-streaming mobile video: production as civic engagement. In Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services (MobileHCI '11). ACM, New York, NY, USA, 425-434. DOI=http://dx.doi.org/10.1145/2037373.2037437

6. Leandre R. Fabrigar, Duane T. Wegener. 2011. Exploratory Factor Analysis (Understanding Statistics). Oxford University Press.

7. William A. Hamilton, John Tang, Gina Venolia, Kori Inkpen, Jakob Zillner, and Derek Huang. 2016. Rivulet: Exploring Participation in Live Events through Multi-Stream Experiences. In Proceedings of the ACM International Conference on Interactive Experiences for TV and Online Video (TVX '16). ACM, New York, NY, USA, 31-42. DOI: http://dx.doi.org/10.1145/2932206.2932211

8. Gunnar Harboe, Crysta J. Metcalf, Frank Bentley, Joe Tullio, Noel Massey, and Guy Romano. 2008. Ambient social tv: drawing people into a shared experience. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '08). ACM, New York, NY, USA, 1-10. DOI=http://dx.doi.org/10.1145/1357054.1357056

9. Kori Inkpen, Brett Taylor, Sasa Junuzovic, John Tang, and Gina Venolia. 2013. Experiences2Go: sharing kids' activities outside the home with remote family members. In Proceedings of the 2013 conference on Computer supported cooperative work (CSCW '13). ACM, New York, NY, USA, 1329-1340. DOI=http://dx.doi.org/10.1145/2441776.2441926

10. Oskar Juhlin, Arvid Engström, and Elin Önnevall. 2014. Long tail TV revisited: from ordinary camera phone use to pro-am video production. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14). ACM, New York, NY, USA, 1325-1334. DOI: https://doi.org/10.1145/2556288.2557315

11. Oskar Juhlin, Arvid Engström, and Erika Reponen. 2010. Mobile broadcasting: the whats and hows of live video as a social medium. In Proceedings of the 12th international conference on Human computer interaction with mobile devices and services (MobileHCI '10). ACM, New York, NY, USA, 35-44. DOI=10.1145/1851600.1851610 http://doi.acm.org/10.1145/1851600.1851610

12. Elihu Katz, Hadassah Haas, and Michael Gurevitch. "On the use of the mass media for important things." American sociological review (1973): 164-181.

13. David Kreps. Foucault, exhibitionism and voyeurism on chatroulette. In Cultural Attitudes towards Technology and Communication. 2010, 207–216

14. Yumi Jung, Rebecca Gray, Cliff Lampe, and Nicole Ellison. 2013. Favors from facebook friends: unpacking dimensions of social capital. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13). ACM, New York, NY, USA, 11-20. DOI: https://doi.org/10.1145/2470654.2470657

15. Cliff Lampe, Donghee Yvette Wohn, Jessica Vitak, Nicole B. Ellison, and Rick Wash. "Student use of Facebook for organizing collaborative classroom activities." International Journal of Computer-Supported Collaborative Learning 6, no. 3 (2011): 329-347.

16. Cliff Lampe, Rick Wash, Alcides Velasquez, and Elif Ozkaya. 2010. Motivations to participate in online

communities. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '10). ACM, New York, NY, USA, 1927-1936. DOI=http://dx.doi.org/10.1145/1753326.1753616

17. Alison Lee, Andreas Girgensohn, and Kevin Schlueter. 1997. NYNEX portholes: initial user reactions and redesign implications. In Proceedings of the international ACM SIGGROUP conference on Supporting group work: the integration challenge (GROUP '97). ACM, New York, NY, USA, 385-394. DOI=http://dx.doi.org/10.1145/266838.267359

18. Anna Macaranas, Gina Venolia, Kori Inkpen, and John Tang. "Sharing Experiences over Video: watching video programs together at a distance." In IFIP Conference on Human-Computer Interaction, pp. 73-90. Springer Berlin Heidelberg, 2013.

19. Donald Melanson. 2011. Skype announces plans to acquire Qik. Engadget. https://www.engadget.com/2011/01/06/skype-announces-plans-to-acquire-qik/ Accessed 2/7/17.

20. Tim Nudd. 2016. Facebook Launches a Big Ad Campaign for Facebook Live, With User Videos at the Core. AdWeek. http://www.adweek.com/brand-marketing/facebook-launches-big-ad-campaign-facebook-live-user-videos-core-174176/ Accessed 2/7/17.

21. Zizi Papacharissi, and Andrew Mendelson. "12 Toward a new (er) sociability: uses, gratifications and social capital on Facebook." *Media perspectives for the 21st century* 212 (2010).

22. Arto Puikkonen, Leena Ventä, Jonna Häkkilä, and Jenine Beekhuyzen. 2008. Playing, performing, reporting: a case study of mobile minimovies composed by teenage girls. In *Proceedings of the 20th Australasian Conference on Computer-Human Interaction: Designing for Habitus and Habitat* (OZCHI '08). ACM, New York, NY, USA, 140-147. DOI=http://dx.doi.org/10.1145/1517744.1517789

23. Stuart Reeves, Christian Greiffenhagen, Martin Flintham, Steve Benford, Matt Adams, Ju Row Farr, and Nicholas Tandavantij. 2015. I'd Hide You: Performing Live Broadcasting in Public. In Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15). ACM, New York, NY, USA, 2573-2582. DOI: https://doi.org/10.1145/2702123.2702257

24. Saquib Shah. Snapchat Teens Beware: Your parents are flocking to your favorite app. Digital Trends. http://www.digitaltrends.com/social-media/snapchat-older-users/ Accessed 2/7/17.

25. David A. Shamma, and Yiming Liu. 2009. Zync with me: Synchronized sharing of video through instant messaging. In *Social Interactive Television: Immersive Shared Experiences and Perspectives*, pp. 269-284. IGI Global.

26. Catherine E. Shoichet. 2016. Facebook Live video offers new perspective on police shootings. CNN. http://www.cnn.com/2016/07/07/us/facebook-live-video-minnesota-police-shooting/ Accessed 2/9/17.

27. Andrew D. Smock, Nicole B. Ellison, Cliff Lampe, and Donghee Yvette Wohn. 2011. Facebook as a toolkit: A uses and gratification approach to unbundling feature use. *Computers in Human Behavior* 27, no. 6 (2011): 2322-2329.

28. Angelica Svelander and Mikael Wiberg. 2015. The practice of selfies. *interactions* 22, 4 (June 2015), 34-38. DOI: https://doi.org/10.1145/2770886

29. Elise Danielle Thorburn. "Social media, subjectivity, and surveillance: Moving on from occupy, the rise of live streaming video." *Communication and Critical/Cultural Studies* 11, no. 1 (2014): 52-63.

30. John C. Tang, Gina Venolia, and Kori M. Inkpen. 2016. Meerkat and Periscope: I Stream, You Stream, Apps Stream for Live Streams. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16). ACM, New York, NY, USA, 4770-4780. DOI: https://doi.org/10.1145/2858036.2858374

31. John C. Tang, Carolyn Wei, and Reena Kawal. 2012. Social telepresence bakeoff: Skype group video calling, google+ hangouts, and microsoft avatar kinect. In Proceedings of the ACM 2012 conference on Computer Supported Cooperative Work Companion (CSCW '12). ACM, New York, NY, USA, 37-40. DOI=http://dx.doi.org/10.1145/2141512.2141531

32. Alexandra Weilenmann, Roger Säljö, and Arvid Engström. 2014. Mobile video literacy: negotiating the use of a new visual technology. Personal Ubiquitous Comput. 18, 3 (March 2014), 737-752. DOI=http://dx.doi.org/10.1007/s00779-013-0703-x