ASYMMETRIC DELAY IN VIDEO-MEDIATED GROUP DISCUSSIONS

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ABSTRACT

Delay has been found as one of the most crucial factors determining the Quality of Experience (QoE) in synchronous video-mediated communication. The effect has been extensively studied for dyadic conversations and recently the study of small group communications has become the focus of the research community. Contrary to dyads, in which the delay is symmetrically perceived, this is not the case for groups. Due to the heterogeneous structure of the internet, asymmetric delays between participants are likely to occur.

We conducted a trial with video-mediated group discussions with five participants in symmetric and asymmetric delay conditions. In this paper, we focus on the asymmetric conditions, in which only one participant has an added delay. Previous research showed that interaction and context are essential factors in the QoE of participants. Therefore, we perform an analysis of our data towards these factors and compare our data between the asymmetric and the symmetric delay conditions. We discuss the differences in perception of delay reported from multi-party to dyadic video-conferencing.

Our data shows that already one person with a high delay, affects the experience of the whole group as strong as the person with delay. This disruption is perceived more intensely by active participants rather than non-active ones– regardless of whether they have the delay or not. Compared to dyadic situations the group scenario shows a less intense perception of delay.

Index Terms— multi-party videoconferencing, subjective study, delay, QoE,

1. INTRODUCTION

Remote communication enables us to talk with far away family members, friends and colleagues. The physical necessary process of capturing, encoding, transmitting, decoding and finally presenting ourselves remotely introduces inherently always a delay in the communication. In video conferencing, we are talking about "real-time" communication since it enables us to talk back and forth in a similar manner as in a face-to-face situation. In face-to-face situations we have learned to unconsciously use the timing of the small pauses in speech to manage a conversation and infer reactions from our interlocutors [1]. A long pause after having said something makes us wonder if the others are still following along and, whether they misunderstood or disagreed with something or they were simply distracted. We usually use other cues to get feedback from our interlocutors, e.g. gestures, body language and facial expression [2]. As the medium that we capture and reconstruct is less rich than what we can capture as humans when we are in the situation, these timings become more important to us [3]. In this respect it has been shown that delay disrupts conversations more in audio-only communication than in audio-video communication [4].

The interpretation and importance of these cues are heavily influenced by the context in which they take place [5][6]. Studies in video-mediated communication which looked at discussions [4], watching video together [7] or playing a game [8] have reported different perceptions of delay. Thus the actual interaction plays an important part in the experience.

Achieving the minimum delay that we can currently deliver requires heavy resources from our communication systems. When the internet is used as a transportation medium, the best effort approach introduces varying and unforeseen delays. Thus, we aim for a fine grained understanding of the effects of delay on QoE to eventually know for what delays we should aim for, what the effects of high delays are and how we can possibly alleviate the situation.

The majority of the studies so far have focused on dyadic use cases [4][9]. Group communication first came into focus with high-end immersive systems [10]. As recently devices and network infrastructures have advanced, multi-party conversations at home has become an area of interest in the research community [11]. So far these studies have focused on the symmetric delay case, while being distributed in different locations suggests (especially if the internet is used as an infrastructure) that the delays will occur asymmetrically between participants.

To gain insight into this situation we conducted a trial a 59 participant study on the effects of symmetric and asymmetric delay in a five-people group discussion. We focus in this paper on the asymmetric conditions, in which we added delay in the connection of one participant, and the comparison between both cases.

The following research questions guided our experiment:

- How is the QoE of the whole group affected by one participant having delay? Is there a difference between the participants with a higher delay as compared to the ones without added delay?
- How is the QoE of a group with all people having high delay different from a group with only one participant having a high delay?
- How does the activity of a participant influence the QoE?

2. RELATED WORK

In the underlying models [12][5][13][6] describing the different factors which shape QoE, delay is established to be a key factor from the system side, especially when it comes to interactivity.

The dyadic case has been investigated for unscripted scenarios [14], for scripted scenarios [9] and unscripted with mutual eye-gaze [4]. The difference between scripted and unscripted scenarios is crucial [15].

That interactivity is a key factor in determining the effects of frequency and type of interaction has been proven useful in a study of people watching video together [7].

The multi-party scenario has been evaluated for the high-end halo system [10] and for scenarios that use unconventional settings (TV screen, several cameras) [11]. Non-conversational test in a three party rock-paper scissors game investigated interactivity and fairness [16].

To our knowledge, there has been no investigation of asymmetric delay effects in an unscripted multi-party video-mediated conversation.

From a technical perspective, several studies evaluate realistic home conditions. For example, Xu et al. [17] analyzed the actual delay of three popular video chat systems: Google+, iChat, and Skype. In an ideal setting, they offer a one-way delay of between 150ms to 270ms, on average. Nevertheless, this significantly increases in realistic settings. For example, when connecting two computers between New York and Hong Kong, the round trip delay is up to 776ms for Google+, and 1467ms for Skype. Other systems, like Mebeam [18], have even higher one-way delay of up to 2770ms on average.

3. METHODOLOGY

Participants

The study was conducted with 59 participants. We conducted all sessions with groups of five people except one session. One participant did not show up and we were not able to find a replacement in such short notice. We recruited 39 participants via social media and flyers in universities and institutes and consisted mainly of students and researchers. We recruited the other 20 participants using a recruitment company to complement our demographic with a different age group and background. The experiment was conducted in English, in which all participants were fluent. 20 participants were assigned to the asymmetric condition and 39 to the symmetric condition. All participants in the asymmetric condition were recruited from universities or institutes. Their average age was 32.7 years (Stdev 10.6, min 20 max 60), and 33 of the participants were female. The average age of the participants recruited from university and institutes was 26.9 years and the average age of the participants recruited via the company was 44.1 years.

Scenario

Our scenario was a consensus based decision making task in a moderated small group discussion. The task of our participants was a quiz style question-select answer scenario. The participants had to discuss together the best answer to questions about surviving in the wilderness. The task is based on the team building exercise from [19]. One participant (randomly chosen) was asked to be the moderator, to submit the final group answers and move the discussion along to keep the 10 minutes time constraint per round.

Conditions

In the symmetric conditions we tested delays up 2000ms one-way delay. In the asymmetric case, we decided to add delay to only one participant, as this should be the biggest difference to the symmetric situation. To reduce the number of test conditions in the asymmetric case, we tested in this case only up to 1000ms one-way added delay. In each session one randomly chosen participant and the moderator (also randomly chosen) got an additional delay (both directions: sending and receiving delay) of 500ms or 1000ms. Table 1 shows the different delay conditions in detail. The GroupConditions denote the maximum delay present in the tested group (e.g. Group500 means in the asymmetric case one participant with 500ms added delay and all participants with 500ms added delay in the symmetric case).

GroupCondition	Asymmetric	Symmetric
Group0	**Symmetric0**: No participant had an added delay. The base delay was ~150ms.	
Group500	**Random500/Moderator500** The randomly assigned participant or the moderator respectively had 500ms added delay (i.e.~650ms)	**Symmetric500** All participants had an added delay of 500ms (i.e. 650ms)
Group1000	**Random1000/Moderator1000** The randomly assigned participant or the moderator respectively had 1000ms added delay (i.e.~1150ms)	**Symmetric1000** All participants had an added delay of 1000ms (i.e. 1150ms)

Table 1 Delay Conditions

Procedure

In the beginning of the experiment, we had an introduction round to shortly get to know each other and introduce our research. Then we seated each participant in separate rooms. For each group we used the delay conditions in randomized order. In each condition, participants had to answer three questions, first individually and then together in a 10 minute group discussion. After each condition, the participants answered a questionnaire. After all conditions, participants had to answer an additional questionnaire assessing demographical data like age and previous usage of tele-communication systems. We concluded with a discussion of the experiment in a semi-structured group interview.

Testsystem

We used the Video-Mediated Communication Testbed [6]. It is a video-communication system designed to conduct tests in a controlled environment. The delay was achieved by increasing buffers in the media-processing pipeline. This approach manipulates the system parameters directly in the software instead of using network simulators. The clocks of the machines were synchronized all 15 seconds with an NTP server at the institute.

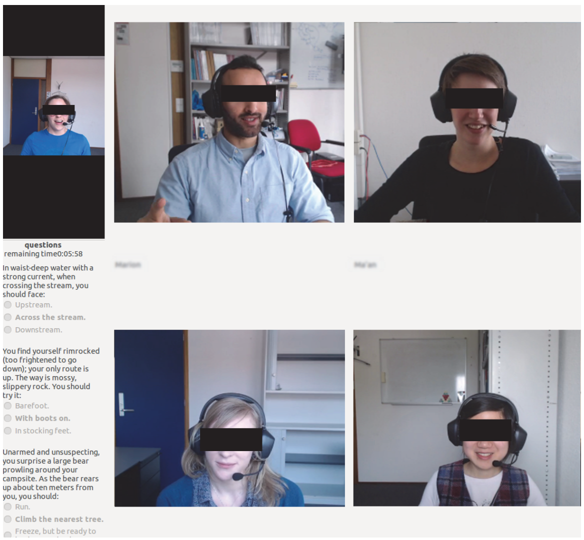

Figure 1 Screenshot of the client from the trial

The delay was measured by inserting timestamps at the sender side and reading them out at the receiver side. As we used a configuration with 30fps, this approach has a measurement accuracy of ca. 33ms. All data was recorded on the sending and receiving side. The system hides the experiment conductor, but gives the ability to interact with the participants if assistance is needed. The configuration of the client interface can be seen in Figure 1. The participant has an image of him/herself in the upper left corner and an equal representation of the other for participants as the main view. In the lower left corner, the questions of this round are presented. The moderator has controls enabled to select and submit the chosen answers.

Apparatus

As we wanted to simulate a home situation we used Desktop PCs (Core i7, 16GB Ram, SSD) with a webcam (Logitech HD C920) and headset (Creative Soundblaster Xtreme 3D). We transmitted the videos in SD Quality (640x480px, 30fps, H264) and the audio was encoded with Speex. The computers were connected over a Gigabit LAN connection and RTP over UDP was used as transportation protocol.

Data

We collected questionnaire data from each participant and each delay condition. Each questionnaire included 15 items, with a nine point likert-type scale. The final questionnaire at the end of the session included questions about the background and the experience of the participant. As objective data, we measure question scores, from the individual and group results.

The questionnaire contained three items to investigate the perceived quality, on which we are focusing in this paper. Table 2 details the questions and labels referring to those questionnaire items. For the analysis, the ratings have been adjusted so that always a higher value means a better perception, i.e. higher quality, less annoyance or less noticeable delay. The three questions are meant to complement each other. Noticeability asks for a judgment-free rating, quality asks for a judgment of the technical aspects and annoyance for the most subjective experience. For the statistical analysis the R-package was used.

Label	Question	Scale Ends
quality	I think the connection I have been using was:	Poor <-> Excellent
annoyance	I felt annoyed by the delay in the connection.	Strongly Disagree <-> Strongly Agree
noticeability	I think the delay in the connection was:	Very Noticeable <-> Not noticeable

Table 2 Questions and labels

4. RESULTS

We concentrate on the three quality items in the asymmetric case, their averages per condition are displayed in Figure 2. The error bars in this and the following Figures represent the 95% confidence intervals.

The items are normal distributed with respect to kurtosis and skew below 2. We investigated the general trend that with higher delay the perception of quality is worse. We performed ANOVA by modeling the responses as a linear function of the delay condition, with the user as a within subject factor and the group as a between subject factor. We compared the fit of our data to this linear function, to see if the differences in the delay conditions are statistically valid. For the pairwise comparisons we used the student's t-test, pairwise for the when comparing only the

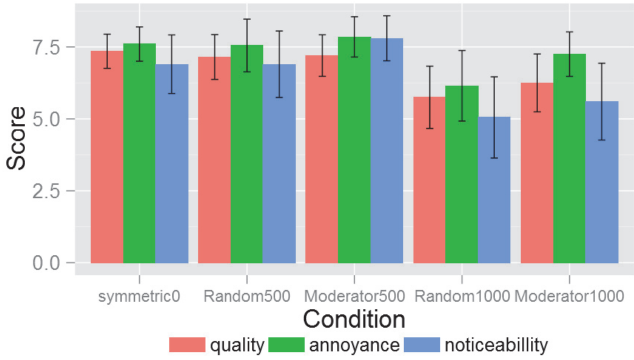

Figure 2 Average Responses to Quality Questions

asymmetric data, unpaired for comparison between symmetric case or different activity groups (see 4.1 and 4.2). The analysis showed that the condition is an influencing factor for all three items with $p = 0.00852$ for quality, 0.01336 for annoyance and 0.00052 for noticeability. The group factor is not considered a statistical significant influence for quality ($p = 0.218$) but for annoyance ($p = 0.0322$) and noticeability ($p = 0.0789$).

We performed a pairwise t-test to see whether these differences are perceptible. The noticeable differences are between symmetric0 and Moderator1000 (p-value = 0.035) and Random1000 (p-value = 0.0165). Random500 and Moderator1000 are different (p-value = 0.012). Moderator500 and Random1000 are also different (p-value = 0.023).

In other words the difference between no delay and one of the participants having 500ms delay is not perceptible but the difference to 1000ms is perceptible. The difference to the 500ms delay cases towards the 1000ms cases is perceptible in some cases. For annoyance and noticeability the difference is perceptible between the 0ms and 500ms and the Random1000 condition ($p < 0.05$) and "likely" differences to the Moderator1000 case ($p < 0.15$).

As we did not find significant differences between the Moderator and Random cases, we merged the Random500 with the Moderator500 and the Random1000 with the Moderator1000 condition, shown in Figure 3.

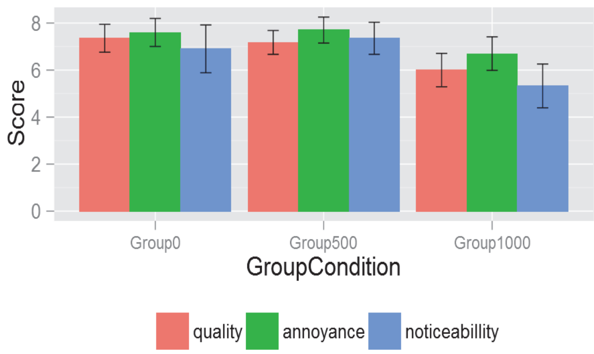

Figure 3 Average responses to quality questions by group conditions

The t-test between the different conditions showed that for all three variables, the difference between Group0 and Group500 is not significant ($p > 0.05$) but between Group500 and Group1000 the degradation in QoE is perceptible ($p < 0.05$).

We further compared how (in these conditions) the perception of

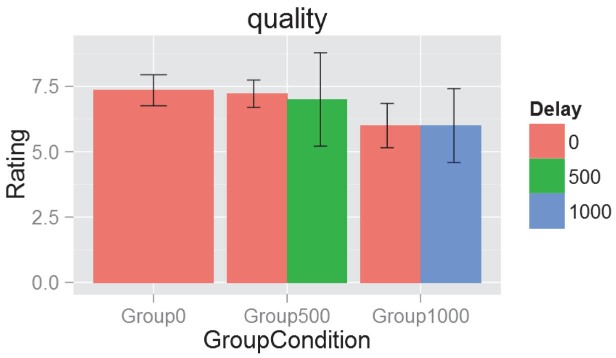

Figure 4 Responses for Quality by GroupCondition and Delay

participants with delay differs from participants without delay. We did not find significant differences between the perception for any of the three variables, Figure 4 depicts the responses for quality.

4.1 Clustering by speaking time

Based on the assumption that the interaction is an important factor in the perception we clustered the participants with kmeans by their percentile-part of the conversation. We had used this clustering into "active" and "non-active" participants in the symmetric delay study as it revealed big perceptional differences between these groups. This resulted in two groups in which both the randomly selected participant and the moderator were active participants and two groups in which one of them was active and the other one non-active. In no group both were non-active.

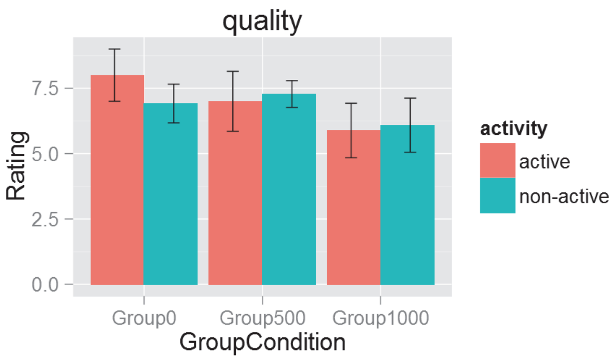

Figure 5 Responses to Quality by GroupCondition and Activity

The responses for quality of this clustering are shown in Figure 5. The difference in perceptions were not as clear as in the symmetric study, we report them here as they follow the same trend. In the Group0 condition, there are strong indications that active participants have a different perception than non-active participants ($p < 0.063$). Differences in perception between the rounds are for active participants a trend with $p = 0.157$ between the conditions Group0 and Group500 and $p = 0.134$ between Group500 and Group1000. For non-active participants the difference is noticeable between Group500 and Group1000 with $p < 0.05$ and not perceptible between Group0 and Group500 ($p=0.39$).

Annoyance was not significant in any of the cases. Noticeability was for active participants better distinguishable between conditions Group500 and Group1000 with $p < 0.05$. While it was for non-active participants less clear ($p = 0.133$).

4.2 Comparison to symmetric delay

We present in this paper only the data we use for comparison. A t-test comparison between the base conditions in which no participant had delay showed that our participants had a significantly different perception to the whole sample ($p < 0.05$) but not different on the sample that we recruited in the same manner ($p = 0.34$).

While our data on the whole set of participants in the symmetric delay case showed that the perception of active participants is significantly different from non-active participants ($p < 0.05$). In the subset of the participant pool that we recruited from university and institutes this pattern is less significant. We, thus, report these findings as trends. For this group of participants, the symmetric case the t-test revealed a p-value of 0.1558 and for the asymmetric case of 0.1572, indicating that the amount of speaking time and the perception of delay is strongly related. The perception for non-active participants is in both cases not significantly different. At a 1000ms case active and not active participants perceive the condition similar.

Further comparison between the symmetric and asymmetric conditions, see Figure 6, shows no statistical significant difference in condition Group500 but in the case of condition Group1000 they are just above the significant confidence ($p = 0.0508$).

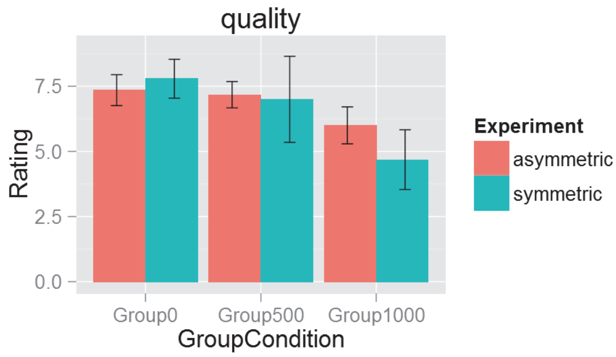

Figure 6 Responses to Quality by GroupCondition for asymmetric and symmetric conditions

If we compare the people with delay in the asymmetric case with the people in the symmetric case, we get a perceivable difference that tends toward that even for people with delay the perception is better than in a group with everybody having delay in the case of 1000ms, with a p value of 0.13, thus we only reporting it as a trend. For active participants however the difference whether they are in a group where a delay is present is perceivable ($p = 0.03171$) already at 500ms compared to the 0ms case.

As we had in this case only two participants in each session and only one participant per round that had delay, we cannot find a statistical significant perception of people with delay. If we compare the perception of active people in the symmetric and asymmetric conditions we do not find evidence that it is different.

5. DISCUSSION

5.1 Perception of asymmetric delay within the group

The data reported by our participants did not show a significant difference for participants with delay compared to participants without delay in one session up to 500ms.

This was also reflected by our participants in the discussion. While some people noticed delay in the connection, they did not attribute it to others. Only very few people reported that they felt they were delayed in respect to others. More people reported that they had the feeling they were delayed compared to people who stated that they had the feeling somebody else was delayed.

Participants did not get the feeling that only communication with the delayed person was problematic but attributed it to a more general group discussion feeling. The comments reflect that people while noticing problematic instances sometimes, do not necessarily concentrate on the details, e.g. with whom this problem occurs. The delay makes the communication harder but contrary to other aspects of video-mediated communication it directly interferes with it. As a participant stated when discussing the experience of delay in a different session:

[P1]: "*There were some awkward moments when you wanted to say something and someone else wanted to say something ... you have to kind of sync it ... but I think I'm used to it*"

There were some reports where people could identify that they or somebody else had some particular delay. After we asked whether they noticed particular instances in which they had the feeling that delay was particularly noticeable.

[P2 - moderator]: "*At some point I realized I said something and I had to wait for quite a while that there was a delay ... I just realized that once.*"

[P3]: "*I noticed after a while you took longer to ask the second question.*"

This leads to the interpretation that experiencing other people in the same discussion having a communication problem also reduces the QoE for the other participants who might not be actively involved in the instance that caused problems.

5.2 Perception of delay between symmetric and asymmetric condition groups

Our study confirms that a delay up to 500ms is barely perceivable in a video-mediated group discussion. The perception of a group in which one participant has delay is not much different from a group in which all people have delay. In the case of 1000ms delay the QoE of the groups with only one participant delayed is significantly better than in a group in which all participants have a high delay.

But our analysis showed that the variance of perception of people with delay is higher than the ones without delay. In turn we could not statistically confirm that the perception of somebody with delay in a group without delay is better than the perception of participants in a round with all people having delay.

5.3 Interactivity

Our presumption of the differences between the two groups in the symmetric case is that the experience has an influence in the perception that accounts for less strong differences for active and passive participants. However, as we performed controlled experiments and not a long term study, we only have little insight into the previous experience of the participants. We asked the participants about the frequency in which they use various communication mediums, but while the younger group had more previous experience, the differences were not statistically significantly different. The correlations between previous experience and perception were also not statistically significant.

Some of our participants reported in the discussion that the overall quality and the delay were never as bad as they had experienced it during some of their Skype sessions. This might indicate that besides the frequency, more data about the actual experience participants had in Skype before is necessary.

As our clustering by speaking time showed, the perception of a group with a delayed active speaker is not much different than the perception of a group with a non-active participant having delay.

5.4 Comparison dyadic and multi-party conversation

Our studies showed that a delay of up 650ms was barely perceivable by not so active participants and in most cases up to 1150ms a normal conversation could still be sustained.

These results are lower than the findings reported from previous research in dyadic communication [9][4]. Our findings are similar to the results from [11] which supports our results. We plotted our results from the symmetric conditions together with the results from Wang et Al. [9] and Berndtsson et Al. [11] in Figure 7. Since these studies differ in their setup and scenario this comparison is not meant to be a head-to-toe comparison, but to show general trends. In all three studies, the same question was used to investigate perceived quality (in Wang et Al. [9] a Chinese translation), only with different scales (5 point and 9 point). We adjusted the scores to a score from 0 to one between the minimum and maximum possible in the corresponding study. Since Wang et Al. [9] used the average length of talkspurts in a sentence influences the perceived quality under the different delay conditions, we computed average length of turns in our experiment (7.9s) and used this as a comparison base. It shows that the perceived quality in our multi-party study and the study performed by Berndtsson et Al [11] degrade much slower than the dyadic study by Wang et Al [9].

The main differences, besides the number of participants, is that Wang et al. [9] employed a scripted scenario. This is likely to also yield more sensitive thresholds. The study by Tam et al. [4], employed an unscripted dyadic conversation, and found strongly noticeable negative impacts at 500ms, suggesting a more relaxed threshold for unscripted conversation but stronger than for group communication. However, as they administered different questions and had a system conveying eye-gaze faithfully, the comparison is even more difficult (thus, we did not plot these results in Figure 7). Further Geelhoed et al. [10] reported that in their multi-party study, a delay of over 1000ms (one-way delay) has a surprisingly small negative impact and people could still have a normal conversation. In addition, this study is hard to compare since it used different questions and a high-end video-system (life-sized displays for every participant, faithful eye-gaze).

6. CONCLUSION

We investigated the effects of delays in video-mediated group discussions. Our results indicate that with between 650ms and

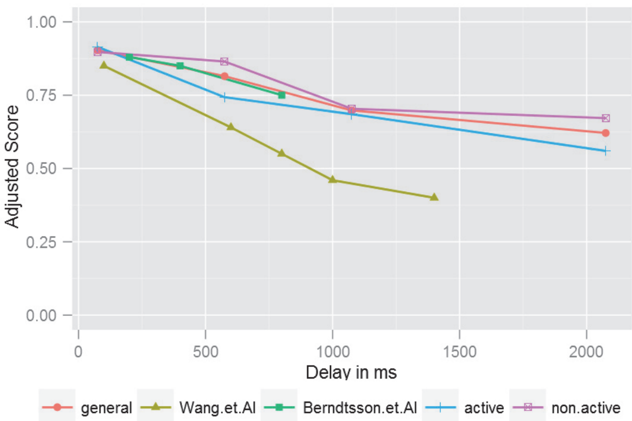

Figure 7 Comparison with Berndtsson et al [11], Wang et al [9]

1150ms of delay in the group, the communication is disrupted in a manner that participants become aware of it. For active participants this threshold lies between 100ms and 600ms. The presence of delay for one participant has a strong negative impact on the whole group experience. At 500ms introduced delay the experience is similar to the symmetric case and noticeable by active participants. With 1000ms the disruption is less intense than in the symmetric case, but similarly perceived by all participants in the group. This indicates that models who want to describe the QoE of participants in the whole group should incorporate the whole session.

The classification by activity shows lower boundaries for active participants. While in a group, participants might not be directly involved in the discussion in every moment, in a dyadic conversations both parties are always involved. This results in lower delay boundaries for dyadic conversations.

The disruption of a single participant towards the experience of the whole group, suggests the presence of a participant with high delay in the group, optimizing the delay to the lowest for each participant might not improve the QoE. For participants with a delay below 600ms increasing the jitter buffer and performing temporal synchronization, as these are influencing factors of QoE [12], can have priority.

7. ACKNOWLEDGEMENT

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