MirrorMirror: A Mobile Application to Improve Speechreading Acquisition

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ABSTRACT

Many people around the world have difficulties in day-to-day conversation due to hearing loss. Hearing aids often fail to offer enough benefits and have low adoption rates. However, people with hearing loss find that speechreading can improve their understanding during conversation, but speechreading is a challenging skill to learn. Speechreading classes can improve acquisition, however there are a limited number of classes available and students can only practice effectively when attending class. To address this, we conducted a postal survey with 59 speechreading students to understand students' perspectives on practicing. Using our findings, we developed an Android application called MirrorMirror – a new Speechreading Acquisition Tool (SAT) that allows students to practice their speechreading by recording and watching videos of people they frequently speak with. We evaluated MirrorMirror through three case studies with speechreading students and found that they could effectively target their speechreading practice on people, words and situations they encounter during daily conversations.

ACM Classification Keywords

K.4.2 Social Issues: Assistive technologies for persons with disabilities

Author Keywords

Speechreading; Hearing loss; Lipreading; Accessibility

INTRODUCTION

Across the world it is estimated that 360 million people (~5%) have disabling hearing loss[1] [46]. The prevalence of hearing loss increases as we age [8], and it is expected that up to one in five people in the UK will have hearing loss by 2035 [1]. Hearing loss results in difficulties understanding what others are saying during conversation [45]. Our relationships and identities are shaped through the various conversations we engage

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[1]Hearing loss greater than 40 dB in the better hearing ear in adults and greater than 30 dB in the better hearing ear in children.

in throughout our lives [13]. As hearing loss causes difficulties during conversations it can result in social isolation [17], career stagnation [36], and a decrease in life satisfaction [45]. Hearing aids are designed to reduce these problems, but can be detrimental in noisy environments [21], and have low adoption rates (~14% [1]) due to comfort issues [37], perceived social stigma [25], and their expense [9].

Speechreading (often called lipreading) refers to using visual information about the movements of a speaker's lips, teeth, and tongue to understand what they are saying [45]. Speechreading is commonly used by people with all severities of hearing loss to understand speech [13], and people with typical hearing also speechread (albeit subconsciously) to help them understand others [23]. Speechreading has the advantage that it does not rely on the other conversation partner's knowledge of a Signed Language or a technique such as Cued Speech [15].

However, speechreading is a skill that takes considerable practice to acquire [31]. Publicly-funded speechreading classes are sometimes provided, and have been shown to improve speechreading acquisition [5]. However, classes are only provided in a handful of countries around the world. It has been suggested that the development of Speechreading Acquisition Tools (SATs) can aid acquisition and allow students to practice outside of classes or when no classes are available [24].

Current SATs have three limitations: 1) a limited selection of content, 2) a limited selection of speakers, and 3) the user cannot customise the content with particular words, situations or people they encounter on a daily basis. Speechreading classes are based around watching people speak, and these classes are tailored to each student's needs. Currently available SATs are not adaptable to individual student needs.

To address this, we conducted a postal questionnaire with speechreading students to explore the challenges and situations they encounter while speechreading, and their approach to practice outside of class. We used the findings to elicit requirements for a new SAT called MirrorMirror. MirrorMirror is an Android application that allows students to practice through recording, watching, and testing their speechreading using videos of people they frequently speak with.

To evaluate MirrorMirror, we supplied three speechreading students with a tablet running MirrorMirror and asked them to use it for daily practice for one week. Participants willingly engaged with our application, and our findings suggest that through the use of MirrorMirror, speechreaders will be able

to augment their class-based learning, or support learning on their own if no suitable classes are available.

This paper makes three contributions: First, we contribute questionnaire data from a postal survey with 59 students from speechreading classes. Second we introduce MirrorMirror, a new SAT that addresses the limitations of current SATs by allowing users to capture and practice with videos of people they frequently speak with. Third, we evaluated MirrorMirror through three case studies with speechreading students and found that participants felt it would improve their ability to practice speechreading outside of classes by targeting their practice on people, words and situations they encounter daily.

BACKGROUND & RELATED WORK

Speechreading

Every word in a spoken language is comprised of perceptually distinct units of sound known as *phonemes*. For instance, */b/*, */æ/*, and */t/* are the phonemes for "bat". There are 48 commonly-recognised phonemes in the English language [42]. When a phoneme is spoken, the speaker's lips, teeth, and tongue produce a visual representation known as a *viseme* [19]. Hearing loss causes some phonemes to be difficult to hear (depending on the type and severity), but visemes are still visible. Speechreading is the process of mapping visemes to phonemes to help understand what a speaker is saying [7].

However, the viseme-to-phoneme mapping is often a 'one-to-many' relationship, in which a single viseme can be mapped to a number of phonemes [34]. For example, */v/* is a voiced phoneme (the vocal cords vibrate), which is audibly distinct from */f/*, which is not voiced. However, the viseme for */v/* is very similar to the viseme for */f/*, making the words *'fan'* and *'van'* difficult to distinguish visually. As a result, novice speechreaders (e.g., someone who has received no formal speechreading training) often find it difficult to fully understand what a speaker is saying, resulting in confusion, frustration, and reduced conversational confidence [13]. In addition to visemes, there are a number of additional factors that affect the difficulty of speechreading (e.g., co-articulation effects [35], rate of speech [45], lip visibility [18], accents [27], and the speechreader's visual acuity [30]).

Speechreading Teaching

Speechreading classes teach people how different mouth shapes look when they are spoken [31], along with how to use conversational repair strategies to gain important contextual information to improve overall understanding [31].

Within classes there are two main approaches to teaching speechreading: *synthetic* and *analytic* [20]. Synthetic methods (sometimes referred to as context-training) use a 'top-down' approach where focus is placed on understanding the topic of a conversation to determine words being spoken [45]. Analytic methods (sometimes referred to as 'eye-training' [28, 12]) use a 'bottom-up' approach where focus is placed on the visual speech pattern to identify what is being spoken [45]. A *hybrid* method uses aspects of synthetic and analytic methods [24].

Using findings from interviews with seven practicing speechreading tutors, Gorman and Flatla [24] introduced a framework that can be used to design Speechreading Acquisition Tools (SATs). During the evaluation of the framework, the authors classified each teaching technique that tutors reported using in classes. The tutors also reported that they felt students practiced at home, however the authors did not interview or ask students how or how often they practiced outside of class.

Current SATs

Currently, there are a limited number of SATs that support speechreading practice. However, it is unclear to what extent these are used by speechreaders.

Lipreading.org is a website-based hybrid SAT that provides practice sessions with vowels, consonants, words, and topics such as going to a doctors appointment. However, there is a limited number of speakers and amount of content available. The website offers what is called "live lipreading" that connects you with another user via a webcam, however this is actually a video with a set of pre-recorded responses. Furthermore, they employ professional lip-speakers [2], so are not able to provide typical examples of human speech production.

ConversationMadeEasy [44] is a SAT comprised of three programs, each presenting videos of speakers with or without audio. Program A is for analytic training, and Program B is for synthetic sentence training. Program C is for synthetic scenario-based training with questions based on the scenarios given within a closed response set of four pictured options.

DAVID [43] is a sythentic SAT offering videos of sentences on everyday topics. The student watches and responds by typing the complete sentence or content words, or via multiple choice. DAVID also provides repair strategies such as repeating the sentence, or presenting words in isolation.

Lipreadingpractice.co.uk is a website-based hybrid SAT offering subtitled videos of consonants, vowels, and passages. The speaker says these with and without voice, shown from the front and from a profile angle, and repeats each a number of times. Words and phrases are provided as written exercises.

Overall, these SATs have three limitations: 1) a limited selection of content, 2) a limited selection of speakers, and 3) the user has no way to customise the content with particular words, situations or people they encounter on a daily basis.

Speechreading classes are based on watching people speak, and these classes are adaptable, however current SATs available are not adaptable to individual student needs. To address the limitations of current approaches, we conducted a postal questionnaire with students from four speechreading classes to gather requirements for a new SAT.

QUESTIONNAIRE

There were four questions framing the questionnaire: 1) Do speechreading students practice outside of class? 2) How do speechreading students practice outside of class? 3) What technology do speechreading students use to practice outside of class? 4) What situations and challenges do students encounter when speechreading outside of class?

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[2] A lipspeaker has been professionally trained to be easy to lipread.

The supplementary material published by Gorman and Flatla [24] reported that speechreading tutors felt students practiced outside of class by using a mirror, watching television, using exercises from class, observing speakers during conversations and using websites such as *lipreadingpractice.co.uk*. We used these findings to influence our questions.

The questionnaire included 25 questions across two sections. The first section contained nine questions that were used to gather basic demographic information; age, sex, highest level of education, level of computer literacy, and details surrounding the participants' hearing.

The second section contained 16 questions and focused on participants' daily experience of speechreading: "Please rate your lipreading ability"[3], "How long have you been in lipreading classes?", "Do you practice lipreading outside of classes?", "If yes, how do you practice lipreading at home?", "Do you use mirror practice outside of class?" "If yes how often do you use mirror practice at home?", "What do you like about mirror practice?", "What do you dislike about mirror practice?", "Do you use videos to practice lipreading outside of class?", "How often do you use videos or watch television to practice lipreading outside of class with subtitles turned on?", "How often do you use videos or watch television to practice lipreading outside of class with subtitles turned off?", "In what situations do you find lipreading challenging? (Tick all that apply)", "What do you find challenging when lipreading?", "Do you rehearse/anticipate possible phrases or words that you may have to lipread before being in a situation?", "If yes, describe how", "Do you own a mobile device?".

Method
We posted an information pack containing questionnaire forms, information sheets, envelopes and stamps to each speechreading tutor who had agreed to take part in the study. Tutors were asked to distribute these to their students during or before class. Potential participants had to be above the age of 18 and be currently enrolled in a speechreading class. Once students had completed the questionnaire they were asked to place it in a provided envelope that they could either post back to the research team directly, or hand to their tutor (who would place them in a larger envelope to be posted to the research team).

Participants
In total, 59 participants completed the questionnaire. Participants were sourced from four tutors and aged between 45-92 years old (M=73.9, SD=10.1) and 76% were female. Participants reported on their highest level of education: University (27 participants), College (14), High School (13) and Other (5). Participants reported on their level of computer literacy: Excellent (3 participants), Good (17), Fair (29) and Poor (9).

All participants self-reported having a hearing loss. Participants were asked to describe their hearing loss using the textual descriptions used by Action On Hearing Loss [2]: Mild (5 participants), Moderate (28), Severe (19), and Profound (5).

Participants also reported how long they had a hearing loss. This was an open text field, that were then categorised into

'0-5 Years' (8 participants), '5-10 Years' (10), '10-15 Years' (5),'15-20 Years' (10) and '20 Years plus' (22).

Participants were also asked to report the cause of the hearing loss. This was presented as checkboxes with an 'Other' field: Ageing (34 participants), Congenital (10), Viral Infection (9), Exposure to loud noise (9), Unknown (5), Surgery Complication (3), Head Trauma (3), Disease (3), Acoustic Neuroma (1), Severe Shock (1), Medication side-effect (1) and Tinnitus (1).

Finally, participants were asked to report if they used any assistive technology. Overall 56 participants reported using hearing aids[4], one participant used cochlear implants and two participants stated they did not use any assistive technology.

QUESTIONNAIRE FINDINGS
Participants were asked to report on their level of speechreading: Excellent (0 participants), Good (19), Fair (28) and Poor (10). Participants were asked to report on their length of time in classes: Less than 6 months (4), 6-12 months (3), 1-2 years (12), 2-5 years (19), 5-10 years (3) and over 10 years (17).

Speechreading Challenges
Participants were asked to report challenges that affect their ability to speechread (summarised in Table 1). 'People turning away' and 'People covering their mouths' were two of the most common challenges reported by participants as these pose direct problems to speechreading because you cannot see the face. 'Words looking the same on the lips' was reported as a challenge by 43 participants, and this is likely to be caused by the ambiguity of some visemes [19].

Challenge	No. of Participants
People turning away	54
People talking quickly	53
People covering mouths	49
Quiet speakers	44
Words looking the same on the lips	43
Accents	34
Fatigue	33
Beards	31
Concentration	25
Other	6

Table 1. Participants' reported frequency of speechreading challenges.

Participants were asked to report situations where they found speechreading difficult (shown in Table 2). Group conversations were reported as the most challenging situation participants face. Restaurants and coffee shops were the next most reported as these locations often have a high amount of background noise, that limits the use of residual hearing [16].

Open-ended Question Analysis
To analyse the open-ended questions we used thematic analysis [10], however we analysed each question independently and therefore did not produce any thematic maps. We did not conduct inter-rater coding due to the rationale outlined in [24].

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[3]In the UK, 'speechreading' is referred to as 'lipreading', therefore in discussions with participants we used the term 'lipreading'.

[4]We recognise that this does not match the reported adoption rate [1] and will investigate in future studies.

Situation	No. of Participants
Group Conversations	54
Restaurants	46
Coffee Shops	32
Transport	33
Dentist	26
Shopping	23
Doctors	17
Opticians	16
Home	10
General	4
Noisy Places	3
Work	2
Classes	1

Table 2. Situations participants found speechreading to be challenging.

Step 1: Becoming familiar with the data: We read through the responses to each question to become familiar with the data set, and if necessary, split single responses into multiple rows.

Step 2: Generating and collating initial codes: We read through all of the responses again, making a note of initial codes. The initial codes were generated using a data-driven approach and then collated and collapsed. This resulted in 120 coded segments under 29 unique codes. Our data file containing our analysis is included in the 'open_ended_analysis.xlsx' file in the supplementary materials.

Step 3: Defining themes: We reviewed the coding of the dataset and identified patterns that could be grouped into themes within each question.

Practice

When asked if they practiced at home, 39 students reported that they did and 20 said they did not. If participants responded that they practiced at home they were asked to describe how they practiced. There were three themes within the data, students would practice through 1) Observation, 2) Watching Television, and 3) using Techniques From Classes.

Observation: Observation refers to when participants would practice by watching faces, speakers or taking part in conversations. In total there were 34 mentions of observation taking place in many different situations. For instance, P34 reports that she practices speechreading by observing when shopping, on public transport and during social gatherings, whereas P17 reported observing the song leader during choir practice:

P34: *"In every situation I find myself in, so in shops, on buses, in social gatherings."*

P17: *"...using opportunities to practice in community choir, lipreading words from song leader."*

Furthermore, P50 reported practicing by taking part in question and answer sessions or by trying to follow the plot when attending the theatre:

P50: *"By taking part in group conversations...e.g., question and answer sessions after talks or lectures. Also going to the theatre and trying to follow the plot!"*

Frequency	No. of Participants
Daily	0
2-3 times a week	0
Once a week	4
1-2 times per month	5
1-2 time per year	4
Never	17
Not Given	29

Table 3. Participants' reported frequency of mirror practice.

Watching Television: In total, 13 participants reported using television to practice speechreading albeit with different factors. For instance, P5 reported practicing by simply watching the news:

P5: *"News on TV sometimes."*

Whereas P1 and P57 reported trying to reduce their reliance on their residual hearing by either turning off the sound or taking out their hearing aids:

P1: *"TV without sound (but not as often as I should to be helpful or make a difference)."*

P57: *"I take my hearing aids out sometimes when watching TV to see if I can lipread. Not really that successful."*

Participants also reported watching TV with subtitles to practice. Although this likely detracts focus from speechreading, as one study found that participants spent around 84% of their viewing time focussed exclusively on subtitles [29]:

P2: *"I also try to watch programmes with subtitles."*

Techniques From Classes: Finally, participants reported practicing using techniques from class such as fingerspelling or watching a DVD produced by The Association of Teachers of Lipreading to Adults [41]:

P40: *"Practice fingerspelling."*

P49: *"Listen to DVD '[look] hear'."*

Mirror Practice

Mirror Practice is when a student speaks into a mirror to practice their lipshapes [38]. Participants reported a varying frequency of using mirror practice as shown in Table 3.

What do students like about Mirror Practice?

There were three themes describing what students liked about mirror practice. Mirror practice allows them to: 1) Learn lipshapes, 2) Compare lip-shapes with others, and 3) perceive a lack of difference between certain words when spoken.

Lip Shapes: The most common part of mirror practice that students reported liking was that it helped them learn lipshapes. For instance, P34 described how mirror practice helps them notice small movements of the lips and this is due to the focussed analytic nature of mirror practice [45].

P34: *"When we do this in class it shows very small, subtle movements of lips, tongue and teeth. Very interesting."*

P36 and P24 reported how mirror practice shows different shapes on their own lips with P24 also mentioning that it shows how their lips form shapes.

P36: *"It helps to see the different shapes on the mouth."*

P24: *"Seeing how good or bad my lips form shapes."*

Compare with others: Participants also reported that looking at their own mouth shapes allows them to compare against others. P2 and P23 both reported how they can see the difference with others, likely from within their speechreading classes.

P2: *"I see the difference between my movements [and] others."*

P23: *"Seeing my speech pattern, sometimes different from others."*

Lack of visual difference: Finally, participants also reported that mirror practice helps highlight how some words do not appear visually distinct. P44 and P20 both reported how some words are difficult to differentiate, likely due to the words in question being grouped under the same viseme.

P44: *"It is [a] good way to [demonstrate] how few words can actually be seen on the lips."*

P20: *"Seeing how some 'sounds' look the same."*

What do students dislike about Mirror Practice?

There were four themes describing what students disliked about mirror practice. These themes were that they: 1) Disliked watching themselves, 2) That they have full knowledge of what they were saying, 3) That it was not akin to speechreading, and 4) That they would over-emphasise words.

Dislike Watching Self: The most commonly reported negative aspect of mirror practice was that participants did not like having to focus on their own appearance in the mirror:

P24: *"Having to look at myself in a mirror."*

P5: *"Don't like watching my own face."*

Additionally, P2 and P13 both disliked seeing the condition of their teeth and P2 mentioned hating seeing her wrinkles

P13: *"Seeing the condition of my teeth."*

P2: *"I hate seeing my teeth [and] wrinkles."*

Full Knowledge: Participants also disliked that they know the words they are saying as they speak into the mirror, therefore it is not a formative type of practice as they already 'know the answer' unlike in natural conversation. P14 reported they know what they are saying, with P5 saying that this is not helpful:

P14: *"The fact that I know what I'm saying."*

P5: *"Not helpful as my brain knows what I am saying so not really lipreading."*

Not Akin To Speechreading: Participants reported that mirror practice is not similar enough to speechreading to be an effective form of practice. This is likely due to the problem of full knowledge reported above, plus a lack of naturalness:

P3: *"Feel it is not quite [a] 'natural' situation."*

P38: *"Not totally true to real life experience."*

This could be because mirror practice shows their own mouth shapes, with P20 saying that it does not help with understanding other people's lip shapes (a core aspect of speechreading):

P20: *"Helpful for me and my lip movement but not for seeing how others move their lips"*

Over-Emphasis: Finally participants reported that during mirror practice they would over-emphasise or exaggerate words when speaking into the mirror, making practice less useful.

P32: *"Perhaps I over emphasise."*

P44: *"One tends to exaggerate too much."*

Video and TV Practice

Participants were asked to report the frequency they practiced with subtitles turned on and off as shown in Table 4.

Frequency	Subtitles Off	Subtitles On
Daily	8	9
Once a Week	5	4
2-3 Times a Week	2	4
1-2 times per Month	7	1
1-2 times per Year	2	2
Never	20	19
Not Given	15	20

Table 4. Participants' frequency of practice with subtitles on and off.

Context Practice

Many participants reported that they did not rehearse or anticipate phrases: Yes (14 participants), No (44) and Not Given (1). If participants responded that they did rehearse or anticipate phrases, we asked them to describe how. There were two main themes, 1) Anticipating Questions and Answers, and 2) Researching Situation and Potential Topics.

Anticipating Questions and Answers: Participants reported that they would anticipate the questions they may be asked in situations, such as when in a restaurant.

P24: *"Restaurants, waiters asking what you would like to drink or eat."*

P4: *"I try to think what answers I will get to the questions I intend to ask."*

Participants would also constrain responses by asking specific questions. For instance P21 asked the time of a train, so they only have to speechread the words about time.

P21: *"You know what you have said if asked, e.g., train time."*

P6: *"In shops have a rough idea how much the shopping will cost."*

Researching Situation and Potential Topics: Participants reported that they would research or rehearse the situation and potential topics before facing it:

P2: *"I rehearse time and dates when making appointments."*

P18: *"Find out as much information as I can about the situation I am about to face."*

Mobile Devices

Finally, participants reported owning a wide range of mobile devices as shown in Table 5. We found the results to be higher than expected for this demographic [39], and these findings further illustrate that a mobile application focussed on speechreading acquisition could benefit this population.

Device	No. of Participants
iPad	20
iPhone	9
Amazon Kindle	14
Amazon Kindle Fire	2
Tablet	5
Android Smartphone	6
Mobile phone	21
Windows Phone	1
Laptop	2

Table 5. Participants' reported ownership of mobile devices.

MOTIVATION BEHIND "MIRRORMIRROR"

Our findings report that 50% of participants have been in speechreading classes for over two years, yet less than a third (32%) of participants rated their speechreading ability as 'Good' and nobody rated it 'Excellent', suggesting that speechreading practice needs to be improved. The supplementary material published by Gorman and Flatla [24], reports that speechreading tutors think students practice outside of class. Our findings suggest that this is only partially correct; the 66% of participants who practiced at home, did so primarily by observing speakers in daily life or on television.

Participants reported a high frequency of watching television (with subtitles on and off) to practice speechreading. Together with the reported use of observation, it can be argued that these techniques are used to provide the speechreader with an endless supply of practice material. However, with television and observation, it is difficult for speechreaders to verify whether they are understanding the speaker correctly. Along with current SATs, neither technique allows for targeting practice around the challenges or situations participants reported impact their speechreading ability.

Tutors report that mirror practice plays a key role in speechreading training [24], and is also recommended by Action on Hearing Loss [3, 38] for practice, as it may develop visual cue integration skills needed during speechreading [4]. Participants reported that mirror practice allowed them to learn lipshapes, compare them with others, and show visual differences between words. However, they disliked watching themselves, that they have full knowledge of what they are saying, that they would over-emphasise words, and that mirror practice was not akin to genuine speechreading. This resulted in a low frequency (57% of those who answered said 'Never') of usage by participants.

The quality of speechreading practice outside of class is of limited value as: current SATs have limited content, TV and observation provide limited feedback, and mirror practice provides too much feedback. To address this, we have designed a mobile application called MirrorMirror that allows speechreaders to practice lipshapes and words by recording videos of people they frequently talk to. By allowing users to record their own videos, MirrorMirror provides an opportunity to practice most of the speechreading challenges and situations reported by questionnaire participants. Additionally, MirrorMirror addresses the limitations of practicing with Mirror Practice, Observation and Television as reported by questionnaire participants. Finally as a mobile application, MirrorMirror matches the device usage patterns of the target population, as reported in Table 5.

IMPLEMENTATION OF "MIRRORMIRROR"

MirrorMirror is an Android application. We chose Android as the target platform as there are a variety of inexpensive Android tablets on the market that could be used for the evaluation. MirrorMirror is primarily designed for tablet based displays, but could also be adapted to smaller and larger screens. MirrorMirror's visual design follows Google's Material Design guide (`https://material.io/guidelines`).

To allow users to record videos, a library that provides more control over video capture settings compared to the default Android activity was required. We used the "LandscapeVideoCamera" library developed by Jeroen Mols (`https://github.Com/JeroenMols/LandscapeVideoCamera`). This library is open source and offers a capture activity with granular controls over video quality, storage location and file size, and it can also restrict recording to landscape orientation.

Application Features

MirrorMirror uses tab-based navigation as this is a popular solution for lateral navigation in Android applications. Android design guidelines (`https://material.io/guidelines/patterns/navigation.html#navigation-patterns`) state that tabs allow users to easily move between a small number of section-related screens, and because MirrorMirror has three main navigation areas ("Library", "Speakers" and "Practice"), tabs are the most effective navigation solution. Users switch tabs by either tapping on the tab name or swiping left to right.

'Library' Tab

Lipshape Library: The lipshape library is initially displayed on the 'Library' tab and is implemented as an Android ListView. Each lipshape is displayed as a row in the list with a title (displaying the lipshape) and subtitle (showing the number of words contained within that lipshape) as shown in Figure 1.A. Tapping on a lipshape item loads the word library for that lipshape as shown in Figure 1.B.

Word Library: The word library displays the word list of a lipshape. Each word is a row in the list with a title (displaying the word) and subtitle (showing the number of videos recorded with it) as shown in Figure 1.B. Tapping on a word loads a collection view of videos. To return to the lipshape library, the user can press the device back button, or the title strip.

Adding and Deleting Words: Users can add words to a lipshape by tapping on the button in the right hand bottom corner as shown in Figure 1.B. Users can delete words from a lipshape by long pressing on a word row, which launches a dialog window allowing confirmation of deletion. When a word is deleted, all videos recorded under that word are also deleted.
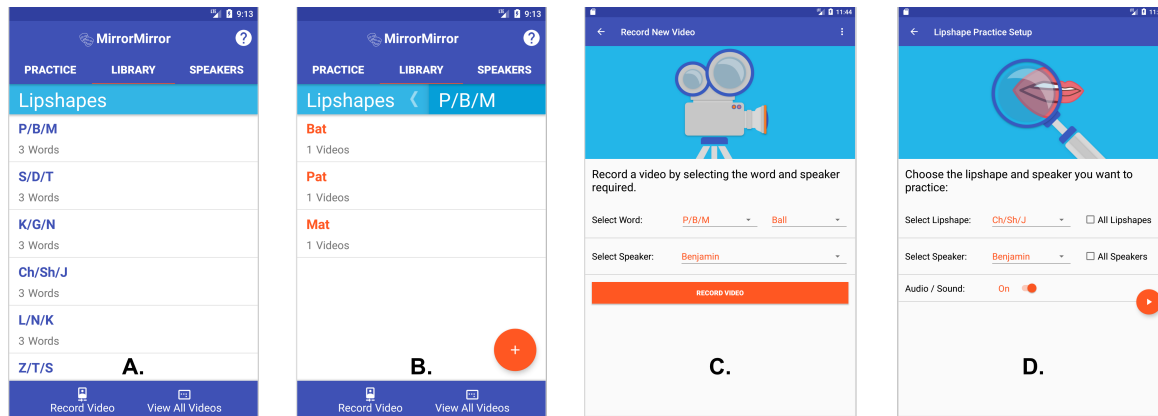
Figure 1. A) 'Lipshape Library' with each lipshape displayed as a row in a list, with a title (displaying the lipshape) and subtitle (showing number of words contained under the lipshape). B) 'Word Library' displaying the word list of lipshape "P/B/M". Each word is an item with a title (displaying the word) and subtitle (showing the number of videos available). Users can add words to this lipshape by tapping on the button in the right hand bottom corner. C) Video Library displaying three dropdown lists: lipshapes, words and speakers. Tapping 'Record Video' starts the video capture. D) 'Lipshape Practice' setup, displaying: a dropdown list of lipshapes and a checkbox for 'All Lipshapes', a dropdown list of speakers and a checkbox for 'All Speakers', an audio switch with a text label displaying if audio is on or off. Tapping on the play button begins the 'Lipshape Practice' session.

Recording Videos

Users can record videos by tapping on the "Record Video" button on the bottom navigation drawer of the 'Library' tab as shown in Figure 1.A. This launches the Record Video activity, which prompts the user to select a word and the speaker who is going to be saying the word as shown in Figure 1.C. When the "Record Video" button is tapped, the video capture activity is launched. To begin recording, the user taps the red circle, and the user is presented with the word they are to speak along with a timer showing the duration of the recording. To stop the video recording, the user taps the red circle again, and is then asked if they wish to save or discard the video.

Video Library

The video library is accessed via the bottom navigation drawer of the 'Library' tab as shown in Figure 1.A. The video library displays a collection of videos and the user can swipe left or right to select a video. Tapping on the play button or the thumbnail plays the video in a fullscreen view. Underneath the video, the word, lipshape, and speaker is displayed. By tapping the edit video button, the user can edit the lipshape, word or speaker of the video, or delete the video.

'Speakers' Tab

The speaker tab displays the collection of speakers as an Android ListView. Each speaker is displayed as a row in the list view with a title (name of the speaker) and subtitle (showing the number of videos available with this speaker).

Adding a Speaker: The user can add a speaker by pressing on the button anchored at the bottom of the list. The 'Add Speaker' activity has a field for the first name and last name. When the users taps the submit button, there is a dialog box that informs the speaker about the research project and asks them if he/she consents to the use of their data and videos.

Speaker View: Tapping on an individual item in the speaker list loads a speaker view. The speaker view displays the full name of the speaker and the number of videos available for that speaker. Tapping on 'View All Videos' opens a video library for this speaker. Tapping on 'Edit Speaker' displays

a button to delete the speaker. When a speaker is deleted, all videos of that speaker are also deleted.

'Practice' Tab

There are two practice modes available in the 'Practice' tab: 'Lipshape Practice' and 'Word Practice'.

Lipshape Practice is a multiple choice quiz game where the user selects the word they think the speaker has spoken in the video. Lipshape practice chooses a random video from the lipshape selected, and two random words are presented along with the correct word as shown in Figure 2. The user selects an answer and is given feedback whether they are correct before the next video is presented. Lipshape practice shows a minimum of one trial and a maximum of ten trials. The lipshape practice setup activity allows for setting parameters for the session as shown in Figure 1.D. The user can select one lipshape to practice, or they can practice with all lipshapes. When all lipshapes are selected, the words can be from any lipshape, which makes the challenge easier (or harder depending on the words present). The user can also choose videos from a specific speaker or from all speakers. Finally, the user can select to have audio on or off. Once the user selects the parameters, they press the play button to begin the session.

The practice session view displays the trial video in a video view as shown in Figure 2. The video plays automatically and can be replayed by pressing the play button. A progress bar and numerical indicator displays the trial number and the progress through the practice session. At the bottom of the video are three buttons displaying three words, one of which is the correct answer. When the user taps on a word they are shown a 'correct' or 'incorrect' message. The 'Lipshape Practice' result view displays a table showing the correct answer, user answer, and the result for each trial.

Word Practice allows for all videos from the word selected to be played in sequence, this allows for a quicker and more focused practice session than the user scrolling through the library section. The user can select the word and if they wish to practice with a specific speaker or all speakers. Finally the user can select to have the audio for the videos on or off.
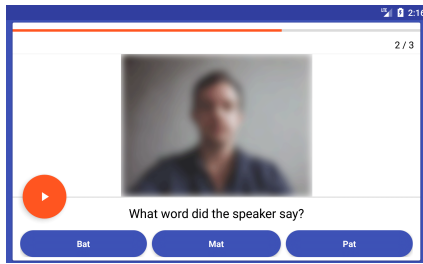
Figure 2. 'Lipshape Practice' session where the video plays automatically and can be replayed via the play button. Below the video are three buttons each displaying a word, one of which is correct.

EVALUATION OF "MIRRORMIRROR"
Procedure, Apparatus & Design
The evaluation of MirrorMirror comprised of three stages: 1) a briefing and tutorial session, 2) a week-long in-the-wild-deployment, and 3) a post-deployment discussion session.

Stage 1: Briefing and Tutorial Session
The first author met with each participant and explained the information sheet. The participant was then asked to sign the consent form before completing the questionnaire.

Pre-deployment questionnaire: The first questionnaire section contained nine questions and was used to gather basic demographic information; age, sex, highest level of education, level of computer literacy and details of participants' hearing. The second section contained four questions and was used to understand participants' daily experience of speechreading, they were: "Please rate your lipreading ability", " How long have you been in lipreading classes?", "Do you practice lipreading outside of classes?", "If yes, how do you practice lipreading at home?", and "Do you own a mobile device?".

Tutorial Session: During this session, the first author introduced and explained each feature of MirrorMirror. The participant was provided with a printed copy of the tutorial.

Stage 2: In-The-Wild-Deployment
We supplied a mobile device with MirrorMirror pre-installed to participants and asked them to use MirrorMirror for daily speechreading practice for one week. At this stage, MirrorMirror included six typical lipshapes that are practiced in lipreading classes [38]. We added three words to each lipshape, and a video of each word recorded by the first author was added to the video library, totalling 18 videos. During the deployment, MirrorMirror recorded details of each lipshape practice session, including the date, time, and results of each trial.

Device: Participants were supplied with a Samsung Galaxy Tab 3 (T210R, White, Wi-Fi) tablet that was rooted and running a slim ROM of Android KitKat. The Samsung Galaxy Tab 3 has a 7 inch 1024 x 600 pixel screen, a 1.3-megapixel front facing camera, and a 3 -megapixel rear facing camera.

Task List: During the course of the one week-deployment, the participants were asked to complete the following tasks: "Add at least three new words to each lipshape.", "At a minimum, we ask you to try and practice at least three lip shapes per day using the 'Lipshape Practice' feature.","Add at least three new speakers to your library (speakers can be family, friends, colleagues, anyone else you see on a regular basis e.g., coffee shop worker, newsagent etc)." and "Record at least one video for each lip shape for each new speaker."

Stage 3: Post-deployment Discussion & Results Gathering
After the week deployment, the first author met with each participant to conduct the post-deployment discussion session. The participant was asked to complete the closing questionnaire ('DiscussionGuide.pdf' in the supplementary materials) in the form of a structured interview, which was audio recorded for later transcription. Our interview transcripts are included in the 'Transcripts' folder in the supplementary materials. The participant was then debriefed. After this session, we took back the device and downloaded the usage statistics, before removing the app and all participant data from the device.

Participants
All participants had to be above the age of 18, and be currently enrolled in a speechreading class. Speechreading tutors were contacted through our existing contacts, and were asked to pass on details of the study to their students. Students were then asked to contact the researcher via email if they were interested in taking part. As participants were expected to have limited hearing, tasks for stage 1 and stage 3 were conducted in a location that was chosen by the participant that suited their hearing needs. Additionally, all study material for stage 1 and 3 were presented in written form, as well as verbally. We recruited three participants (mean = 67.66 years, SD = 11.84, two males). The participants' backgrounds, hearing loss history, and speechreading experience were varied:

P1, (Male, 74) is a retired teacher and his highest education level is university. He self-reported having moderate-to-severe hearing loss for 40 years due to ageing[5]. He wears one in-the-ear hearing aid in his right ear. He has been in speechreading classes for over a year and rates his speechreading ability as 'Fair'. He reported that he practices outside of class by watching television. He owns a Samsung Android phone and rates his computer literacy as 'Good'.

P2, (Female, 54) is a librarian and her highest education level is college. She self-reported having profound hearing loss for an unknown amount of time, and unknown cause. She wears one cochlear implant in her left ear. She has been in speechreading classes for two years and rates her speechreading ability as 'Fair'. She reported that she does not practice outside of class. She owns an iPhone and rates her computer literacy as 'Good'.

P3, (Male, 75) is a retired medical physicist and his highest education level is university. He self-reported having severe hearing loss for 20 years due to exposure to loud noise. He wears behind-the-ear hearing aids in each ear. He has been in speechreading classes for two years and rates his speechreading ability as 'Good'. He reported that he does practice outside of class by speechreading as often as he can. He owns an Android tablet, and rates his computer literacy as 'Excellent'.

Task Results
P1 added two speakers (his wife and his son), added 19 new words and recorded 18 videos. P1 had 12 lipshape practice

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[5]Although early-onset age-related hearing loss (as evident with P1) is rare [22], it is not unknown [33].

sessions that included 59 individual trials. **P2** added four speakers (herself, her husband, her daughter and a colleague), added 36 new words and recorded 145 videos. P2 had 72 lipshape practice sessions that included 706 individual trials. **P3** added two speakers (himself and his wife), added 36 new words and recorded 72 videos. P3 had 43 lipshape practice sessions that included 367 individual trials.

Post-deployment Discussion

P1: When asked about his overall impressions of MirrorMirror, P1 said that he felt it was *"quite easy, straightforward...and quite helpful"*. The aspect he liked the most was the lipreading practice and being able to see *"other peoples faces sort of close up like yourself, my son and my wife"* and that he found it *"interesting to be able to try [and] work out which word was being used"*. When asked how his speakers felt about MirrorMirror he said they *"...thought it was a very good idea"*, and that his son found it easier than his wife adding that they had *"No problem"* with being recorded. When asked if he had practiced speechreading with them before, he said *"no I maybe tried once with my wife...maybe lasted a minute or two but really no I would say basically no"*. Therefore, using MirrorMirror allowed him to practice his speechreading on those closest to him. He did add however that when they recorded videos they *"both started exaggerating the word[s]"*.

When asked if he thought his speechreading would be improved using MirrorMirror he said *"Yes...I think so yeah...because I wasn't practicing often enough but that would be a nice easy way to practice particularly if there were videos of people I didn't know how they spoke"*. When asked if he would continue to use MirrorMirror he said he would and there was not anything that he did not use or dislike on the application. When asked what the most important aspect of MirrorMirror was he said *"I think the videos, because I don't know your lip movements"*. When asked if he thought that MirrorMirror could be more useful if used on people's lipshapes he was not familiar with, he said that it would be *"Harder but I think more valuable...I don't mean impossibly harder but the lack of familiarity with their speech patterns would be better"*.

P2: When asked her overall impressions of MirrorMirror, P2 said that *"Once it was set up, it was nice and easy."* She added that *"It was very interesting, that even after practicing the words...I was still getting them wrong."* She believed this was because some of the words appeared visually similar; *"I don't think I got mat once...because it was too like bat and pat"*. This was mainly with her husband who spoke these words *"very similar."* However, she added that *"It was also interesting seeing my daughter, I found her lipreading quite easy...I think I got more of her ones right than I did my husband."*

When asked what she disliked, P2 found it cumbersome to choose words she wanted to redo, as she had to go into the practice and set all the options again. When recording videos, she said it would be better if you could record a batch of videos at a time, with MirrorMirror remembering you had just recorded a video with a speaker and a certain lip shape. She also said that where a person holds the camera results in how difficult the video might be, for instance her daughter *"had [the tablet] slightly lower down [so] I could actually see her*

lip moving sometimes where as everybody else was much more face on.". She added that *"I think you probably need to say 'have it at the level of your head' "*. She also said that because the camera on the tablet is not central, it can be difficult to record a video because you have to *"reach across the camera to put it on and off "* and that sometimes *"because you are looking at [the camera]"* while recording *"it is quite difficult"* adding however *"once you got used to it, it was fine"*.

She discussed never using mirror practice before, but felt that looking at her own mouth shapes with MirrorMirror was *"As difficult as everybody else"*. On practicing single words, she said that it was *"the most difficult thing for us to do anyway, so if you said you know the bat feeds at night then I know you are not talking about a mat or you are not talking about pat"*. However, she added that practicing *"one word, heightens it, and makes it really obvious that I'm not picking it up."* and that it was *"really good for practice having one word."* When asked if MirrorMirror could improve awareness of her need to speechread, she said that her colleague *"was [now] more aware that [speechreading] is really difficult"*.

When asked if she thought her speechreading would be improved using MirrorMirror she said *"Definitely...yesterday, I did the whole lot straight through...and did the worst ones again and...instead of getting four [correct] I was getting five or six."*. She also said that *"I think if there was something in particular that you were going to, an event or something and you knew you were going to be asked certain questions [MirrorMirror] would be really handy."*. Overall, she felt that MirrorMirror *"was nice to get confidence, and there was times when I'm just like saying 'you know I am saying that!"*. When asked if she would continue to use MirrorMirror she said she *"probably would."* and that more videos would be useful.

P3: When asked about his overall impressions of MirrorMirror, he said that *"[he] found it very interesting."* adding that he *"liked the basic idea of it. It's different from what [his] training in lipreading has been"*. When asked what he liked, he said it was *"interesting with [MirrorMirror] that words like parked and packed and I was surprised I could actually tell the difference...I got the 'r'...and that made me think that this was useful"*. When asked what he disliked he said *"nothing fundamental"* but echoed what P2 said, that it was repetitive having to enter the lipshape and speaker when adding multiple videos. He also said that because the camera on the tablet is not centered, it was important how the speaker held the tablet when recording a video and that it would be better if the tablet was on a stand or fixed position. Furthermore, he said that it was *"very important whether a person starts with their mouth closed or open"* because with the mouth open he *"thinks you are opening your mouth to speak as the first syllable...and that is confusing"*. He felt that speakers needed more instruction before taking a video to ensure all videos were consistent because if he knew the speaker was *"starting with [the] mouth closed [he] could lipread"* as normal.

He said that his wife had *"no problem"* with being recorded and that he could *"lipread her from [MirrorMirror] much better than [he] normally lipread her"*. When asked if his wife became more aware of his need to speechread through

use of MirrorMirror, he said that *"she may have found it quite instructive because she was watching"* when he was practicing and that he *"was getting them wrong"* even though she could hear the audio. On watching his own videos, he found it *"quite revealing watching [himself] recorded"* and that he did not think he was a very good person to lipread and that he will try to improve this during speechreading classes.

He said that he practiced lipshapes *"always within groups because it's too easy when you do it across groups"* and that *"you do come to learn...well, he never said two of these words"* so sometimes he knew the answer without needing to speechread. He said that he did not use the word practice feature as he *"didn't feel like it was practical"* however he did watch individual videos. He also did not look at his statistics because he felt that he *"didn't feel they would be very encouraging"*. Although earlier in the interview he mentioned that *"the best [he] ever got was 9/10"*. When asked if he thought MirrorMirror would improve his speechreading long term he said he *"thinks it might"* and that he would continue to use MirrorMirror if it had more videos of other speakers.

DISCUSSION
Summary of Contributions
Through a postal questionnaire with 59 speechreading students we identified that students are not currently supported for practice outside of class. Using our findings, we elicited requirements for a new SAT called MirrorMirror that addresses the limitations of current SATs by allowing users to capture and practice with videos of people they frequently speak with. Third, we evaluated MirrorMirror with three speechreading students who felt it enabled them to target their practice on people, words and situations they encounter daily.

Limitations
Our evaluation of MirrorMirror had a relatively small number of participants that may not be representative of the wider population of people with hearing loss. Recruiting highly specialised participants for evaluations that require face-to-face contact has always been a challenge in accessibility research [40], and our work here is no exception. To address this, we are currently extending MirrorMirror to address the feature-specific requests from our participants (e.g., simplified batch video recording, video library sharing – see below) before deploying for longer to a more diverse set of participants.

Although we found MirrorMirror could improve participants' ability to practice outside of class, we recognise that we have not evaluated (nor provide evidence of) MirrorMirror's effectiveness in improving overall speechreading ability. This would be difficult to prove (especially as participants only used it for a week) but we have shown that MirrorMirror has the potential to improve speechreading ability and will look to run a larger scale deployment as part of our future work.

A limitation of MirrorMirror that participants reported was that as speakers capture the videos, sometimes these videos are not the best quality (e.g., bad angle). It is possible to reduce this by including a tutorial within the application for new speakers, informing them how to capture the best possible video. However, when speechreading, it is not always possible to have perfect conditions, as we found from the questionnaire

responses on speechreading challenges; although they may increase the difficulty of practice, imperfect videos could be beneficial to the user's speechreading acquisition. A second limitation of MirrorMirror is that effective practice is dependant on the number of videos captured; users may become familiar with certain videos. This could be addressed by allowing users to share their video libraries with one another so that the number of possible practice videos is increased.

Finally, although we asked participants how recordees felt about MirrorMirror, we did not ask recordees directly. Our participants reported that their recordees had no problems with being recorded. This is likely because their recordees were family members who understand their communication challenges. However, the adoption of MirrorMirror is dependant on the participation of recordees. Therefore, we will consult with recordees directly in follow-on-studies.

Generalisations & Extensions
All of our participants discussed that being able to practice sentences with MirrorMirror would be valuable, as it adds context to the practice. In the future we will add a 'Sentence Practice' mode to the 'Practice' tab. However, we will need to revisit how speakers will record videos as recording sentences versus words will increase the difficulty for speakers. In addition, MirrorMirror could also be extended through 'Context Practice' where words and speakers could be tagged with a scenario such as a doctor's appointment.

MirrorMirror is currently built for English speechreading practice, but by updating the lipshape categories could be extended to support other languages. For example, French [6], German [11], and Japanese [26] each have distinct viseme-phoneme mappings. Finally, there are many popular ways to learn a foreign language (e.g., Duolingo (*duolingo.com*) or Rosetta Stone (*rosettastone.co.uk*)), however, immersing yourself in a new country is another way to practice [14, 32]. MirrorMirror could be adapted to help people learn by recording speakers of the target language, which could also help with learning pronunciation or region-specific dialects.

CONCLUSION
Speechreading can help people with hearing loss improve understanding during conversation, but is a challenging skill to acquire. Current Speechreading Acquisition Tools (SATs) are not adaptable to individual student needs unlike speechreading classes. To address the limitations of current approaches, we conducted a postal questionnaire with students from four speechreading classes to gather requirements for a new SAT called MirrorMirror. MirrorMirror allows speechreaders to practice lipshapes and words by recording videos of people they frequently talk to. We evaluated MirrorMirror through three case studies with speechreading students and found that it improved participants' ability to practice outside of classes. Our future work is focussed on expanding MirrorMirror with a new practice mode based on sentences and allowing users to share their library of videos with each other.

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