Effect of Occlusion on Deaf and Hard of Hearing Users' Perception of Captioned Video Quality *

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Abstract. While the availability of captioned television programming has increased, the quality of this captioning is not always acceptable to Deaf and Hard of Hearing (DHH) viewers, especially for live or unscripted content broadcast from local television stations. Although some current caption metrics focus on textual accuracy (comparing caption text with an accurate transcription of what was spoken), other properties may affect DHH viewers' judgments of caption quality. In fact, U.S. regulatory guidance on caption quality standards includes issues relating to how the placement of captions may occlude other video content. To this end, we conducted an empirical study with 29 DHH participants to investigate the effect on user's judgements of caption quality or their enjoyment of the video, when captions overlap with an onscreen speaker's eyes or mouth, or when captions overlap with onscreen text. We observed significantly more negative user-response scores in the case of such overlap. Understanding the relationship between these occlusion features and DHH viewers' judgments of the quality of captioned video will inform future work towards the creation caption evaluation metrics, to help ensure the accessibility of captioned television or video.

Keywords: Occlusion · Stimuli · Caption · Metric.

1 Introduction and Banckground

In recent years, the transcription accuracy of captions appearing on television programming has improved, a phenomenon attributed to the use of caption-evaluation metrics which allow efficient assessment of accuracy of captioned television broadcasts [29]. However, beyond the issue of whether the captions are an accurate transcript of the words spoken by individuals in the video, other factors are known to negatively affect DHH viewers' experience with captioned video, including whether captions occlude other visual content [10, 41]. The placement

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of captions can pose unique challenges for DHH viewers, such as reducing the overall amount of information viewers can perceive from the visual content [20, 21] or making it difficult to use speechreading if the face of the person onscreen is blocked by a caption [37, 42]. Captions can also block other important visual information content, e.g. non-verbal behaviors that indicate a speaker's emotional state; in addition, captions can block other onscreen text, e.g. headlines or scrolling "news tickers" on television news broadcasts [5].

Providing captions for spoken content is essential for providing full access to information contained in television programming, e.g. from TV news, talk shows, classes, meetings, and other sources. For instance, real-time captioned news is vital for providing DHH viewers access to critical information about their local communities, nationwide events, or emergencies [3]. Many specialized software and commercial vendors provide real-time captioning services for live television programming spanning news, current affairs, and sports [28]. There are many users of captioned programming, including people who are Deaf or Hard of Hearing (DHH), who constitute a large proportion of society. Over 360 million people worldwide experience hearing loss [9], and 15% of the U.S. adults are Deaf or Hard of Hearing (DHH) [8]. However, relatively few prior research studies with DHH participants have provided empirical evidence of how various visual properties of captions, e.g. onscreen placement, influence viewers' judgment of video caption usability.

While there exist standards and regulations in many countries about providing captioning during television programming, e.g. Federal Communication Commission guidelines in the U.S. [15], there is evidence that DHH viewers are not fully satisfied with the quality of the captioning, e.g. for live or unscripted television programming in smaller U.S. television geographic markets [4, 27]. To enable regulatory agencies or others to monitor the quality of captioning in various settings, metrics[1] are needed that can efficiently and accurately evaluate television captioning quality. While evaluation studies with DHH participants can be seen as a gold standard for such assessment, more automatic metrics would enable more frequent and pervasive monitoring of quality, as long as these metrics are well-correlated with the judgements of people who are DHH.

Prior automatic metrics for evaluating captioned television programming have largely focused on features relating to transcription accuracy, e.g. Word Error Rate (WER), Named Entity Recognition (NER), Closed-Caption Eval-

[1] Throughout this paper, we use the term "metrics" to refer to some formula or algorithm that can produce a numerical score to represent the quality of a captioned video, whether it requires some human judgements or is calculated in a fully automatic manner. Thus, a metric may consider various features, and research on the relationship between features and the judgements of DHH viewers is foundational to deciding to incorporate particular features into a metric. Furthermore, we use the term "features" to refer to the aspects or properties of captioned video that may contribute to its quality. For instance, some prior research has investigated how DHH individuals' judgements of the quality of captions may be influenced by: incorrect transcription of speech into text [32], the latency of the caption relative to the timing of speech [33], font size or color in captions [5, 7], and other features.

uator, Automatic Caption Evaluation (ACE) [1, 32, 4, 23]. Some metrics have considered latency issues, i.e. detecting when the timing of the appearance of caption text does not align temporally with the timing of spoken words [30–36]. However, there are emerging trends in the field of computer vision, which may enable such metrics to consider a new set of features, which we investigate in this paper. As the accuracy of automatically identifying people or text in videos increases, it will become possible to automatically calculate occlusion features, i.e. whether a caption blocks information that appears at a particular location and time in the video, e.g. a speaker's face or some onscreen text.

Prior research has suggested that such occlusions are a concern among DHH viewers of captions [10], and in this paper, we conduct a two-part experimental study to examine whether two such occlusion features (whether captions block portions of a speakers face, whether captions block onscreen text) influence DHH viewers' judgements about quality of captions in a video. Prior to incorporating such features into existing caption-evaluation metrics, basic research of this nature is necessary, to determine how they may affect DHH viewers' judgements of caption quality. Specifically, in our study, DHH participants indicated "how useful" captions were, how much they "enjoyed watching the video with the caption," and how "easy the captioned video was to follow" when viewing videos that varied according to these features. Thus, the contributions of this paper are empirical: We provide evidence that both factors have a significant effect on DHH viewer's judgements of caption quality. These findings provide motivation for future work into how to calculate such features automatically, for incorporation into caption-quality metrics.

2 Related Work

As discussed above, several researchers have proposed different techniques of measuring the quality of captions and identified some DHH users' preferred caption attributes while watching captioned TV programs. To contextualize our work within these prior efforts, section 2.1 explains features used within existing caption metrics, and section 2.2 summarizes prior empirical evidence of how appearance features of captions influence DHH users' TV-watching experience.

2.1 Existing Metrics of Caption Quality

A variety of metrics (both automatic and some requiring human judgements) have been proposed for the evaluation of television captioning quality, but these metrics have largely focused on the issue of text transcription accuracy and certain related features. For instance, Word Error Rate (WER) is the standard approach for evaluating automatic speech recognition systems [1], and this metric simply penalizes individual words that have been incorrectly inserted, deleted, or replaced – when comparing what was actually spoken (the "reference" text) and what the captions displayed (the "hypothesis" text). The Number, Edition

error, Recognition error (NER) metric [32] is a semi-automated metric that requires human experts to label the severity of individual errors in the text, to calculate an overall error score for a text. National Center for Accessible Media (NCAM) introduced a semi-automatic caption evaluation metric called the Closed Caption Evaluator, which is another weighted version of WER [4]. A recently proposed version of this metric is fully automatic, and it uses automatic speech recognition to analyze the speech in video broadcasts and then to compute the caption error using a statistical model [4]. While not proposed for evaluating television captioning (but rather for real-time captioning of live meetings), Kafle and Huenerfauth introduced the Automatic Caption Evaluation (ACE) metric, which uses an automatically calculated word-importance model [23]. This model considered the predictability of individual words, as well as the semantic distance between the reference and hypothesis word [23]. Furthermore, ERRICSON and BBC research unveiled an approach to reduce latency in live captioning. Specifically, they focused on reducing encoding and compensating time during live broadcasts [31]. Finally, a recent machine-learning model has been introduced to detect latency between audio and captions [30].

Although various metrics like those above have been proposed for evaluating the quality of captioned television programming, regulations often include provisions that captions should not only have high transcription accuracy but also have other desirable properties. For instance, regulation from the U.S. Federal Communications Commission has included provisions that captions be not only textually verbatim but also visually sound: Specifically, the caption should be complete, should be synchronously displayed with the speech, and should not conflict with any salient visual information [16] – in other words, it should not block other important visual content. However, these issues have not previously been included in prior proposed automatic metrics of caption quality.

While teams of human judges could view samples of captioned television programming to determine when some of these issues may be occurring, recent advances in several fields have made it possible to create software that can automatically process videos to identify which person in a video is speaking, or when captions may be blocking the faces of people in the video. For instance, in computer-vision field, researchers have created technologies which can be used for detecting human faces and onscreen salient text in videos. Some of these technologies include multi-frame fusion-based face recognition [39], natural scene text detection [40], and onscreen caption detection and type recognition [38]. Since it seems possible to soon identify these features in videos, research is now needed on whether these properties do influence DHH viewer's judgements of the quality of videos – and to what degree.

2.2 Features Affecting DHH Viewer's Perception of Captioned Video Quality

In addition to the features of text transcription accuracy and latency (discussed in the context of automatic metrics above), there has been prior experimental research to investigate how various other aspects of captions may affect DHH

viewer's judgements of their quality. For instance, previous work has investigated the effect of latency between caption appearance and speakers' speech, in real-time captioning circumstances [24, 25] and identifying the current speaker in a panel discussion [17]. Prior work has also examined how inserting correct punctuation or pauses during the captioned video can benefit DHH viewers and increase readability [19, 36]. Other researchers have investigated how DHH users' subjective impression of the readability and quality of captions is influenced by aspects of caption appearance, e.g. styles, font, and background [5, 12]. Prior experimental studies have also revealed that proper segmentation (caption boundaries aligning with syntactic boundaries) can improve caption readability [28, 36]. Finally, caption speed has also been found to affect DHH viewers' comprehension of captions [11]. In addition to research on these various features above, some prior work has been even more closely related to the focus of our study, i.e. on captions visually occluding salient video content, as discussed below:

Captions Occluding Portions of an Onscreen Speakers' Face: As discussed above, prior research has found that text-visibility in captions and video-content being blocked by captions are common concerns among DHH viewers [10]. While some recent televisions support users re-positioning captions to a different location upon request [12, 41], this is a relatively new feature, and it is unclear how often DHH users would actively use their remote control to change caption locations while viewing television programming. Other recent work has examined dynamically varying the placement of captions onscreen [22], in accordance with the underlying video content; however, this technology does not yet avoid occlusions with important video content and is still being evaluated with DHH viewers [35, 2]. While even captions that remain in one location on the screen have the potential to block important content onscreen, as new dynamic placement technologies emerge, there may be an even greater possibility for visual occlusions across a wide range of the video region.

The concern here is that prior research has found that while captions are essential for providing access to spoken content for DHH viewers, they have the potential to reduce the amount of information DHH viewers perceive from other visual content on the video, e.g. facial movements of the speaker or onscreen text [20, 21]. Captions blocking the face of the current speaker is a concern, as some DHH viewers may use speech and oral-based communication, e.g. performing speechreading while looking at the mouth of the speaker [37, 34, 42]. In addition, a prior experiment showed that even when an onscreen interpreter is present, DHH users still focus their gaze on a speakers' mouth for 12% of total television program time [37]. Thus, captions that block the mouth of the speaker may hinder the understandability, enjoyability and perception of captioned videos for such viewers. In addition, the facial expressions of the speaker may enable the viewer to understand the speaker's emotional state, as prior work has established that emotions are expressed through verbal and non-verbal forms, including body posture, facial expressions (e.g. raising or lowering the eyebrows), eye gaze, and etc. [26]. Thus, if captions block any of these portions of the body, the emotional

state of speakers may be less apparent to DHH viewers. Given this prior work, in our study described below, we investigate the impact of captions blocking the eyes or mouth of the speaker.

Captions Occluding Portions of Onscreen Text: In addition to the speed of speech, how dynamically scenes change, the number of onscreen speakers, and their visibility, research has also established the importance of caption placement onscreen. Specifically, the existence, number, and layout of onscreen text elements should also be considered before placing captions on the video [13]. Captions overlapping with other text onscreen can be particularly problematic for live news broadcasts, as captions can hinder the ability of DHH viewers to read textual information transmitted as part of the video itself. This text content may include the name of the person who is speaking during a news interview, the headline of the current story, or the news ticker at the bottom of the screen, which often features additional facts or headlines for other stories. A prior experimental study revealed that DHH users focused on non-caption onscreen text 7% of a TV program's total time [37]. However, we found no prior research that had investigated quantitatively the effect of captions occluding onscreen news text on DHH viewers' judgments of captioned video quality. Recently, researchers have proposed methods that can detect text that appears in a video, either when this text appears in the real world and is simply captured by the video camera (as in the case of a real-world sign that is within the video frame) as well as text that has been added to a video image digitally (whether static or horizontally scrolling) as in a live news transmission [38, 40]. Given these advancements, future metrics that assess the quality of a captioned video could penalize captions that block onscreen text, but research is needed to understand how such occlusion affects the judgements of DHH viewers.

3 Research Questions

As discussed above, prior work on automatic metrics of caption quality has not yet integrated occlusion features, i.e. information about the degree to which captions block other onscreen visual content that appears, potentially ephemerally, at a specific place and time in a video. As technologies emerge for automatically identifying speakers' faces or onscreen text in videos, there is a need to understand how occlusion of these forms of visual information may affect DHH viewer's judgement of the quality of captioned video. Therefore, in this study, we experimentally evaluate how variations in two such features may affect viewers' judgments of video quality, in the following research questions:

RQ1: Are DHH viewers' subjective judgments about whether captioned videos are useful, enjoyable, and easy-to-follow affected by whether captions overlap with the onscreen (a) speaker's eyes and (b) mouth?

RQ2: Are DHH viewers' subjective judgments about whether captioned videos are useful, enjoyable and easy-to-follow affected by whether captions overlap

with onscreen text containing the (a) current news headline and (b) other news headlines?

4 Methodology and Results

Our experiment consisted of one-hour appointments with a set of DHH participants, with each appointment partitioned into two time-segments: In the first segment, we conducted a study to investigate RQ1, and in the second, we conducted another study to investigate RQ2. This section provides an overview of both studies, beginning with details that were common across both studies. Later, individual sub-sections below focus on the details that are unique to each of these studies.

4.1 Study Design and Question Items

For both studies, a website was developed to display to participants several videos with different variations of occlusion features, and participants responded to questions, to provide their subjective impression of the quality of the videos displayed. For the first time-segment of this study, participants viewed three stimuli videos on a webpage in a side-by-side manner, in which captions: (1) overlapped with speaker's eyes, (2) overlapped with speaker's mouth, or (3) did not overlap with speaker's face at all. For the second time-segment of this study, three stimuli videos were shown, in which captions: (1) overlapped with onscreen text displaying the headline of the current news story, (2) overlapped with a scrolling news ticker displaying headlines for other news stories, and (3) did not overlap with onscreen text at all. After participants watched each stimuli on the web page individually, they responded to three subjective scalar questions, of which Question 1 was adapted from [23] and Question 3 from [5].

Q1: How useful did you find the captions? ("Usefulness" question)
Q2: Did you enjoy watching the video with the caption? ("Enjoyability")
Q3: It was easy to follow the video. ("Easy-to-follow")

4.2 Data Collection Procedure

This study was originally planned to be conducted as an in-person study, in which a researcher would sit with participants to introduce the study and answer questions, in American Sign Language or spoken English, depending upon the participant's communication preference. The participants viewed the stimuli videos on a web page on a computer, and they responded to questions by writing responses on a paper answer sheet. However, partway through collecting data from our 29 participants, the experiment had to move to an online remote format, due the need to maintain social distancing during the COVID-19 pandemic. Therefore, while for the first 3 participants, the responses to these questions were taken on paper, for following 26 participants, these questions

were embedded together with video stimuli in a survey hosted on SurveyMonkey. Our study had been approved by the university Institutional Review Board (IRB), and the modification of the study for online remote participant was also approved by the IRB prior to the final 26 appointments. We conducted the in-person segment of the study in our lab. A researcher started the experiment with participants by obtaining signatures on the informed consent form, and then participants filled out a demographic questionnaire. Next, the researcher showed participants the website (containing stimuli videos) that we had created and provided brief instructions about the study procedure. Then, a questionnaire form was handed over to the participants, consisting of the scalar and open-ended questions (described above), and participants responded to each set of questions after watching each video stimulus.

For the remotely conducted segment of the study, a researcher sent an informed consent form to our participants through email, which participants read and reviewed, prior to a video conference meeting between the researcher and the participant. Participants responded to a demographic questionnaire, which was presented as a Google Form. The researcher then sent the participant a link to the experiment, hosted on SurveyMonkey, which contained both the stimuli videos and the corresponding questions for each. We added a sample page at the start of the survey to familiarize our participants with the format of the study, to facilitate the researcher explaining the study procedure, which had been easier in the in-person format, since the researcher could point to on-screen elements of the survey.

4.3 Recruitment and Participants

Participants were recruited by posting an advertisement on social media websites. The advertisement included two key criteria: (1) identifying as Deaf or Hard of Hearing and (2) regularly using captioning when viewing videos or television. Participants received $40 cash compensation for either the in-person or the remotely conducted hour-long study conducted using a video-conferencing. A total of 29 people participated in the study including 14 females, 14 men, and one non-binary, aged 18 to 55 (median = 25). 19 of our participants identified as deaf and 10 identified as hard of hearing. All our participants except 2 reported regularly using American Sign Language at home or work. 20 of our participants reported that they began learning ASL when they were 9 years old or younger. The remaining participants reported using ASL for at least 2 years and that they regularly used it at work or school.

4.4 Sub-Study 1: Face Occlusion

For the first time-segment of the experiment appointment, we conducted our "face occlusion" study, to investigate how captions overlapping with the onscreen speakers' face during live captioned TV programming may affect DHH viewer's judgment of caption quality. There were three different placements of the caption shown during this study:

– captions overlapped with the speaker's mouth,
– captions overlapped with speaker's eyes, and
– captions not overlapped with the speaker's eyes or mouth.

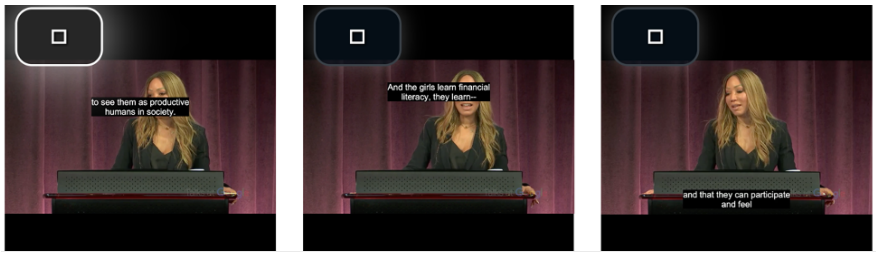
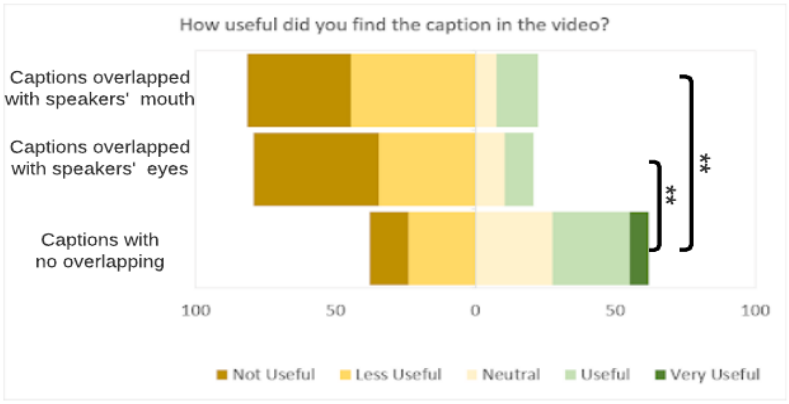


Fig. 1. Video stimuli samples from Face Occlusion sub-study.

For this study, we created nine video stimuli, based on video sources collected from the YouTube distribution channels from mainstream television news agencies. Each of these video stimuli was around 30 seconds long, and it consisted of a news broadcast with a single individual speaking. We avoided videos related to any sensitive, trending, or polarizing issues, in an effort to keep the content as neutral as possible. Our rationale for this selection was that videos containing these issues might lead to divergent reactions among participants. We truncated each video to the desired length using FFMPEG [14], an open-source video-editing tool. We extracted the caption files for each video, which consisted of Advanced Substation Alpha files. We manually inspected each caption file to ensure that there were no word omissions or other errors in the text, to prevent errors in text quality from influencing DHH viewers' judgements of the captioned video. We manipulated the settings within the caption file, to adjust the placement of the caption on the video. For the condition in which the captions overlapped with the speaker's mouth, we ensured that the overlapping occurs for the entire length of the video. Similarly, for "overlapped with eyes" condition, we ensured that the caption overlaps with speaker's eyes throughout the duration of the stimuli video. Finally, we embedded the caption file in the stimuli video, and we created three sample videos, for each condition, using the same source video.

Participants viewed three videos, with captions placed on different parts of the screen (speaker's eyes, speaker's mouth, and at the bottom), serially, and they answered three scalar questions for each video. Figure 1 shows the placement of captions on the screen in each of the three videos. A Greco-Latin schedule was used to determine the left-to-right placement of the videos and their assignment to conditions to video stimuli.

Figure 2 displays a divergent stacked bar graph (with the neutral response item plotted on the midline of the x-axis) for responses to the "usefulness question" (Q1), "enjoyability question" (Q2), and "easy-to-follow question" for the



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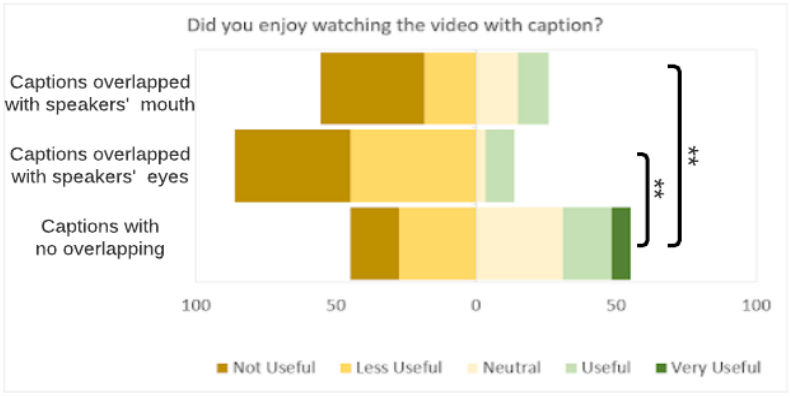

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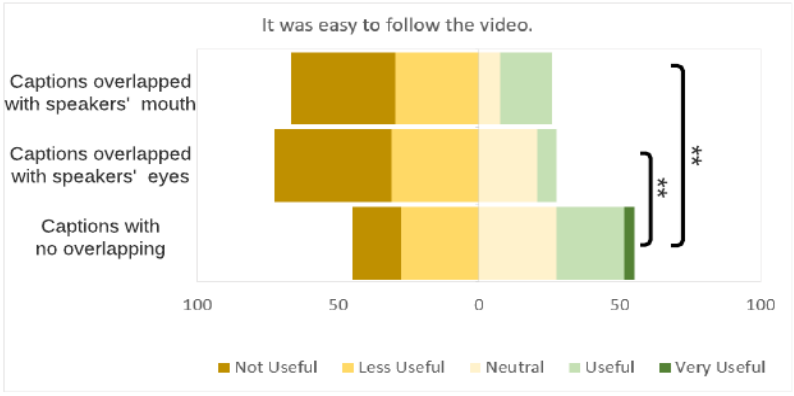


(c)

Fig. 2. Participants' subjective scalar responses for videos in each of the three conditions in the Face Occlusion sub-study, for for (a) How useful did you find the caption? (b) Did you enjoy watching the video with the caption? (c) It was easy to follow the video. Double asterisks ** mark significant pairwise differences ($p < 0.01$).

Face Occlusion study, across the three conditions. All significant pairwise differences are indicated with double asterisk (**) in the figure if the p-value is less than 0.01. The statistical analysis performed for the two questions is described below.

To evaluate the responses to the "usefulness question," a Wilcoxon Signed-Rank test was used. The results indicated that participants found captioned videos with no overlapping (Median=4) more useful than the videos in which the caption overlapped with speaker's eye (Median=2), ($Z = -3.3456, p < 0.001$). In addition, participants found videos with no overlapping to be more useful than videos in which the caption overlapped with the speaker's mouth (Median =2), ($Z = 2.6784, p < 0.01$). For the "enjoyability question," a Wilcoxon Signed-Ranks test revealed that DHH participants found captioned videos with no overlapping (Median =4) more enjoyable than videos in which the caption overlapped with speaker's eye (Median =2), ($Z = -3.0001, p < .01$), or than videos in which captions overlapped with the speaker's mouth (Median =2), ($Z = .00236, p < .01$). Similar results were observed for "easy-to-follow question": with users preferring no-overlap vs. overlap-with-eyes ($Z = -2.688, p < .01$), and preference for no-overlap vs. overlap-with-mouth ($Z = -2.6416, p < .01$). For each of the above mentioned question item, no significant pairwise difference between responses for the "overlap with eyes" condition and the "overlap with mouth" condition was observed.

4.5 Sub-Study 2: Text Occlusion

For the second time-segment of the experiment appointment, we conducted our "text occlusion" sub-study, to investigate how captions overlapping with onscreen text during live captioned TV programming may affect DHH viewer's judgment of caption quality. There were three different placements of the caption shown during this study:

- captions overlapped with onscreen 'current news' text (headline of the current story)
- captions overlapped with onscreen 'scrolling news' text (about other news stories)
- captions not overlapped with any onscreen text

For this study, we created nine video stimuli which were collected from the same video source as previous "face occlusion" study. These videos consisted of TV news and panel discussions which are identified by prior work as the video genres of the highest captioning importance [6]. In all of these videos, a region of the screen included some text indicating the topic of the current news story, and another region contained a scrolling text area that presented headlines for other news stories. Both regions were near the bottom of the video image. As in the earlier "face occlusion" study, we cautiously selected videos in which speakers discussed a topic, which was not related to any political or trending issues, so that participants would not have strong emotional reactions to the content.

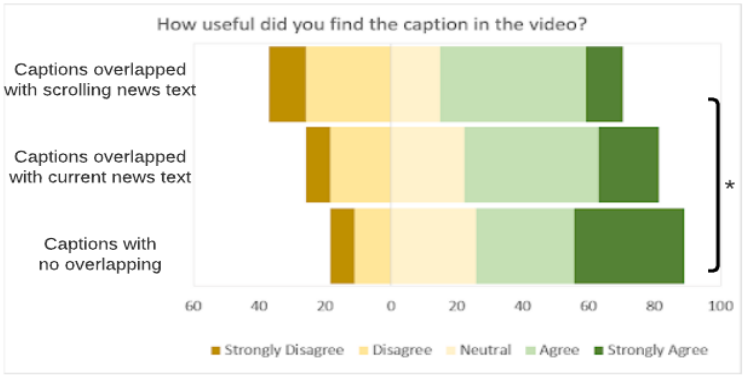
As before, to modify the caption transcript provided by the broadcaster, we extracted the caption file from the video source. Then we manually positioned the caption in such a way that a small fraction of 'current news' region (shown as black text on a white background in Figure 3) was visible to participants. The rationale behind this decision to reveal a tiny amount of the 'current news' text was that if captions would completely overlap the text, then participants might not be aware that this text existed in the first place. We also ensured that there were no errors in the caption transcript, as we did in the first sub-study. Using FFMPEG, we created a total of nine videos, i.e. 3 sample videos produced under three different 3 caption-overlap conditions.

Fig. 3. Video stimuli samples from second segment of the study.

Participants viewed videos, with captions placed on different positions such that it (1) overlapped current news text, (2) overlapped scrolling news text, or (3) did not overlap any text onscreen. On a screen that displayed three video stimuli side-by-side, participants viewed each video individually, and then answered the scalar questions after each. The left-to-right placement of the videos and the assignment of condition to each video was again determined using the Greco-Latin square method.

Figure 4 displays participants' responses to the "usefulness question" (Q1), "enjoyability question" (Q2), and "easy-to-follow question" (Q3) for the Text Occlusion sub-study across the three conditions. All significant pairwise differences are indicated with an asterisk (*), if the p-value is less than 0.05. The details of the statistical analysis performed for each question is described below.

For the "usefulness question," a Wilcoxon-Signed Rank test revealed that participants found captioned videos more useful when the caption does not overlap with any onscreen text (Median=4) as compared to videos in which the caption overlaps with scrolling news text (Median=3), ($Z = -2.0121, p < 0.05$). However, no significant difference was observed in the response to this question, for any other pairs of conditions. For the "enjoyability question," a Wilcoxon-Signed Rank test revealed that participants preferred captioned videos in which the caption does not overlap with any text on screen (Median=4) as compared to videos in which the caption overlapped with scrolling news text (Median=3), ($Z = -2.128, p < 0.05$). Finally for "easy-to-follow" question, similar results were observed: preference for no-overlap vs. overlap-with-scrolling-news



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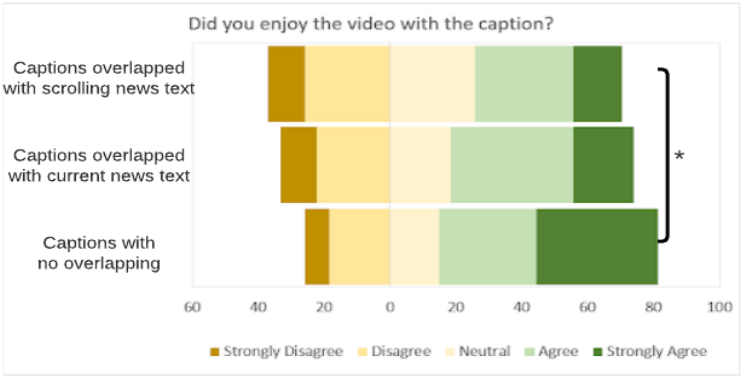

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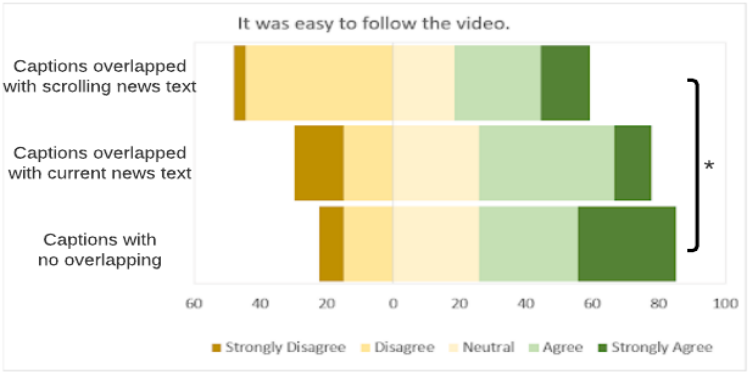

(c)

Fig. 4. Participants' subjective scalar responses for videos in each of the three conditions in the Text Occlusion study, for (a) How useful did you find the caption? (b) Did you enjoy watching the video with the caption? (c) It was easy to follow the video. Asterisks * mark significant pairwise differences ($p < 0.05$).

($Z = -2.2012, p < 0.05$). However, no significant pairwise difference between responses for the "overlap with scrolling news" condition and the "overlap with current news" condition was observed for any of these three questions.

5 Discussion

Our experimental studies had examined each of our research questions, which concerned how variation in occlusion features in a captioned video may affect the judgements of DHH viewers about the video's quality, specifically in regard to whether users found the captioned video useful or enjoyable to watch.

RQ1: Are DHH viewers' subjective judgments about whether captioned videos are useful, enjoyable, and easy-to-follow affected by whether captions overlap with the onscreen (a) speaker's eyes and (b) mouth? In the Face Occlusion sub-study, we observed that participants found captioned videos in which the caption did not overlap with the speakers face, to be more useful, enjoyable and easy-to-follow, as compared to videos in which the caption overlapped with the speaker's eyes or mouth. These quantitative findings provide an answer to both part (a) and (b) of research question RQ1. This finding aligns with prior work, which had highlighted DHH viewers' opinion with the captions overlapping with critical onscreen content [5]. This finding also establishes that the onscreen speaker's face (their eyes and mouth, specifically) should be considered essential onscreen content, which should be visible to DHH viewers. Our findings also integrate with results of prior gaze-tracking studies with DHH viewers, which had revealed that users spend a significant amount of time focusing on a speakers' mouth [37] for speechreading. Above all, future design of caption evaluation metrics should be informed by this quantitative findings to reflect DHH viewers' judgment accurately.

RQ2: Are DHH viewers' subjective judgments about whether captioned videos are useful, enjoyable and easy-to-follow affected by whether captions overlap with onscreen text containing the (a) current news headline and (b) other news headlines? In the Text Occlusion sub-study, participants' responses revealed that captioned videos in which the caption did not overlap with any onscreen text were more useful, enjoyable and easy-to-follow, as compared to videos in which captions occluded scrolling text displaying headlines for other news stories. Our results did not show any significant difference between videos in which captions did not overlap any text and those in which captions occluded the current news story. Thus, our study only provided an answer to part (b) of research question RQ2 - indicating that our participants were bothered by captions blocking scrolling news headlines about other stories.

In addition to providing guidance for future caption-evaluation metrics, as discussed above for RQ1, both sections of our study have also illustrated methodologically how empirical responses can be collected from DHH participants in studies with captioned video. Such participation is essential in research in this area, to ensure that DHH viewers' perspectives are considered in the design of caption-quality metrics.

6 Limitations and Future Work

There were several limitations in our study, some of which may suggest directions for future research, e.g. to generalize these findings to other groups of users or other video genres: Our study focused on DHH individuals that were recruited at a university, which reflects only a particular subset of the diverse DHH community. Future studies should examine the judgements of other potential users of captions, e.g. DHH individuals recruited from broader geographic settings or educational backgrounds, hearing individuals who may become DHH later in life, people with situationally induced hearing loss due to environmental noise, or specific sub-groups of the DHH community who prefer particular modes of communication (sign-language users vs. speech communication). In addition, a variety of educational factors or other demographic characteristics may affect how variations in these features may affect users' responses.

The motivation for our work has been to identify potential features for inclusion in new metrics for evaluating live television programs, where the near-real time context makes it more challenging for television broadcasters to provide high-quality captions. Given this focus, when preparing stimuli for our studies, we used videos of news broadcasts, including news anchors speaking to the camera, conducting interviews, panel discussions, or televised segments of speeches. Additional research would be needed to investigate a wider range of television genres, e.g. sports. A different set of critical onscreen content might be present in such videos, e.g. current scores during a sports competition, and such research may broaden the list of critical onscreen content that captions should not block.

Our study investigated DHH viewers' judgements of caption quality in regard to two specific questions, the usefulness of the caption (a question adapted from [23]) and how enjoyable the captioned video was. However, there are a variety of other measurement instruments that could be used to assess caption quality, either to gather further dimensions of subjective judgements, or to evaluate captions through some objective measure. For instance, our study did not explore the effect of occlusion on the understandability of onscreen text, which could be measured using objective comprehension questions.

While our study investigated two specific occlusion features, there may exist many other types of high-importance or high-information regions of videos which could be defined, which would further influence users' judgements of quality. More broadly, there are other features of caption quality that may have interaction effects with these occlusion features. For instance, in our "face occlusion" study, we observed the effect of one feature (captions overlapping with the speaker's face), for a set of videos that consisted of a single speaker in the video, and with perfect transcription accuracy. There is a potential for interaction effects between face-occlusion and other captioned-video qualities, e.g. the number of speakers in the video segment, the latency in the captioning, etc. In future work, a multi-factor study design would be needed to investigate whether such interactions may exist among caption properties.

7 Conclusion

Although transcription errors in live television captioning have reduced in recent years, with efforts driven in part by the availability of caption evaluation metrics [18], DHH users are still not fully satisfied with the quality of captions provided on live or near-live television broadcasters. Prior literature has suggested other important features of captioned video, such as whether captions occlude a speaker's face and other critical onscreen content. However, no prior empirical studies had examined the effect on DHH users' judgement of captioned videos from occlusion features, i.e. features relating to the overlap of captions with onscreen content that appears at particular times and locations in a video.

As discussed in our Introduction, to enable regulatory agencies responsible for monitoring the quality of captioned television programming to evaluate larger samples of captioned broadcasts, improved metrics are needed for automatically analyzing a captioned video to predict how it would correlate with DHH viewers' judgements. However, the currently available metrics do not account for whether captions occlude important video content, despite some regulations on caption quality that discuss this issue, e.g. [16, 15].

Herein lies the key contribution of this study, namely: This research has identified properties of captioned video content – occlusion features – and has quantified the extent to which they affect DHH users' judgement of captioned videos. Basic empirical research, to examine how such features influence DHH viewer's quality-judgements, is foundational to the creation of high-quality, automatic metrics for efficiently evaluating captioned television programming. Having demonstrated this effect on DHH viewers' judgments, future research can investigate this relationship and examine how such features can be incorporated into existing metrics, which focus predominantly on text transcription accuracy. Since being able to measure something is often the first step toward improving it, by supporting the creation of metrics that consider a broader set of captioned video properties, this work may lead to more accessible television and video experiences for DHH viewers.

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