

# Simplified Audio Production in Asynchronous Voice-Based Discussions

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## ABSTRACT

Voice communication adds nuance and expressivity to virtual discussions, but its one-shot nature tends to discourage collaborators from utilizing it. However, a text-based interface makes voice editing much easier, especially with recent advancements enabling live, time-aligned speech transcription. We introduce SimpleSpeech, an easy-to-use platform for asynchronous audio communication (AAC) with lightweight tools for inserting content, adjusting pauses, and correcting transcript errors. Qualitative and quantitative results suggest that novice audio producers, such as high school students, experience greater success and decreased workload when using SimpleSpeech to produce audio messages than without editing. The linguistic formality in the voice messages was also studied, and found to form a middle ground between oral and written communication media. **Our findings on formality and workload characteristics of the editable speech input draw fresh implications for determining optimal use case and future design of AAC systems.**

## Author Keywords

Speech editing; transcription-based editing; asynchronous audio communication.

## ACM Classification Keywords

H.5.2. User Interface: Voice I/O

## INTRODUCTION

Asynchronous audio communication (AAC) is rapidly becoming available to mass audiences through social platforms such as WhatsApp, iMessage, and Facebook. While text is still by far the most prevalent (and often most convenient) mode of communication on the Internet, audio is desirable in many situations because of its ability to convey more expression and nuance than text. For instance, Mayer's work on multimedia learning [?] indicates that audio communication is particularly useful for managing cognitive load where primary material is conveyed visually (e.g., by pointing), and in situations where an emotional connection between speaker

and listener is desirable. AAC holds considerable potential for improving online education, where voice communication has been demonstrated to improve student-student and student-instructor engagement as well as a sense of the instructor's social presence [15, 21, 27]. Our research is primarily motivated by the implications of AAC as a peer-to-peer educational tool, though it may also be applicable to other collaborative settings.

The problem with replacing textual communication with speech, however, is that speakers may face difficulty articulating their ideas vocally. For instance, **Marriott and Hiscock's** study using Wimba voice boards for discussion forums found that students overwhelmingly preferred text over speech comments, in part because it required them to speak fluently without making errors [20]. Since this problem affects students even in physical classrooms, it could certainly prevent some learners from participating in online oral discussions. AAC platforms in such situations, then, must somehow compensate for the linearity and immutability of audio on the production side.

Our solution is to provide lightweight, easy-to-use editing tools based on automatic speech recognition (ASR)-generated transcripts. Many prior studies have utilized transcription to assist in audio editing [6, 22, 31], but only recently has fast, live editing become possible through advances in ASR technology [7, 23]. We implemented an audio production tool, which we call SimpleSpeech, that allows users to delete and insert segments of the recording in real-time, simplifying quick word-level editing even when transcription errors are present.

Qualitative evidence indicates that SimpleSpeech's simplified interface gave users enough control over the editing process and enabled them to produce more polished audio comments in an online forum discussion. A subsequent quantitative evaluation with high school students showed that the mental workload of recording voice messages was significantly decreased with editing functionality, demonstrating that SimpleSpeech would be a valuable enhancement to online audio communication platforms. Finally, some linguistic characteristics of messages created using AAC are also discussed in comparison to other forms of communication, leading to new considerations and insights on optimal applications of this technology.

## RELATED WORK

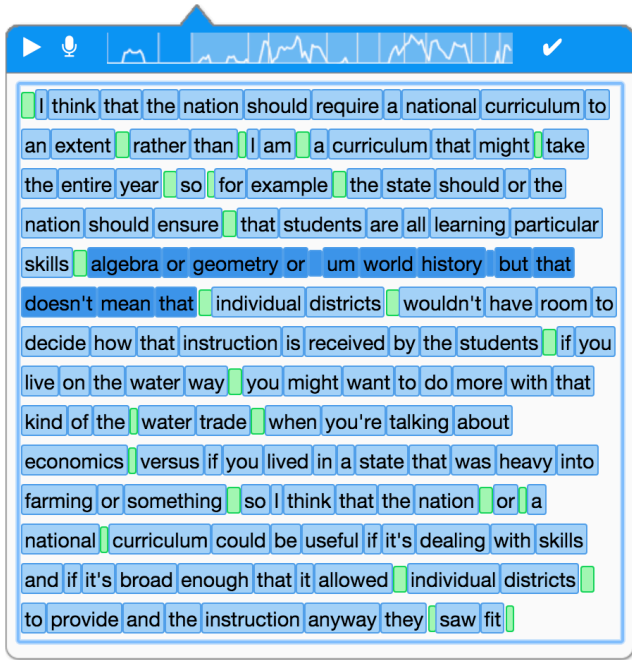
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**Figure 1.** The user interface for SimpleSpeech presents an automatically-generated transcription of a voice comment, which can then be manipulated through normal word-processing operations, such as selection, deletion, and insertion. Word and pause tokens are mapped with audio via time alignment data.

The linear, sequential nature of voice communication not only precludes skimming and navigation capabilities [10], but can also hamper the speech *production* process. Mistakes in recorded speech are harder to revise than textual typos, mainly due to the lack of lightweight voice editing software [19]. In addition, producing voice is a temporarily linear process which demands the commentator to think and speak simultaneously [19, 34]. Therefore, additional cognitive load arises from the fact that the speaker has to keep speaking to prevent undesirable long pauses. Building on the qualitative implications of these previous works, our study presents a quantitative measure about how such burdens are reduced when the voice production system includes lightweight editing features.

Since lower-level audio waveform editing is an onerous task, speech manipulation tools have been developed that present audio in semantically meaningful higher-level chunks, such as phrases. Acoustic detection of the presence of speech provides binary visual guidance so that users can edit or index the speech recording [1, 14]. On the other hand, a pure acoustic approach had limited resolution of the recognition granularity. Time-aligned automatic speech recognition (ASR) has become a popular tool to achieve the word-level structuring of speech [24, 32]. Compared with acoustic structuring, ASR brings higher temporal resolution with semantic information, but also suffered from high computation load and delay. However, recent technical developments have made ASR faster and more accurate, and we take full benefit of this real-time transcription capability.

Since speech transcription elicits the contents of the recording, researchers have utilized it to assist in visual skimming and navigation. MedSpeak [18] and SCANMail [8] were well recognized as a precursor of such systems that use time-alignment data of the transcript for indexing audio. Since transcription errors tend to obstruct visual comprehension, Vemuri et al. suggested a novel visualization of the transcript that adjusts transcription brightness to the word’s ASR confidence score [28].

On the production side, there have been several systems that use a time-aligned transcript for editing audio [22, 31, 33] or video [3, 6]. Among them, Whittaker and Rubin’s editing system leveraged users’ familiarity to text-editing interfaces, and adopted audio editing in that framework. Since we targeted non-professional users, our interface took the text-editing like approach, but was more geared toward supporting a *live* production process and going beyond editing already-transcribed speech. We thus present versatile features for supporting live production, such as voice insertion, pause extension, and fluid revision of transcription errors.

As in the case of listeners, ASR errors can be detrimental for understanding and skimming audio contents for the purpose of editing [11]. In the MedSpeak interface, Lai et al. provided a separate graphical window for fixing transcription errors [18]. In a speech production system like SimpleSpeech, though, users could easily get lost between the audio editing and transcription correction modes, so we chose to guide the user’s attention through these modes via the movement of the editing caret into a quasi-modal interface.

Pauses in speech deliver nuanced meaning such as hesitation or emphasis, so easy and powerful manipulation of pause duration is important. A system called SpeechSkimmer automatically condenses pauses for fast auditory skimming [2]. Other previous systems supported pause editing via a designated button [3] or specialized tags [22]. Rubin et al.’s system used the period key as a shortcut to insert the pause tags, but the duration of the gap was preset and required the use of a separate menu. Our approach is in line with the overall interaction concept of providing a text-like experience, and we adopted the more conventional delete key and spacebar for in-situ removal or arbitrary extension of pause tokens.

Perhaps most importantly, studies of the mental and linguistic effects of AAC discussion are limited despite the proliferation of AAC system designs. Those studies that exist are focused on the larger category of computer-mediated communication (CMC), which is dominated by textual media such as SMS, email, or Facebook posts. For example, Kiesler, Siegel, and McGuire [16] found more equalized group participation and more uninhibited expression of opinions in synchronous text-based CMC than in face-to-face discussions. Asynchronous CMC, similar to a discussion board, induces more prosocial behavior and, in fact, more informal communication styles over time than face-to-face [30]. On the other hand, formality and politeness in emails has been shown to increase as the social distance, status gap, and importance of a request increase [5]. How these findings about textual media relate to spoken modes of CMC has not been heavily investigated, however.

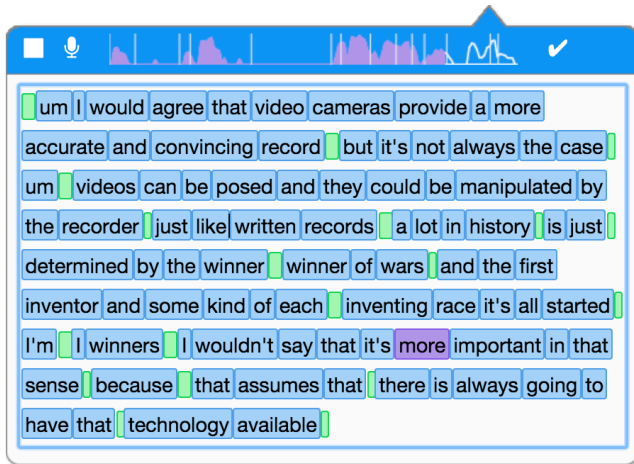


Figure 2. The waveform visual at the top of the SimpleSpeech editor does not support direct millisecond-level editing; instead, it serves as a visual cue connecting the transcript to the working recording. For instance, the waveform is highlighted during playback in tandem with the current word that is being played.

## DESIGNING SIMPLESPEECH

Building on the capabilities developed in these prior studies, SimpleSpeech is a web-based application for recording and editing short voice messages in a discussion setting (see Fig. 1). Design of SimpleSpeech is largely inspired by transcription-based speech editing systems in a strand of studies by Rubin [22], Yoon [33], and Whittaker [31], which also use ARS transcript as a semantic and visual proxy for supporting lightweight audio editing. In addition, some slight conceptual modifications were necessary to suit the “live” editing paradigm where the user is supposed to record and edit spoken comments in a rapid succession in real-time.

We followed an iterative procedure to progressively improve the design and interactions of SimpleSpeech. After building an initial prototype of the application, an informal pilot test was conducted with 5 participants (4 female, 1 male). Each user was given a brief introduction to the software and shown how to use the basic features, then given the scenario of creating an audio response to a written claim on an online forum. (The prompts used in the tests were adapted from the GRE Pool of Issue Topics.) The user feedback helped us improve the capabilities of SimpleSpeech, including adding a transcript editing quasi-mode and enabling pause insertion as following:

- *Pause manipulation.* An important finding in the pilot study was the importance of being able to introduce and adjust pauses between words, not just to remove them. These gaps in the audio help make natural-sounding cuts between audio clips as well as to punctuate claims (e.g., the end of a sentence). The original system only allowed the user to delete pauses, so we added a spacebar action to insert a fragment of silence from the original audio resource into the rendered message or to extend length of an existing pause token on which the cursor is prompting.

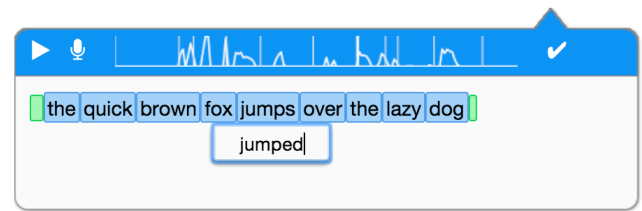


Figure 3. To keep the user interface from becoming cluttered with secondary functionality, the transcription editing feature was implemented as a modal interaction. The pop-up box shown above “opens” the selected tokens for text editing in a separate control element, thus notifying the user that he or she is no longer directly editing the audio.

- *Live insertion.* The users often misspoke a word or phrase in the middle of a message. Since re-recording entire message is a large burden, a partial deletion and re-recording capability was required. Our interface maintains a principle of text-major editing system that the cursor position plays a primary role indicating the focus of editing. Therefore, in SimpleSpeech, hitting the ‘recording’ button inserts new stream into a point of the existing audio that corresponds to the cursor position.
- *Modal caption editing.* In consideration of the message recipient’s good, the SimpleSpeech commentators wanted to correct ASR errors. However, we found that our versatile text-like audio editing interface might confuse the user between the audio-editing mode for revising speech and text-editing mode for correcting mistranscription. This lead us to design a separate modal window (see Fig. 3) that pops up while editing caption text so that the cursor can deliver a clear visual sense that the system is in a separate mode of text-editing, accessed by pressing the Return key.

Our text-based approach to speech editing requires a reliable transcription as well as time intervals corresponding to each word. Both of these requirements are fulfilled by the IBM Watson Developer Cloud speech-to-text transcription service, which is reported to have a word error rate of 10.4% [25].

## QUALITATIVE EVALUATION

The interaction paradigm of SimpleSpeech was tested in a qualitative assessment to determine (1) the practicability of a lightweight text-based audio editor, (2) the effects of minor transcription errors on audio consumption and production, and (3) the implications of being able to edit audio in an asynchronous online discussion.

Participants were introduced to the functionality of the system, then given two untimed tasks. First, to simulate an asynchronous audio discussion, the test users were asked to listen to an audio comment left by the previous tester and create an original audio response. Next, they received a different, textual prompt and created an audio comment which would be consumed by the next user. In both cases the user was asked to edit his or her recording to be polished and clear. The participants were interviewed at the end of the test; these interviews were transcribed with conversational elements filtered out. Themes were extracted from the remaining sentences via open coding, followed by flat coding to sort statements



among the themes. Cohen's  $\kappa$  between the two coders was .78, indicating the reliability of the categorized themes.

The sample for the study consisted of 9 test subjects (4 male, 5 female, mean age 21.6 yrs; henceforth denoted  $P_1, P_2, \dots, P_9$ ). All participants were native English speakers. Two individuals,  $P_2$  and  $P_3$ , were professional media editors who provided technical feedback and a comparison to pure audio editing. The remainder were interns at an educational company and high-schoolers at a summer program for gifted students.

## Results

The coding process revealed some themes that replicated the findings of Whittaker and Amento [31], as well as some novel results. For instance, the consensus was that a text-based editing paradigm provides sufficient control to render waveform manipulation unnecessary ( $P_4, P_5, P_6, P_8$ ). Most participants characterized the editing experience as a text-focused one as well as “more accessible, more doable” than pure waveform editing ( $P_3, P_7$ ), suggesting that the translation to text was a useful proxy for editing audio. On the consumption side, users found the transcript to be helpful in allowing them to “see all the points [the speaker was] making instead of having to remember them” ( $P_3, P_4, P_6$ ). Overall the presence of errors was not a heavy distractor from the content of the messages, echoing findings from Whittaker's voicemail study [8], although one user described a greater focus on the audio because of these errors ( $P_8$ ).

An important implication of these findings was the relative role of audio and text in SimpleSpeech usage. Some of the initial qualitative evidence did suggest that some users preferred to interact primarily with the transcript instead of the voice. Participants explained that this preference was due to the fact that “I learn from text a lot better” (participant number), or that they saw the tool as primarily for dictation (participant number); another possible reason was that they were initially more accustomed to text-based communication. However, participants also agreed that the expressive potential of voice was desirable, since “you can feel the emotions coming across, so ... you can still relate to what the persons feeling” (participant numbers). This result is consistent with prior studies [15, 21, 27] and indicates that text played the most significant role in *factual* comprehension, while audio was most useful for *tonal* comprehension. Since both audio and text seem necessary to the purpose of SimpleSpeech, we decided to maintain the combined paradigm throughout the remainder of the study.

In addition to these transcript-related results, the qualitative study also yielded the following new themes:

*The primary use of lightweight voice editing is to make fine-grained rather than large-scale adjustments.* The most commonly-used manipulation during the qualitative study was the removal of disfluencies ( $P_1, P_2, P_4, P_5, P_7$ ), followed by pause deletion ( $P_2, P_3, P_5, P_6, P_8$ ). Only  $P_1$  and  $P_8$  edited large chunks of audio by deleting or rerecording, and  $P_8$  reported doing so only to improve the smoothness of a smaller change in a sentence. Perhaps because Simple-

Speech was presented as a tool to be briefly used to “clean up” recordings, participants focused on removing the “embarrassing” and “awkward” sounds ( $P_1, P_5$ ).

*The linearity of audio leads to a pressure to organize one's thoughts during recording.*  $P_4, P_7$ , and  $P_9$  described a “psychological sort of ... need to get it all out, and the fact that it won't necessarily be as organized there.” Another tester,  $P_5$ , had “a tendency to get like a blank slate” in which he “couldn't think of anything to say.” The elevated mental task load that  $P_5$  describes could be inherent in oral discussion;  $P_9$  noted that “[it] might just be the fact that I was recording,” and that “editing would make it nicer.” The fact that users reported this pressure despite the capability to edit their recordings afterward is likely due to the previous theme of lightweight editing, and also because the pressure arose in the moment of recording rather than throughout the entire message-composition workflow.

*Awareness of the recipient and the editability of the audio drive up the quality of contributions.* Four users mentioned the formality of their recordings ( $P_1, P_5, P_7, P_9$ ), which they attributed to “an expectation” to edit, given that “I know that I've had that opportunity and someone else would know that I had that opportunity” ( $P_8$ ). The speakers' inclination to consider their listeners is exemplified by  $P_9$ , when asked why she was motivated to edit her messages:

Personally I'm editing to express myself a little more in a polished way when I'm writing.... especially if I know someone else is going to review it and be able to respond, I want to make sure I'm as clear as possible and as concise in a way that doesn't really come across when I'm talking.

Listening to another participant before initiating their own comment may have been a factor in determining the users' performance, since the exposure “gave ... an understanding of how long of a comment, or what kind of direction people were trying to take the discussion” ( $P_9$ ). Editing contributed to the increased quality as well: “Since you have the ability to edit things, it feels like you're talking to somebody who's prepared a point or a conversational view” ( $P_5$ ). The negative viewpoints of a few users on the editing ability were generally expressed in terms of formality, so we considered this theme important for the success of AAC. *Can you condense this section into a single paragraph? Though I really liked this quote, the description about the 'Awareness of the recipient' theme here is a bit verbatim.*

## QUANTITATIVE EVALUATION

Our second, quantitative experiment was conducted in order to validate the three original themes discussed above. In particular, we sought to determine if the formality aspect of AAC was real or simply perceived by the speakers, and to what extent it was affected by the ability to edit. These measurements would collectively assess the efficacy of SimpleSpeech and, indirectly, the usefulness of audio editing tools in general for educational discussions.

## Procedure

Two between-subject dimensions were studied: students versus teachers, as well as the formality of initial stimulus recordings (see “Stimuli and Formality Measures” below). In addition, the dimension of no-editing versus editing was studied on a within-subject basis. Participants in the study were given two task parts in random order: recording messages without editing functionality (the No Editing, or NE task) and using SimpleSpeech (the Editing, or E task). Each task consisted of “discussion threads,” in which users read a prompt statement, listened to another person’s opinion on the issue, then produced an original response. Participants responded to two threads for each task, for a total of four messages of about one-minute duration each. (Before starting the E part, participants were given a standardized tutorial to learn how to edit using SimpleSpeech.)

After each task, the NASA Task Load Index (NASA-TLX) questionnaire was used to quantify the pressure or mental task load of producing a voice message [12]. NASA-TLX is a subjective analytical tool that measures task load along six dimensions: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration. After rating the level of each aspect of mental workload from 1 (least workload) to 20 (greatest workload), the subject is asked to compare the scales pairwise to produce a weighted TLX value representing the overall pressure during a situation. Participants in the study completed the TLX procedure once after each task to obtain comparisons between the mental workload induced by no-editing and editing situations.

The quantitative study was conducted at a small suburban public high school in the midwestern U.S. with 28 volunteer participants (16 students, ages 16-18, and 12 teachers; 13 male, 15 female). This location was ideal for the study because the sample contained a variety of learning and speaking styles as well as different aptitudes for technology and discussion.

#### *Stimuli and Formality Measures*

The initial stimulus recordings for each of the prompt statements were generated by a group of five initial volunteers. Since the qualitative study had indicated the possibility that prior exposure to other individuals’ messages could affect users’ perception of formality in the discussion, we divided the stimuli into formal and informal sets. Half the participants of the study (Group A) listened to only formal recordings, while the other half (Group B) listened to only informal ones. We hypothesized that the participants in Group A would produce more formal messages due to the stimuli they received.

The criterion used for formality was the F-score, a measure of contextuality introduced by Heylighen and Dewaele in 2002 [13]. The F-score is a purely textual metric based on the frequencies of various parts of speech in a text: nouns, adjectives and prepositions decrease the contextuality and increase the F-score since they are independent of the circumstances around the text, while deictic words such as verbs, adverbs, pronouns, and interjections increase contextuality and decrease the F-score. For our stimulus recordings, the initial participants were asked to plan and edit some of the com-

ments and improvise on the others. After splitting the resulting messages by formality, the average F-score was 53.7 for the Group A messages and 49.4 for the Group B messages, reflecting the greater contextuality of the recordings produced on-the-fly. Group A stimuli also tended to use longer words than those for Group B (4.62 versus 4.38 letters) and tended to be more concise (113 versus 193 words). After obtaining and categorizing these messages, the voices were anonymized by adjusting the pitch randomly.

## **Results**

We analyzed the effects of the live voice editing features by analyzing system logs, speech contents, and the task load survey data. The results fell into the following three categories:

### *Utilization of SimpleSpeech Features*

As in the qualitative study, most participants appreciated and took advantage of the ability to edit their messages. They found the interface intuitive and natural, presumably due to familiarity with text-editing interfaces.

The amount of editing that users engaged in varied widely: on average, about 17.7 edits were made to each comment ( $SD = 17.5$ , including inserting a new recording, inserting a pause, deleting words, or deleting a pause). Of these changes, the vast majority were subtractive: 6.6 word deletions ( $SD = 11.5$ ) and 6.3 pause deletions ( $SD = 7.7$ ) per message. This was consistent with the previously-observed inclination to remove disfluencies and “awkward” hesitations from the recordings. Both teachers and students exhibited this impetus with no significant difference (12 deletions for students, 16.2 for teachers,  $p = 0.36$  by unpaired  $t$ -test), so misspeeches were fairly universal across participants. Insertions of any kind were less common, at 1.1 per message ( $SD = 1.9$ ), probably because users tended to correct themselves *post hoc* during the initial take and delete the mistakes afterward. **number** users went without performing any edits at all on at least one message; **number** out of these were teachers, and their messages were generally already fluent.

The average length of each comment was about 1 minute ( $M = 62.4$ ,  $SD = 32.4$ ). The mean word count per session was 130.1 ( $SD = 67.4$ ). There was no statistically significant differences in the speech length or word counts across the different conditions.

One error that several participants made was to use the Delete key on tokens to fix transcription errors, which resulted in the permanent deletion of that audio token. However, emphasis in the tutorial that the Delete key deleted the audio permanently did help other participants avoid making this mistake. Another misconception we observed in a few participants was a tendency to treat SimpleSpeech as a dictation tool. These users paused for long periods of time during recording sessions and neglected to play back the messages during editing. Furthermore, their inclination after stopping a recording session was to go back and correct transcription errors so that the visual representation made sense.

### *Effect on Task Load*

Since the NASA-TLX scale is subjective, it does introduce variability between participants due to the differences between their perceived skill at the task [12]. For instance, one participant could rate the recording task at a 3 out of 20, while another could rate the very same task at a 15. Therefore, the strongest comparisons of task load were made in the within-subject dimension, which was the ability or inability to edit.

Overall, the students reported significantly *lower* levels of mental task load or pressure during the E task than the NE task ( $M_E = 8.7$ ,  $SD_E = 3.0$  compared to  $M_{NE} = 10.8$ ,  $SD_{NE} = 2.3$ ,  $p = 0.011$  by paired  $t$ -test). The values for the individual components of the TLX, shown in Table 1, yielded the following contributory dimensions on the TLX questionnaire:

- *Temporal demand.* Students rated the temporal demand at 7.8 for the E task, significantly less than the NE rating of 10.2 ( $p = 0.037$  by paired  $t$ -test). As described by the TLX form, temporal demand refers to “time pressure due to the rate or pace at which the tasks or task elements occurred” [12]. Students verbally described the increase in time demand reported on the TLX in terms of having to think of words quickly, with the knowledge that every second not filled with speech would be an embarrassing silence.
- *Performance.* Students felt more concern about the quality of their messages in the NE task, with a marginally significant difference of 10.0 compared to 8.3 for the E task ( $p = 0.083$  by paired  $t$ -test). Just as the participants in the prior qualitative study had articulated a desire to make their messages better for the sake of their listeners, the students also evidently wanted to improve their recordings in the NE task. The inability to do so resulted in elevated task load due to performance, while for the E task the stress was lower because they were afforded the chance to correct their mistakes. However, it is worth noting that even despite the capability to edit, the student participants still rated Performance close to the middle of the scale, perhaps representing self-consciousness or comparisons with the stimulus recordings.
- *Effort.* Similarly to performance, students reported having to work significantly harder in the NE task to complete it to their desired level (rated 11.6 compared to 9.1 in the E task,  $p = 0.014$  by paired  $t$ -test). This increased effort could correspond to the additional mental activity which had to be expended in order to generate speech fluently and without excessive hesitation.

While the teachers also reported slightly lower average workload levels in the E task, as shown at the right of Table 1, this difference was not significant. In fact, 7 of the 12 participating teachers actually rated the E task as requiring a higher workload than the NE task. This subset of the teachers, 5 of whom were in Group A, reported an average task load greater in the E task than the NE task for *all* dimensions, especially Mental Demand, Performance, and Frustration. The reason for this rating, these teachers explained, was that the availability of the editing tools caused them to feel more worried about their performance. Editing in turn required them to expend more effort to preserve the existing fluidity of their messages.

Overall, the fact that the differences in perception of workload varied so much among teachers indicates that they were not as heavily affected by the ability to edit as the students, who clearly appreciated the security that SimpleSpeech offered.

#### *Speech Formality Between Subject Groups*

Contrary to the hypothesis that prior exposure to audio messages would affect the formality or linguistic traits of new messages, the F-scores of the participants’ output was unrelated to the group they were in, as shown in Fig. 2. The average F-score for students was slightly higher for Group A (55.83,  $SD = 10.1$ ) than for Group B (53.42,  $SD = 7.4$ ), but not statistically significant. The F-scores for teachers were almost distinguishable, with a difference of only 0.72. However, the students’ speaking rates in Group A were significantly faster than those in Group B ( $p = 0.016$  by unpaired  $t$ -test), which may reflect an auditory component of formality as observed by the qualitative test users.

Interestingly, the same teachers who reported higher task load in the editing task also produced more formal messages than the other teachers (mean F-score 56.6 compared to 53.1,  $p = 0.12$  by unpaired  $t$ -test), with longer words (4.58 compared to 4.36 letters), and fewer disfluencies (1.3 compared to 2.1 per 100 words). In fact, the student participant group also contained members who rated the E task as more demanding than the NE task, though fewer in number (4 out of 16); these students produced much more formal messages than their peers as well (57.9 compared to 53.5,  $p = 0.027$  by unpaired  $t$ -test). These participants could have had more experience speaking extemporaneously or felt less inclined to speak conversationally, ultimately leading to SimpleSpeech not being as useful to them.

Overall, the formality of the recordings was not affected by the stimulus message or even whether the participant was a teacher or a student. Therefore, considering that the F-score measures contextuality between the speaker and the audience, the principal sources of variation in F-score must have been personal aptitude and preference for the medium and the scenario of an online forum discussion.

#### **FORMALITY COMPARISON**

Contextuality in the online voice-based forum scenario could be highly indicative of AAC’s potential applications, and to our knowledge this trait has not been studied extensively. We therefore conducted a comparison between the voice messages composed during this study and several publicly-available corpora. To our knowledge, no corpus exists that was collected in an audio-text situation like SimpleSpeech, so contrasts in formality inevitably arise from the differences in medium.

The SimpleSpeech text, the focal point of the comparison representing AAC, contained 14,569 words from 112 messages. For written documents, we used several sections of the well-known Brown corpus to compile general categories of text: nonfiction, fiction, and technical writing (consisting of government documents, scientific articles, and news) [17]. We

	Students ( <i>N</i> = 16)		Teachers ( <i>N</i> = 12)	
Task	<i>E</i>	<i>NE</i>	<i>E</i>	<i>NE</i>
Mental Demand	9.6 (4.1)	11.1 (4.0)	11.4 (4.6)	10.8 (4.9)
Physical Demand	3.7 (2.4)	2.6 (1.9)	4.0 (4.6)	2.8 (2.0)
Temporal Demand	7.8 (4.2)	10.5* (4.2)	7.5 (4.8)	10.0 (4.6)
Performance	8.3 (2.6)	10.0 <sup>+</sup> (2.5)	8.5 (4.9)	9.7 (4.5)
Effort	9.1 (4.2)	11.6* (3.6)	9.8 (6.0)	10.4 (4.9)
Frustration	7.8 (4.3)	8.9 (4.1)	8.4 (5.6)	10.0 (5.9)
Total (weighted)	8.7 (3.0)	10.8* (2.3)	9.5 (4.2)	10.6 (4.5)

**Table 1.** The unweighted mental work load ratings reported by students and teachers from recording voice messages. *E* and *NE* refer to the tasks in which editing was allowed and disallowed, respectively. Each value ranges from 1 to 20, indicating the subjective level of task load that participants rated for each metric; standard deviation is reported in parentheses. (<sup>+</sup> –  $p < 0.10$ , \* –  $p < 0.05$ , paired two-tailed comparison of *E* and *NE*)

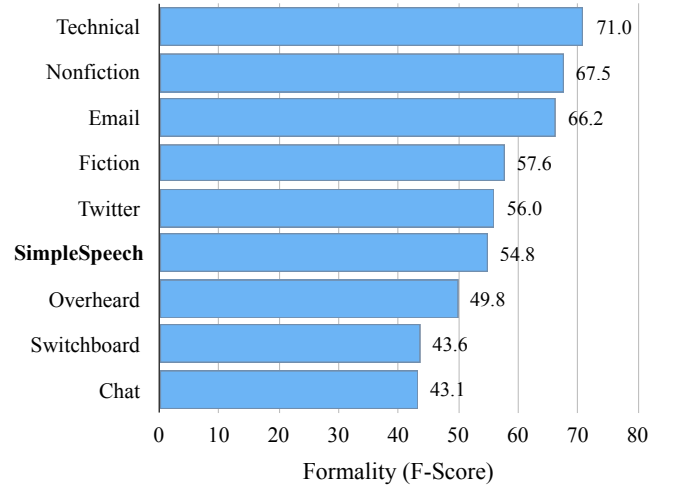
	Students		Teachers	
Group	A	B	A	B
Formality (F-score)	55.8 (6.42)	53.4 (7.34)	54.7 (7.68)	55.5 (7.49)
Word Length	4.4 (0.35)	4.4 (0.25)	4.5 (0.32)	4.5 (0.27)
Disfluencies (per 100 words)	1.6 (1.96)	2.4 (2.30)	1.3 (1.32)	1.4 (1.88)
Word count	101 (36.6)	140 <sup>+</sup> (71.5)	155 (95.2)	130 (46.05)
Speaking rate (words/min)	130 (28.4)	115* (21.8)	137 (33.4)	138 (34.22)

**Table 2.** Various metrics describing the formality of the audio messages produced by each participant group. Group A listened to more formal initial stimulus recordings than Group B. There were few significant differences in these criteria between the groups, indicating that formality was dependent on the general context of AAC as well as the speaker’s preference (especially for teachers). (<sup>+</sup> –  $p < 0.10$ , \* –  $p < 0.05$ , unpaired two-tailed comparison of groups A and B)

obtained chatroom text from the `nps_chat` corpus, face-to-face conversation data from the `webtext` corpus, and telephone data from the `switchboard` corpus, all available as part of the Natural Language Toolkit (NLTK) [4]. Finally, we also analyzed email communication in non-spam messages from the Enron corpus [26], as well as a corpus of Twitter posts [9].

The results of this comparison, shown in Fig. 4, illustrate the middle-ground that AAC takes relative to oral and written media. The least formal and most contextual corpora were those based on oral communication (with the notable exception of web chat messages), while the most formal and least context-dependent were the written texts, including email and Twitter posts. We will note three additional explanations for the formality of each medium based on the ordering of the corpora:

*Speaker-audience relationship.* Since the F-score is inversely related to contextuality, it is reasonable that the chat and telephone corpora had the lowest F-scores because the participants knew each other and were conversing on a one-to-one basis. On the other hand, the written forms of communication (with the exception of email) were more formal because the audience was defined more loosely and not necessarily acquainted with the speaker. AAC using SimpleSpeech was more closely related to the latter condition (as an online forum discussion), which probably contributed to its greater formality compared to the other spoken corpora.



**Figure 4.** The formality of corpora in different genre and media. The messages produced using SimpleSpeech during the quantitative study are intended to reflect general AAC discussion characteristics, and seem to be more formal than other spoken forms of communication but not as formal as email.

*Immediacy of communication.* The tendency to speak or write more contextually when the recipient must respond immediately helps explain why the online chat text, though written, was more contextual and less formal than the oral corpora. It also justifies the fact that the email corpus was more formal than all of the other direct communication media. Again, AAC falls toward the more formal end of this spectrum because there is little temporal proximity between the speaker and the audience.

*Tendency toward verbosity.* Media that pressured the creator to be brief or precise were more formal and less contextual. For instance, writing technical documents requires the preferential use of nouns over pronouns to maximize clarity. Twitter messages are, of course, limited to 140 characters, leading to a greater concentration of meaning that favors less contextual words. For AAC, therefore, the ability to edit could influence the contextuality if discussion members were pressured to trim down their recordings. For our study, however, the participants were not affected by verbosity; though non-edited recordings had on average 10% more words than edited ones, these edits were more concentrated on removing disfluencies than improving concision.

## DISCUSSION

In this study two forms of responding to pressure in a communication task were measured: the mental workload involved in completing the task and the degree of formality in the messages created in the task. Using this information, we will evaluate the strengths and weaknesses of SimpleSpeech as a tool for enabling AAC as well as the viability of AAC in educational and collaborative contexts.

### Imbalance Between Speaker and Listener

As Grudin notes, it is critical for collaborative software to spread the burden of usage equally on its constituent members. For instance, he cites email as a medium in which “everyone generally shares the benefits and burdens equally” [10]. On the other hand, voice applications create inequality between speaker and listener since the former must expect that the latter will listen thoroughly and carefully to the message, a relatively slow task compared to reading.

However, the premise of SimpleSpeech is that the bias toward the speaker is reversed. ASR transcription can greatly facilitate the listener’s task, as has already been demonstrated [8, 29], bringing the workload down and closer to that of reading. Meanwhile, students who record messages could experience a *greater* workload relative to writing because of the linearity of audio, which prevents them from correcting mistakes after the fact and thereby elevates the pressure to do well the first time.

SimpleSpeech was demonstrated to be a useful counterbalance in situations where the speaker’s workload is elevated. In the qualitative study, some users noted the pressure “to have organized thoughts” and to “sound composed more” during recording, but that “editing would make it nicer because you can go back and fix the mistakes” ( $P_2$ ). Furthermore, the level of control was just right for most users: since they focused on deleting the disfluencies and pauses in their

speech, the word-tokenized editor for the most part provided exactly the information needed to quickly delete undesirable sounds. For the few users who did want to edit on a larger scale, the audio insertion feature was deemed helpful as well.

In the quantitative evaluation, we found strong evidence to support the use of SimpleSpeech, especially for students. There was a significant decrease in task load on students when given the capability to edit, even in spite of the added time required to listen to the message and perform the editing. Several students mentioned relief at the fact that the voice comments they were producing in the NE task would be anonymized; considering that most applications of AAC would not afford them this security, editing would become even more important to students’ comfort level in voice communication. On the other hand, teachers did not find SimpleSpeech editing as useful, probably because they already perceived their recordings as being of acceptable quality. One teacher reasoned that he was “already used to hearing [his] own voice” from lecturing, a medium where statements cannot be retracted as easily as with SimpleSpeech. However, many teachers did use the editing tools, even though their workload levels were not significantly different with or without this opportunity. This would indicate that the editing tools are a valuable option for producers to have, but users should not be obligated to use them.

### Implications for Formality in AAC

Our comparative analysis of formality using Heylighen et al.’s F-score [13] is unique in its application to mixed-media discourse. While the corpora against which SimpleSpeech messages were tested were generated through either purely-verbal or purely-written means, users in this study were required to consider both the textual, semantic meaning of the transcript and the auditory, connotative meanings expressed by the voice. As a result, our comparison of contextuality scores inherently lacks the auditory component that may be communicated through slang, dialect, or speaking rate. We do not know of any one single measure that can capture these phenomena across different media. However, our findings are useful for describing the formality of the textual message content, which is arguably the primary purpose of the communication as well as the aspect on which message consumers focused most.

The textual formality of the SimpleSpeech discussions was not significantly affected by the experimental conditions, indicating that for the most part, users are likely to adopt their own style for audio messages without being pressured by the discussion context. Nevertheless, it is critical to the success of general-purpose AAC that the formality of discussion be controlled to some extent, so that collaborators feel willing to participate. Furthermore, for students this impetus toward quality is not as problematic, since they felt more relaxed rather than more stressed with editing functionality. If discussion quality were driven up by artificial means, however, such as by grading students on the eloquence of their comments or evaluating employees on the basis of their online interactions, then individuals might gravitate toward socially “safer” modes of communication over which they feel more



control (namely, text). Proper acquaintance with audio editing capabilities is essential for AAC's survival under these pressures toward high-quality production.

To provide an example, discussion groups within an online course would be an ideal use of AAC using SimpleSpeech because students could send messages to a well-defined audience, thereby compensating for the additional formality imposed by the spatiotemporal distance between the participants. The editing tools would also drive students to produce better discussion input, increasing productivity and enhancing the learning experience. On the other hand, enabling editing for personal communication, such as WhatsApp voice messages, would be detrimental to the desired informal speaking style of the platform. Since the contextuality demanded by each situation is different, future audio-based collaboration platforms must consider the factors presented here and tailor their functionality accordingly.

## CONCLUSIONS

SimpleSpeech represents a novel contribution to asynchronous audio collaboration because of its lightweight, easy-to-use live editing tools. Its functionality alleviates the pressure associated with the linearity of audio because users have the capability to easily remove superfluous words, pauses, and sounds as well as insert new phrases, all after the fact. Furthermore, we designed SimpleSpeech to be as intuitive as possible and to emphasize the synergy of audio and text, from the visual cues provided by the waveform to the modal interface for correcting transcription errors. Students' use of these editing tools resulted in them feeling much more comfortable producing comments for a general audience than they were without SimpleSpeech. The true utility of this software, then, was to (at least partly) un-linearize audio, even making it more text-like.

Because studies of the linguistic and social characteristics of computer-mediated communication have been mostly limited to textual interactions, we also explored the formality and contextuality of AAC. Our finding that it was roughly in between spoken and written media is not discouraging *per se*; however, the relatively formal characteristics of AAC must be taken into account before such a system is implemented in practice. Nevertheless, we feel that the small-scale edits that users engaged in during this study are reassuring for potential applications of AAC. Removing disfluencies and pauses allows users to feel comfortable with their recording while maintaining the spontaneity of thought in a spoken message.

The results of the qualitative study point to new directions for improving SimpleSpeech. For instance, on initial exposure to the application users initially tended to focus preferentially on the text instead of on the voice. Slightly different visual layouts of the application, such as overlaying or juxtaposing the transcription on a more prominent waveform, could help users understand better that the text is a secondary tool. Another possible feature could be automating certain edits, such as removing disfluencies and hesitations, to improve efficiency and edit quality even further. Additionally, the findings in our quantitative study revealed promising trends concerning the benefits of AAC for online discussion, but may

need a larger pool of test participants to attain statistical significance.

Our hope in developing SimpleSpeech is that asynchronous audio communication will gain greater usage in education and other collaborative settings. With the combination of ASR transcription for listeners and low-barrier editing tools for speakers, voice-based communication tools can engage students and improve the quality of collaboration on the Web.

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