SlidePacer: A Presentation Delivery Tool for Instructors of Deaf and Hard of Hearing Students

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ABSTRACT
Following multimedia lectures in mainstream classrooms is challenging for deaf and hard-of-hearing (DHH) students, even when provided with accessibility services. Due to multiple visual sources of information (e.g. teacher, slides, interpreter), these students struggle to divide their attention among several simultaneous sources, which may result in missing important parts of the lecture; as a result, access to information is limited in comparison to their hearing peers, having a negative effect in their academic achievements. In this paper we propose a novel approach to improve classroom accessibility, which focuses on improving the delivery of multimedia lectures. We introduce SlidePacer, a tool that promotes coordination between instructors and sign language interpreters, creating a single instructional unit and synchronizing verbal and visual information sources. We conducted a user study with 60 participants on the effects of SlidePacer in terms of learning performance and gaze behaviors. Results show that SlidePacer is effective in providing increased access to multimedia information; however, we did not find significant improvements in learning performance. We finish by discussing our results and limitations of our user study, and suggest future research avenues that build on these insights.

CSS Concepts
• Human-centered computing---Accessibility---Accessibility systems and tools • Social and professional topics---User characteristics---People with disabilities

General Terms
Measurement, Design, Experimentation, Human Factors.

Keywords
Deaf, Learning, Pace, Lecture, Interpreter, Multimedia, Visual Sources, Presentation.

1. INTRODUCTION
Over the past decades there has been a change in the face of deaf education. In the United States, the Education for All Handicapped Children Act (Public Law 94-142), passed in 1975, combined with the 1990 Individuals with Disabilities Education Act (Public Law 101-476) assured free and public education for children with disabilities. Since then, the number of deaf and hard of hearing (DHH) students in integrated or mainstream classrooms has increased considerably [28]. Still, DHH individuals struggle to achieve academic parity with their hearing peers [17].

A major assumption underlying mainstream education is that support services, such as sign language interpreters, provide access to classroom communication comparable to that of their hearing peers. Yet, the visual demands of learning through sign language interpreting are usually ignored. In addition to the interpreter, a typical university-level classroom includes the instructor and slides. In fact, educational researchers often cite the dependence of deaf students on the visual modality and encourage the use of visual materials and displays in the classroom [9, 11, 16]. Ironically, this practice forces students to divide their attention and rapidly change across simultaneous visual sources (interpreter, instructor, and slides), often resulting in missing critical information [10, 14, 18]. Thus, even though information is presented, students may not be able to simultaneously attend to all of it because their visual channel becomes overloaded. Moreover, because the interpretation and the instructor's spoken feedback are not synchronized, the likelihood of misunderstanding information on slides increases even more.

Previous work on classroom technologies has focused in assisting DHH students in managing multiple visual sources by integrating multiple views in a single screen and directing their attention to changes [2, 6, 7, 12]. However, students still have to integrate multiple (unsynchronized) sources of information, which takes working memory resources that could be used for learning [1].

Our work explores a different research avenue. Rather than focusing on the already overloaded student, we investigate how technology could facilitate and improve the delivery of instructions in mainstream classrooms to fit DHH students' learning needs. Instructors are often unaware of the specific challenges of DHH individuals and how to deal with them. To this end, we developed SlidePacer, a system that promotes better pacing behaviors for classroom multimedia presentations. The system opens a communication channel between interpreters and instructors, creating a single cohesive instructional unit, while synchronizing verbal and other visual resources (i.e. slides).

We base our design on cognitive load theory [29] and educational research. In fact, pace of instruction is widely mention as one of the main problems faced by DHH in mainstream classrooms, preventing them to access all classroom communication and engage in active learning (e.g. through participation) [3, 5, 8, 10]. Additionally, evidence from cognitive psychology research shows strong relationships between instructional pace and learning performance, particularly when using multiple sources of information [4, 20, 22]. Yet, there is a lack of empirical evidence on the effectiveness of adjusting the pace of instruction in mainstream classrooms. Therefore, our goal with this work is two-fold: 1) promote an adequate instructional pace by temporally

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integrate disparate sources of information, thus freeing cognitive resources for learning; and 2) assess the effectiveness of our approach by measuring learning performance.

We conducted a user study with 60 participants aimed at understanding whether SlidePacer enables more effective learning in multimedia classrooms. Results show higher access to visual materials. Learning performance was also higher than the control condition, although we did not find a significant effect.

The contributions of this paper include, first, SlidePacer, a novel system informed by multimedia learning and educational research that promotes a change in pacing behaviors. Second, we present results on the learning effect of our tool on both DHH and hearing participants. Third, we analyze the perceptions of students about presentations' pace. We close by discussing our results.

2. RELATED WORK

We discuss related work in three areas: first, we analyze previous work on multimedia learning and its implications for instructional design. Second, we discuss cognitive psychology research aimed at understanding how DHH individuals learn in mainstream classroom environments. Finally, we describe previous attempts to improve classroom accessibility using new technologies.

2.1 Multimedia Learning

Cognitive load represents the amount of mental effort in use in the working memory, which has a limited processing capacity. The cognitive theory of multimedia learning states that our working memory is capable of processing information received from visual and auditory channels simultaneously [19]; thus, separating content over both channels reduces the load on working memory.

For instance, aligning graphics (visual materials) to spoken text can be better processed in working memory rather than non-simultaneous information [19]. This is usually what happens in a classroom where hearing learners receive information through the auditory channel (speech) and visual channel (e.g. slides, notes). On the other hand, DHH students are at a disadvantage in comparison to their peers, since they do not have the opportunity to segregate verbal and visual information.

DHH learners need to be constantly shifting their attention between visual sources (lecturer, slides, accessibility services) in order to access information. As expected, this split-attention behavior impairs learning [1]. Although research in cognitive science has shown that aligning verbal information with graphics have clear benefits in retention and long-term recall [25, 30], most mainstream classrooms do not take into account these recommendations. The cognitive overload of learners prevents them to engage with information and organize the material in a rational structure, thus inhibiting the integration of the new content with the prior knowledge in the long-term memory [20].

Nevertheless, previous research has shown that presenting content sequentially and at a slower pace may have benefits, particularly when content is complex or words are unfamiliar [20, 22, 24]. Our work aims to leverage this knowledge as a new delivery tool.

2.2 Learning and Deafness

Previous studies [14] that investigate the differences between DHH (with interpreting services) and hearing students when accessing classroom content show that DHH students take away less from classroom lectures presented via sign language interpreting as compared to their hearing classmates. However, that difference does not appear to be related with either students' sign language skills nor interpreters' skills. Interestingly, Marschark et al. [14] do not provide a clear explanation on why removing the obvious communication barrier in mainstream classroom does not provide DHH learners with sufficient access to learning at a level comparable to their hearing peers.

Nevertheless, in a series of following experiments, the authors aimed to understand the extent to which interpreting provides deaf students with true access to education by comparing direct (instructor uses ASL) and mediated instructions (via ASL interpreter) [15]. Results showed that direct and mediated instructions can be equally effective; however, the quality of instruction for deaf students is more important than mode of communication per se; that is, when the class is well designed, there is no learning "gap". This highlights the importance of presentation delivery in classrooms.

Despite more than 40 years of research on the challenges that DHH students face in classrooms [13, 15, 26], there is little work done by cognitive scientists on potential solutions or guidelines to solve these issues, which include students not being able to attend to two different sources of visual information, classroom pacing, interpreters not being fully qualified, and interpreters being confronted by multiple conversations and interruptions,.

Previous studies have shown that instructors assume that the presence of support services is enough to guarantee an effective teaching [10]. In this paper, we offer a technological solution to be used by instructors and interpreters to delivery better presentations. Although it is still not clear what are the main characteristics of an effective class, lecture pace is perceived as one of the most important by DHH students and faculty [8].

2.3 Classroom Assistive Technologies

W3C offers a set of guidelines on making presentations accessible to all[1]. Still, these guidelines mostly focus on creating accessible presentation documents or general advice on content delivery, such as speak clearly, use simple language, and so forth.

ClassInFocus [2] attempts to assist DHH students in mainstream classrooms with the split-attention problem; that is, managing multiple visual sources. The system merges all visual sources in a single window and automatically notifies students of change in any visual source, such as slide changes. Results showed that students who gathered information from multiple visual sources performed better on content learning. Moreover, the tool enabled a reduction of visual dispersion.

More recently, Kushalnagar [7] addressed the same problem by leveraging hearing students' eye gaze to create reference cues in lecture videos. It was found that students who liked these cued notifications were more likely to demonstrate reduction in delay time associated with shifting visual attention. Lasecki et al. [12] investigated pausing and highlighting to help DHH students to keep up with classroom captioning. Results showed that the tool was effective and helped them to follow visual content that might otherwise have been missed.

Although some attention has been given to the split-attention challenges that DHH face in mainstream classrooms, all these new technologies put an extra cognitive (and sometimes physical) load on the students. On the other hand, much less attention has been paid on helping instructors and accessibility services in addressing DHH learners' needs. Moreover, it is crucial to assess the effect of technological interventions in terms of learning performance. Some studies solely rely on learning preference; however, there is

[1] https://www.w3.org/WAI/training/accessible

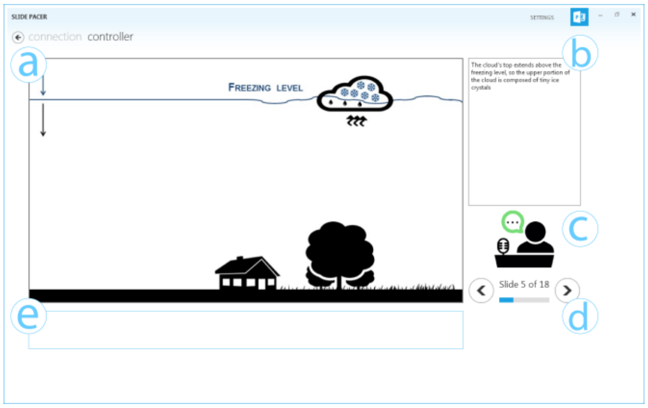

Figure 1. SlidePacer – presenter interface: a) current slide, b) presenter notes, c) illustration representing whether the instructor should wait to start speaking again; d) slideshow controls; and e) notification area.

little correspondence between students' perceptions of lesson effectiveness and actual instructional value [27].

3. SLIDEPACER

Previous research has shown that presentation delivery pace has an effect on learners' retention and understanding of information [20, 22, 24]. The effect is most noticeable when learners' working memory is overloaded with information. This is often the case for DHH students that receive all instructional content (verbal, images, text, etc.) via visual channel. Despite this knowledge there is a lack of delivery and practice tools for presenters that promote adequate pacing behaviors.

3.1 Design

SlidePacer was designed to reduce information overload on learners by promoting a change in pacing behaviors during the delivery of multimedia presentations.

The main goal is to coordinate presenters and interpreters, turning them into a single unit of content delivery, and enabling DHH learners to read slide's content. We encourage presenters to wait for interpreters before advancing with the slideshow. Notice that interpreters can lag behind due to several reasons, such as: inherit overload related with interpreting (listen, understand, build interpretation, and verbalize), presenter's speech speed, complexity of content, etc. The lack of synchronization can dramatically hinder DHH learners' understanding of content, especially when there are references to visual materials.

SlidePacer reduces the lag between instructor and interpreter, and then waits for learners to shift attention and read visual materials. This gives DHH learners the opportunity to access slides, which are often missed in fast-paced presentations. The tool is intended to be used in mainstream classrooms and comprises two components: 1) a PowerPoint add-in to be used by instructors, and 2) an Android application to be used by interpreters. Both components are connected and communicate with each other in order to coordinate instructors and interpreters.

3.2 Instructor

The instructor component was implemented as a PowerPoint add-in. This means that SlidePacer works with any PowerPoint presentation file. We chose PowerPoint due to its popularity as a slideshow authoring tool. In order to use SlidePacer, which is a delivery tool, instructors need to enable the add-in. Once in presenter mode, SlidePacer consists of a familiar interface, similar to PowerPoint's built-in interface (Figure 1). SlidePacer was developed as a C# WPF application.

By default, SlidePacer behaves as a traditional presenter view with the same next/previous controls. However, if there is an interpreter available, instructors can connect to his/her app through Bluetooth. From then on, when they change slide, SlidePacer attempts to synchronize both interpreter and instructor by waiting for the interpretation to finish. Notice that the slide still has not changed at this point, since DHH students have not had the opportunity to see it. Pressing the forward/backwards key twice overrides the waiting time.

After the interpretation is finished there is a delay in order to give DHH students the chance to read the slide, before advancing to the next one. In the current implementation, the delay is a fixed but configurable value. Depending on the complexity or amount of content on each slide, the instructor can set the most appropriate delay in the settings menu. While waiting, instructors receive feedback through the presenter view, whether they are waiting on the interpreter or students (Figure 2).

3.3 Interpreter

The interpreter component has two main functions: 1) inform the interpreter that the instructor intents to advance the slideshow, and 2) inform the instructor that the interpretation is finished.

The component was implemented as an Android application. We first prototyped and informally tested a mobile app with professional interpreters. Feedback collected from 3 classroom interpreters showed that notifications needed to be subtle and inconspicuous, since they already deal with high cognitive load while performing their jobs. Moreover, all interactions should be eyes-free, short, and require minimal attention in order to keep users focused on their main task: interpreting.

Our final implementation consisted of a mobile and a companion smartwatch app. The app uses visual and vibrotactile feedback to inform interpreters that an action is required. When the instructor changes slide, the smartwatch gives a short (1 second) vibrotactile stimulus and changes the screen color to red (Figure 2). When the user finishes interpreting, s/he performs a single tap anywhere on the screen. This indicates that students are now free to look at the slides. After a delay (see previous section) the slide changes and the workflow restarts. Through this simple coordination

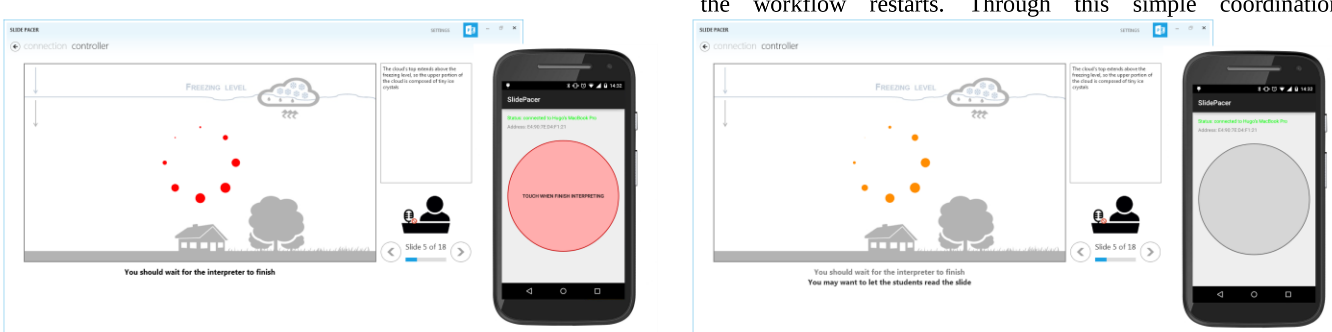

Figure 2. From left to right: presenter view waiting for interpreter to finish; mobile app is waiting for interpreter input to signal that interpretation is finished; presenter view waiting for students to read slide content; mobile app is inactive.

mechanism in presentation delivery, we aim to provide DHH students with the opportunity to access multimedia content. Possible side effects of using SlidePacer are longer presentation times. Overall, we believe this to be a small limitation when considering we are providing both hearing and DHH students with equal access to information in classroom environments.

4. EVALUATION

This study focuses on assessing the effects of using SlidePacer during delivery of multimedia content. We conducted a laboratory study, replicating a validated experiment from the field of cognitive psychology to measure learning performance using multimedia presentations [19–21, 24].

4.1 Research Questions

We aim to answer five main research questions: 1) Is SlidePacer effective in improving learning for DHH students? 2) Does SlidePacer improve DHH students' access to visual materials? 3) What is the learning effect on hearing students? 4) What is the relationship between DHH and hearing students performance? 5) What are students' perceptions about the lecture's pace?

4.2 Participants

Sixty participants took part in this study, 30 deaf and hard-of-hearing and 30 hearing. They were recruited at the Rochester Institute of Technology through flyers around the campus. Participants first filled an online screener questionnaire where they self-reported ASL skills. Participants were eligible for the user study if they 1) reported fluency with ASL (i.e. able to express yourself easily, articulated, and understand others), 2) used ASL on a daily basis, and 3) requested ASL services in mainstream classrooms. This criterion was only applied to DHH users. In addition, all participants needed to be college/university level students. Eligible participants were emailed to schedule their session and were assigned to one of two conditions: lecture without SlidePacer (control) or with SlidePacer. Participants were given a $20 compensation for their time.

4.3 Apparatus

To ensure internal validity and consistency, we used pre-recorded videos to simulate a classroom lecture. The lecture was about the process of lightning formation [19–21, 24] and featured an instructor, interpreter, and slides displayed in 3 similar computer monitors. We recorded two lectures; one with SlidePacer (5 minutes) and one without (control condition, 2 minutes and 20 seconds). An American graduate student acted as an instructor reading from a script, whereas a professional classroom ASL interpreter volunteered to record the lectures. He had access to the instructor's script in advanced in order to practice before the recording session. This was done to guarantee consistency in ASL instructions and to make sure all vocabulary was known beforehand. Slides illustrated verbal instructions and contained minimal text (Figure 1). We made sure both lectures were similar: same content, verbal instructions, and slides. The only difference was the pacing of the lecture and the interpreter's (subtle) interactions with the SlidePacer app. SlidePacer's delay between the interpretation and change of slide was set to 5 seconds.

During the experimental sessions, the computer displays were placed adjacent to each other in front of participants. The left monitor showed the slides, the middle monitor showed the ASL interpreter, and the monitor at the right showed the instructor. Participants had no control over the pre-recorded videos. Also DHH participants had no access to audio feedback in order to control for auditory abilities. They were asked to sit facing the middle screen, which had a built-in camera that was used to record the participant's face. These recordings were later used to analyze participants' eye gaze.

4.4 Procedure

At the beginning of each evaluation session, participants were told that the overall purpose of the study was to investigate how we could improve the delivery of multimedia lectures in mainstream classrooms. We then handed out the informed consent, which explained the experimental setup and procedure.

Before starting the lecture, participants were asked to fill a pre-questionnaire about demographic information, fluency in ASL, and previous knowledge of lightning formation [20]. They were asked to fill in a 5-point Likert scale ranging from very little to very much, to the questions: *1) I regularly read the weather maps in the newspaper / online; 2) I can distinguish cumulus and nimbus clouds; 3) I know what a low pressure system is; 4) I can explain what makes the wind blow; 5) I know what this symbol means ▲▲▲. 6) I know what this symbol means ◠◠◠.*

After filling the pre-questionnaire, depending on their experimental condition, participants were informed that slideshow would advance after the interpretation was finished for the current slide (SlidePacer) or as the instructor spoke (control). After the lecture, participants were given a post-questionnaire with two questions: *1) how difficult was it for you to learn about lightning from the presentation you just saw? and 2) what do you think about the pace of the presentation?* Both questions had a 7-point Likert scale ranging from *very easy* to *very hard*, and *very slow* to *very fast*, respectively.

Afterwards, participants were given 20 minutes to complete two tests (10 minutes each) to assess their learning performance. The session took on average 45 minutes.

4.5 Dependent Measures

In this study we leverage the concept of *deep learning* [22], which is defined as "attention to important aspects of the presented material, mentally organizing it into a coherent cognitive structure, and integrating it with relevant existing knowledge". Learning is the ability to retain knowledge and apply it to new situations [23]. Therefore, we measured learning performance by using *retention* and problem-solving *transfer* tests. In addition to asking whether participants can recall what was presented in the lecture (*retention* test), we also ask them to solve novel problems (*transfer* test). Although learners may perform satisfactorily on retention tests, deep understanding may be limited.

The *retention* test consisted of the following instruction: *Please write down, to the best of your ability, a detailed explanation of how lightning works*. The *transfer* test contained the following 4 questions: *1) What could you do to decrease the intensity of lightning? 2) Suppose you see clouds in the sky but no lightning. Why not? 3) What does air temperature have to do with lightning? 4) What causes lightning?* In addition to learning performance measures, we also collected video recordings that were later analyzed to measure gazing behaviors. Finally, we collected participants' perceived difficulty and pace for the lecture.

4.6 Design and Analysis

We used a between subjects design to mitigate learning effects between conditions. Each participant tested one condition, either with or without SlidePacer. We had two groups of users (DHH and Hearing) with 30 participants per group and two conditions (with and without SlidePacer), resulting in a total of 15 participants per condition.

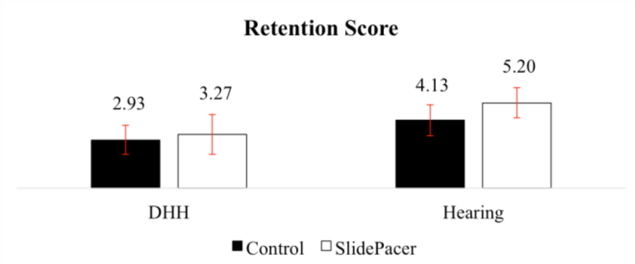

Figure 3. Mean retention score for both user groups and experimental conditions.

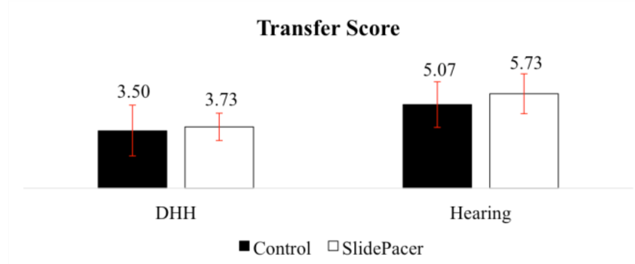

Figure 4. Mean transfer scores for both user groups and experimental conditions.

Both retention and transfer tests were scored individually by two of the authors. Scorers were not aware of the treatment condition of each participant. In order to achieve high agreement and cohesion, all scores were revised and differences were solved in a consolidation session with a third author.

A *retention* score was computed for each participant by counting the number of major idea units (out of eight possible) that the participant produced [21]. One point was given for each of the following idea units: 1) air rises, 2) water condenses, 3) water and crystals fall, 4) wind is dragged downward, 5) negative charges fall to the bottom of cloud, 6) the leaders meet, 6) negative charges rush down, and 8) positive charges rush up. We also calculated *transfer* scores for each participant by counting the number of acceptable answers produced across the four transfer problems. Examples of acceptable answers for the first question could be removing negative charges from the clouds; acceptable answers for the second question include the top of clouds might not be above the freezing level; for the third question, an acceptable answer could be that the air must be cooler than the ground; for the fourth question, an appropriate answer included the transfer of charges between the clouds and the ground.

Regarding eye gaze, we annotated the recorded videos with the current monitor participants were looking at. Annotations were first done for a single participant by two of the authors. Differences between experimenters were within 1% for each monitor, which corresponded to a difference of four seconds. From then on, two of the authors annotated videos separately.

We performed Shapiro-Wilk test on all dependent measures. We applied parametric statistical tests, such as ANOVA and unpaired t-test, for normally-distributed values or non-parametric tests (Kruskal-Wallis and Mann-Whitney) otherwise. We applied Bonferroni corrections when performing pair-wise comparisons.

At the start of the study, participants were asked about their previous knowledge of lightning formation. We did not find any correlation between prior knowledge and retention performance [$r_{(7)}$=-0.034, *p*=0.802] or transfer performance [$r_{(7)}$=.223, *p*=.093], thus no participant data was excluded from the data analysis.

5. RESULTS

Our goal is to understand the effect of SlidePacer on mainstream classrooms. In this section, we describe participants' learning performance, gaze behaviors, and perceived pace.

5.1 Learning Performance

To assess learning performance we used retention and transfer scores. Figure 3 and Figure 4 illustrate the obtained results for both user groups and conditions.

DHH participants improved an average of 0.34 on retention score from the control (M=2.93, SD=.95) to SlidePacer (M=3.27, SD=.89) condition (Figure 3). Although there was an increase, we did not find a statistical significant effect [Z=.298, *p*=.766, r=.05]. Regarding transfer scores, DHH obtained an average of 3.5 (SD=1.39) in the control condition and 3.73 (SD=1.55) in the SlidePacer condition (Figure 4). Again, this difference was not statistically significant.

Considering hearing participants, we found a similar increasing tendency from the control to the SlidePacer condition. Participants improved, on average, 1.07 points on retention score from 4.13 (SD=0.93) to 5.20 (SD=1.23) (Figure 3). Nonetheless, we did not find a significant difference between conditions [Z=1.509, *p*=.131, r=.28]. Regarding transfer scores (Figure 4), hearing participants obtained similar results with both control (M=5.07, SD=1.22) and SlidePacer conditions (M=5.73, SD=0.84) [Z=.696, *p*=.486, r=.13]. Overall, although there was an increase in learning performance for both hearing and DHH participants, we did not find this difference to be statistically significant. Still, not finding a significant effect does not mean it does not exist. In Section 6, we will further discuss these findings and likely factors that might have influenced results.

Comparing user groups, hearing participants performed significantly better on the control condition in the retention test [Z=-1.939, *p*=.05, r=.35] but not in the transfer test [Z=1.55, *p*=.121, r=.28]. Regarding the SlidePacer condition, hearing participants seem to benefit more than DHH participants as the gap in learning performance increases, resulting in significant effect with larger effect sizes for both retention [Z=2.419, *p*<.05, r=.44] and transfer scores [Z=2.347, *p*<.05, r=.43].

5.2 Gaze Performance

Figure 5 shows the average time DHH participants spent looking at each monitor in the control and SlidePacer conditions. Most of the time was spent looking at the ASL interpreter in both conditions; however, participants significantly increased the time assessing visual materials from an average of 30 (SD=15) to 80 (SD=41) seconds in the control and SlidePacer conditions [$t_{(28)}$=-6.848, *p*<.001], respectively. These values correspond to an average of 2.7 seconds per slide in the control condition and 7.3

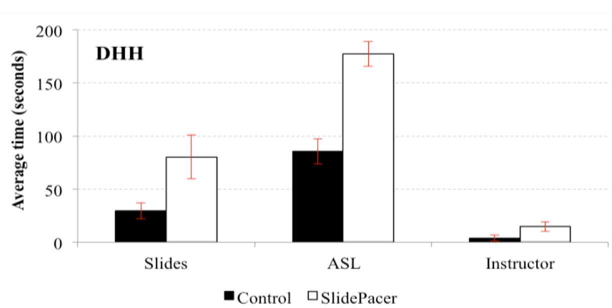

Figure 5. Average time DHH participants spent looking at each visual source.

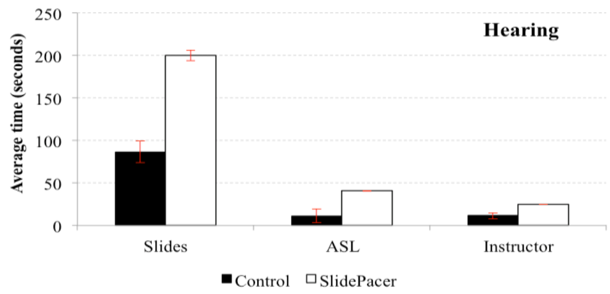

Figure 6. Average time hearing participants spent looking at each visual source.

seconds per slide in the SlidePacer condition. Since the SlidePacer delay for students assess slides was only 5 seconds, it means that participants were still splitting their attention between visual sources, which in turn may have limited their learning gains.

Time looking at ASL interpreter also increased significantly [$t_{(28)}$=-10.819, p<.001] from an average of 86 seconds (SD=23) in the control condition to 178 seconds (SD=23) in the SlidePacer condition. These results suggest that DHH participants choose to spend their additional time assessing visual materials and ASL, even though interpreting time was similar between experimental conditions. This result may be related with slides' complexity. Slides consisted of illustrations of verbal feedback and contained few text (1 or 2 words) and minimalistic images. Their content could be quickly assessed in less than 5 seconds. Additional time should be used to mentally organize information and integrate it with previous relevant knowledge [22]; however, it seems that DHH students spent it splitting their attention, monitoring when ASL interpretation would start again.

Analyzing the relative percentage of time DHH participants spent on each visual source, we found a significant decrease from 71% on control condition to 65% on SlidePacer condition for ASL [Z=2.053, p<.05, r=0.37], and a small significant effect for Slides with an increase from 25% to 29% [Z=1.597, p=.11, r=.29] on control and SlidePacer, respectively. There was also a significant increase for the time looking at the instructor ($M_{Control}$=4%, $M_{SlidePacer}$=6%) [Z=2.012, p<.05, r=.37].

Regarding hearing participants, results show the opposite effect; that is, students spent relatively less time looking at slides ($M_{Control}$=80% $M_{SlidePacer}$=75%) and instructor ($M_{Control}$=11% $M_{SlidePacer}$=9%) and more time looking at the ASL interpreter ($M_{Control}$=9% $M_{SlidePacer}$=15%) [Z=1.929, p<0.05, r=.35]. Nonetheless, in terms of average time, hearing participants assess all visual sources for longer periods of time (Figure 6).

As expected hearing and DHH participants had different gaze distributions across visual sources. While hearing students spent most of their time looking at the slideshow while receiving verbal auditory feedback, DHH students needed to focus on the ASL

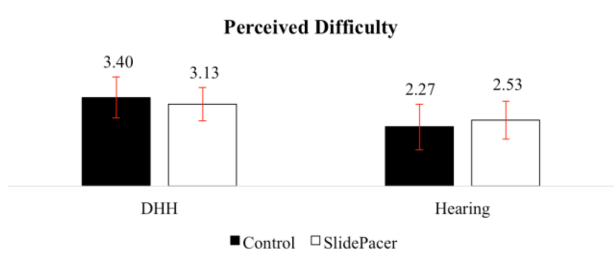

Figure 7. Perceived lecture difficulty for both user groups and conditions.

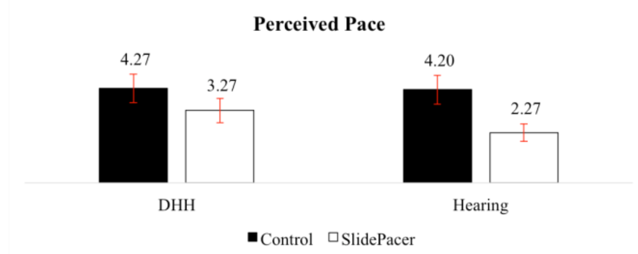

Figure 8. Perceived lecture pace for both user groups and conditions.

interpreter to received verbal feedback. Nonetheless it is noteworthy that SlidePacer enabled DHH participants to achieve the same degree of access to visual materials than hearing participants in the control condition (80 seconds vs. 86 seconds). The same rationale can be applied to learning performance; adjusting the lecture pace enables DHH students to achieve retention [Z=1.452, p=.15, r=.27] and transfer [Z=1.547, p=.122, r=.28] scores similar (no significant differences) to their hearing counterparts in current classroom settings. Although these results do not show that differences do not exist, they suggest that we are closing an accessibility gap between user groups.

5.3 Subjective Feedback

After watching the lecture, participants were asked about its difficulty using a Likert scale (1 - Very easy to 7 - Very hard). As shown in Figure 7, perceived difficulty was similar between experimental conditions. We did not find significant differences between control and SlidePacer conditions for DHH participants [Z=.4, p=.689, r=.07] or hearing participants [Z=.6, p=.519, r=.1].

Overall, hearing students perceived the lecture to be significantly easier than DHH students in control condition [Z=1.909, p < .05, r=.35], but not in SlidePacer condition [Z=1.085, p=.278, r=.2]. This was due to a decrease of perceived difficulty from DHH. On the other hand, hearing participants perceived it as slightly harder with SlidePacer ($M_{Control}$=2.27 $M_{SlidePacer}$=2.53).

In addition to difficulty, we also asked participants about perceived pace using a 7-point Likert scale (1 - Very slow to 7 - Very fast), where 4 corresponded to appropriate pace. There was no difference of perception between DHH and hearing students in the control condition [Z=.379, p=.705, r=.07]. On average, both user groups rated the pace of the lecture as appropriate (M_{DHH}=4.3 $M_{Hearing}$=4.2). Although at a smaller extent to DHH students, SlidePacer had a significant negative effect on perceived pace. As shown in Figure 8 participants' scores were lower by 1 point (M=3.27 SD=1.28) [Z=2.046, p<.05, r=.37], while hearing participants' scores dropped 1.93 points (M=2.27 SD=1.1) [Z=3.916, p<.001, r=.71].

6. DISCUSSION

In this section, we answer our research questions and discuss the limitations of this work.

6.1 Answering the Research Questions

After analyzing the effect of SlidePacer for both user groups, we are now able to answer the proposed research questions.

1. *Is SlidePacer effective in improving learning for DHH students?*

The presented study assessed the effect of SlidePacer on DHH students' learning performance. Although there was an increase in both retention and transfer scores, we did not find a statistically significant effect. There are several plausible reasons for this result, which should be the aim of future research. First, our lecture content could have been too simple and easy to follow. Particularly, our slideshow content was mostly image-based, which is not always the case in college-level lectures. Programming classes are a good candidate for future research, since they place on DHH students a high demand to follow verbal instructions and slides full with textual information. Another reason might have been that the pace of our lecture was already slow. If we combine slow pace and minimalist slides, then students do not require additional time to access visual materials. Indeed, this is a known effect [20, 22, 24].

In this work, we were mainly interested in understanding the effect of SlidePacer on learning performance. However, DHH students face other challenges that might be alliviated by our proposed solution. For instance, reducing the pace of the lecture might enable students to engage in active learning by participating more in the classroom or take their own notes [10, 13, 15, 26].

2. *Does SlidePacer improve DHH students' access to visual materials?*

Overall, DHH students spend 2.7 more time looking at slides with SlidePacer, which corresponded to a significant increase in accessing visual materials. This results in a re-distribution of attention across visual sources in comparison with the control condition. Significantly less time (6%, 16.4 seconds) attending the ASL interpreter and more time (4%, 11 seconds) viewing slides.

Although participants had 5 seconds to attend to slides after verbal instructions, results suggest that DHH students still split their attention between verbal instructions and visual materials. This behavior may be natural to students, since it is their current strategy to cope with multiple visual sources in a classroom. However, it is not clear whether this behavior prevented them from receiving all verbal information from the ASL interpreter.

DHH students could spend an additional 4% of their lecture time looking at the slides, which corresponds to about 80 seconds. This value is similar to what hearing learners experienced in the control condition. Hence, results indicate that SlidePacer can support access to visual materials from DHH students.

3. *What is the learning effect on hearing students?*

Similarly to DHH students, we found a positive effect on learning performance for hearing students. Although there was a measurable increase for both retention and transfer scores, we did not find significant differences.

4. *What is the relationship between DHH and hearing students performance?*

Hearing participants performed better than DHH in both retention and transfer tests. This result goes in line with previous research on mediated learning research [14, 15]. Interestingly, hearing participants seemed to benefit the most from SlidePacer as their gains were higher than DHH participants. Moreover, results show that SlidePacer allows DHH students to achieve similar levels of learning performance as hearing students in the control condition. This is also true regarding access to visual materials. It is clear that mainstream classrooms are an unequal playfield regarding access to media materials used by instructors to support student's learning; that is, hearing students have constant access to verbal and visual information, while DHH students are restricted to one of these information sources. SlidePacer guaranteed a similar level of access to slides (~7 seconds per slide) to DHH as mainstream classrooms to hearing students.

5. *What are students' perceptions about the lecture's pace?*

SlidePacer had a significantly negative effect on perceived pace. Results from hearing and DHH questionnaires showed that the pace of the lecture was perceived as "slightly slow". Although it can be attributed to a novelty effect, since participants were not familiar to the change in pace from the *status quo*, it is still a significant result. Even more so for hearing students as the effect was higher. Interestingly, this user group benefited the most from the change in delivery pace.

6.2 Limitations

In this paper we propose a novel approach to improve classroom accessibility for DHH. Rather than building new tools for students, we focus on delivering better lectures that fit learners' needs. Changing the pace of multimedia presentations have previously shown to reduce students cognitive load, improving their learning performance [20, 24]. This effect is most noticeable when content is unfamiliar and complex. However, the slideshow used in this study featured almost no text, which does not represent a typical college class.

Also, in mainstream classrooms ASL interpreters usually refer (point) to content in the slides to illustrate a concept. However, due to the multi-camera setup of the experiment, such pointing reference was not possible to represent. Although it was consistent across experimental conditions, it might have had a negative impact on learning performance of DHH participants. Finally, SlidePacer inherently increases the duration of lectures. Still, we believe that its potential benefits outweigh this limitation. Moreover, instructors should have the flexibility (and obligation) to adjust covered content to better accommodate DHH students.

7. CONCLUSION

In this paper we introduce SlidePacer, a novel tool to be used by instructors and interpreters to collaboratively control the delivery of multimedia presentations. Our goal is to promote effective lectures by promoting better pacing behaviors that take into account the needs of DHH students. Coordinating verbal instructions and accessibility services can reduce the attention split effect and cognitive load that these students experience in mainstream classrooms, providing the opportunity to attend to visual materials and improve learning performance.

We have investigated the learning performance of 60 students using SlidePacer. Results show a positive effect, as DHH learners are able to give further attention to multimedia content. Although this did not result in significant learning improvements, participants achieved similar levels of access as hearing students in mainstream classrooms. We also found that DHH learners still split their attention during verbal instructions. Thus, additional research is needed to evaluate the effectiveness of SlidePacer in more demanding learning settings. Results are in line with previous research, showing that DHH students take away less from a lecture than their hearing counterparts. Interestingly, hearing students benefit the most from SlidePacer.

8. FUTURE WORK

One of the challenges instructors of students who are DHH face is managing the split attention implicit in multimedia learning; however, teachers are often unaware and assume that accessibility services deal with those issues [10]. In this paper we introduce a novel approach of creating the tools that can ease the process of delivering accessible and effective multimedia presentations. This is a design space fairly unexplored. As future work we propose three main research topics: First, improve SlidePacer prototype to better-fit students' behaviors and interpreters needs. This can include dynamically adapting slideshow delays based on slide content or smart classroom environments that are able to track students' head movements and infer when the current slide was read. Additionally, gesture recognition approaches can be added to the system in order to automatically identify when ASL interpretation is finished, removing the need (and cognitive load) for interpreter to actively advance slideshow.

Second, conduct further studies with new experimental designs to understand the effect of SlidePacer on different types of slideshows (text-intensive vs. image-intensive) and lectures (e.g. procedural vs. tutorials). It would also be interesting to measure the effect of SlidePacer beyond short-term learning and assess students' engagement (questions asked), note-taking behaviors or long-term retention. Finally, it is crucial to involve and understand the effect of presentation tools on all stakeholders, including accessibility services, presenters, DHH students, and their hearing peers. Does SlidePacer affect quality of interpretation? Does it reduce cognitive load of interpreters? Regarding instructors, can SlidePacer be included in real-world classroom activities? How would instructors cope with different pacing behaviors? How fast would they learn to adopt more adequate pacing behaviors? These questions should be thoroughly investigated in future work.

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