Understanding, Designing and Developing Assistive Technology for Students with Dyslexia in a Singapore Classroom

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Abstract
When developing assistive technology (AT) for individuals with learning or developmental difficulties, considering input from various stakeholders in the planning process increases the likelihood of sustainable AT programme implementation (Stoner, Parette, Watts, Wojcik & Fogal, 2008; Wong & Cohen, 2015). The study seeks to understand AT use in dyslexia intervention so as to effectively design and develop an innovative AT platform for primary school students with dyslexia. Focus group discussion sessions were conducted at the Dyslexia Association of Singapore (DAS) with 9 Educational Therapists (EdTs) to discuss the challenges faced by dyslexic children, their experiences, feedback and concerns with AT platforms, as well as existing intervention methods. Observations of DAS students (n=13, male=9, age range=7-12-years-old) during their regular intervention sessions with the EdTs were carried out to understand AT use during the sessions. Finally, in a User Feedback Study, the same students from the observation sessions tried out different form factor versions of a reading tool that we are developing that facilitates word recognition and comprehension using the latest optical-character-recognition and text-to-speech technology. Qualitative thematic analyses of the data suggest that the current AT used in existing intervention is insufficient for addressing the specific reading and learning difficulties of the students, mainly due to a lack of resources, accessibility, and knowledge. Comparative analyses suggest that the development of a mobile application would be best suited to address these aforementioned limitations. The functional and logistical requirements expressed by the EdTs and students would serve as guidelines for further AT development and implementation.

Keywords: Dyslexia Intervention, Assistive-Technology, Mobile-Interventions

Introduction

Dyslexia is one of the more prevalent forms of specific learning disabilities (SLD) that affects approximately 10% of the population (Hulme & Snowling, 2016). In recent times, there has been a surge in employing assistive technology (AT) to improve students' reading and learning in dyslexia intervention programs (Jamshidifarsani, Garbaya, Lim, Blazevic, & Ritchie, 2019). AT is generally defined as an equipment or device that can be used to overcome one's disabilities, perform specific tasks or improve their functional capabilities (Ahmad, 2015). Current AT in dyslexia intervention allows for access to printed text, such as Text-to-Speech software, reading and phonetic apps (Landulfo et al., 2015; Lindeblad, Nilsson, Gustafson & Svensson, 2016). Studies have reported that AT-inclusion in classrooms has improved reading, writing and comprehension for dyslexic students (Nordström, Nilsson, Gustafson, & Svensson, 2018; U.S. Department of Education, 2007; Wood, Moxley, Tighe & Wagner, 2018).

Besides improved reading and learning outcomes, AT use can also help to address students' psycho-social and behavioural needs (Lindablad et al., 2016). Compared to their typical-developing (TD) peers, dyslexic individuals display higher anxiety and lower levels of self-esteem and motivation, which can lead to the task avoidance in reading and schoolwork (Carroll & Iles, 2006; Terras, Thompson, & Minnis, 2009). This decreased exposure to reading and language further widens the achievement gap between dyslexic versus TD students. By developing AT that is perceived to be effective, meaningful, enjoyable, and acceptable, dyslexic students would be more willing to use AT in reading and schoolwork, which in turn promote greater independence in reading and learning, and subsequently, increase motivation and engagement. As dyslexia intervention is usually fairly intensive and requires therapist instructions, AT use can help to alleviate instructor load and allow for reduced or little instructor involvement (Vaughn et al., 2003; Firth, Frydenberg & Bond, 2012).

In light of these positive reports of AT use for dyslexia remediation for both students and educators, there have been many assistive and educational tools developed to address dyslexia-related deficits, such as technological devices, educative platforms, and smartphone and tablet apps. As of 2000, there has been a growing interest in technology-based intervention in the past few years (Jamshidifarsani et al., 2019). There is a plethora of apps available for download in app stores that are touted as suitable for individuals with dyslexia. In spite of that, there is a limited number of AT-based ones that are truly suitable for dyslexia. In a meta-analysis of 531 apps, Dawson, Antonenko, Sahav and Lombardino (2016) found that 24% of the apps developed had an oversimplified conception of dyslexia and neglected the fact that a holistic and multisensory approach is optimal for learning. Only a small percentage of apps have been developed with input/collaboration from dyslexia experts. Collaborative efforts between developers and dyslexia experts are important to ensure that the app is appropriately designed for the target audience.

Our project thus aimed to develop an AT platform that would meet users' needs by getting inputs from both dyslexic students and their Educational Therapists (EdTs) during the design and development process of an AT platform. EdTs are trained professionals who provide specialised and targeted support to dyslexic students beyond their daily curriculum (Landulfo, Chandy & Wong, 2015). The perspectives

of the EdTs are important because they help tailor appropriate interventions to individual learning. They have a deep awareness of the needs of the dyslexic students and the challenges that these students face. Getting prospective input from various stakeholders, such as the dyslexic students and teachers, is necessary for the long-term successful implementation of AT (Borg & Östergren, 2015). Thus, understanding both the students and the EdTs' perspectives is one of the important steps toward developing an AT program that can be effectively utilized during the therapy sessions, as well as in the larger classroom and home contexts.

Three studies were conducted at the Dyslexia Association of Singapore (DAS) – (1) Focus Group Discussion Study, (2) Observation Study and (3) User Feedback Study. The purpose of the first two studies was to understand the AT-based dyslexia intervention landscape in Singapore, so as to be better able to create an AT device that could address the specific needs of stakeholders (in this case primary-school students with dyslexia and intervention therapists) and incorporate successful features of existing intervention methods. Thus, we explored the difficulties and challenges faced by children with dyslexia and EdTs, the perceived benefits and limitations of existing non-AT based intervention methods as well as current experience and perception of AT use in dyslexia intervention in Singapore. In addition, getting the EdTs' feedback on AT intervention would provide us with guidelines for the reiterative development of our existing device prototypes. This input would help to directly address any gaps or limitations in existing AT-based intervention so as to better support learning and reading in primary-school children.

Similarly, acceptability of AT by a dyslexic child needs to be considered when developing the AT. A user feedback study was carried out to determine students' preferences for the form factor of an assistive device. Feedback and reception towards two device form factors were presented. This would allow us to determine which version of an assistive reading device could be developed further.

Part 1. Focus Group Discussion (FGD) and Observation Study (OS)

Methods

Participants

Nine EdTs from DAS were recruited across two-DAS approved centres for participation in two FGD sessions. The EdTs' years of relevant experience ranged from 2 years 7 months to 37 years. The centres were selected by DAS, based on location to account for scheduling and travel constraints of the EdTs. The FGDs lasted for 1 hour 13 minutes (n=3) and 1 hour 30 minutes respectively (n=6).

Thirteen students (4 females, 9 males) were recruited across six DAS centres for participation in the OS. The students ages ranged from 9 to 12 years old (Primary 3 to Primary 6). Students whose parents provided consent were allowed to participate in the OS.

Procedure

For the FGD, IRB-approved consent forms were disseminated to the EdTs prior to the FGDs. One researcher facilitated an open-ended discussion in each FGD session with the therapists who consented to study participation. Two more researchers were present as note-takers to take note of key discussion points and the EdTs' responses throughout the session (Krueger & Casey, 2001). During the FGD session, the EdTs were also given the opportunity try out two AT devices – 1) a C-Pen Reader Pen (a commercially available handheld scanner pen with an in-built dictionary), and 2) a mobile application with a detachable prototype version of a finger-worn camera that we were developing. The EdTs were asked for their feedback, suggestions and concerns on the devices. Each FGD was audio recorded and subsequently transcribed. The transcriptions were reviewed alongside the notes and coded separately by the two researchers who collected the data. A third coder, who had not been involved in the data collection process, reviewed what the two researchers had coded. The final themes and topics extracted were derived from discussion and consensual agreement amongst the three researchers.

Observation sessions were carried out during the regular intervention sessions at DAS. Students at DAS attended dyslexia intervention for either one-hour twice weekly or two-hours once a week. Each student was observed for a total of 2 hours. One researcher sat passively at the back of the classroom to ensure minimal interference in the class activities. Observational notes were made specifically about AT use in the classroom and the child's behavior in response to AT use. The observation sessions were audio-recorded if permitted by the students' parents. Recordings were later reviewed alongside the researchers' notes to corroborate the observations. Findings from the OS served to supplement our understanding of the findings from the FGDs.

Results

Findings from the FGD and OS were consolidated and qualitative thematic analysis of the FGD and OS transcriptions and notes was carried out (Braun & Clarke, 2006). Based on our research questions, themes and topics were extracted, coded, discussed and subsequently agreed upon by the researchers. The findings were categorized into 4 broad themes: 1) Challenges faced by dyslexic students, 2) Perception of existing non-AT intervention methods, 3) AT use in dyslexia intervention, and 4) Feedback on AT introduced.

1) Challenges Faced by Students with Dyslexia

In line with the literature, dyslexic students in Singapore experience similar difficulties in academic, socio-emotional and cognitive aspects (Carroll & Iles, 2006; Hulme & Snowling, 2016; Terras et al., 2009). Dyslexia-associated deficits with reading and learning such as poor phonological awareness, comprehension, spelling, word recognition, fluency and vocabulary were cited. Students had poor attention, memory, self-esteem, confidence, and motivation. Anxiety (particularly academic-related anxiety), task avoidance and an aversion to reading were also common problems faced.

2) Perception of existing non-AT intervention methods

Socio-emotional benefits: The EdTs lauded the importance of current intervention in addressing the students' socio-emotional challenges as it allowed the child to develop confidence in the classroom. This in turn would foster a sense of academic self-esteem that could subsequently increase the child's intrinsic motivation and interest in reading and learning.

Importance of individualised student-centred intervention: Existing DAS intervention programs, curriculum and strategies were perceived to be effective due to the incorporation of Universal Design for Learning (UDL) principles in class (Messinger-Willman, & Marino, 2010). Differentiated intervention methods were tailored to the child's learning profile to better address learning and motivation. The small teacher to student ratio at DAS (maximum of 1:4) was seen as beneficial compared to the large class sizes in mainstream schools as it allowed for more individualized teaching.

Lack of integrated support across the family, school and DAS: The EdTs indicated that although they equipped the students with learning and reading strategies, there was still a need to rely on external efforts, such as the home and school environment, to implement and reinforce these strategies. Multi-directional communication between the home, school and intervention environment is important for ensuring consistency in learning. However, the current lack of an integrated learning and support environment limits the child's learning progress.

Insufficient time: The EdTs also deemed the current intervention duration of 2 hours a week as insufficient. However, school and external commitments constrained the time in which students are able to attend intervention sessions.

3) AT Use in Dyslexia Intervention

Experience with AT used: The present dyslexia intervention classroom experience with AT is limited mainly to the projector, laptop, iPad, and commercially available mobile applications. Online platforms and browsers like YouTube or Google were used to search up word definitions or show educational videos and examples. Interactive websites with quiz or game platforms were also used to facilitate classroom learning and participation.

Perceived benefits of AT use: The EdTs perceived AT as being useful for student motivation and engagement in the classroom (see Table 1). The integration of different sensory modalities and teaching methods through AT allowed for the reinforcement and repetition of concepts learned. AT use was typically enjoyed by the students and could also foster a sense of autonomy by allowing for independent learning.

Table 1. Sample of Responses Regarding Perceived Benefits of AT Use

Socio-Emotional Benefits	*"I think using assistive technology, AT in short, iPads right, the first advantage is that it makes them motivated to learn. So we'll settle their emotional part, because they all come with a barrier. They hate to read. All our kids, they don't like to read. So with something different, and with the colors and all that, it's visual and they can touch. I think that is good motivation, for a start." (EdT05)*
Independent Learning	*"...You can go over it again if let's say the word they forgot in that sense, so they have the autonomy in that sense to read by themselves? Yeah, so I think that's one benefit." (EdT3)*

Limitations for AT implementation: There was a perceived apprehension of introducing AT in the DAS classroom as students are typically not allowed to use AT in their mainstream curriculum (see Table 2). Discrepancies between the assessment format versus instruction in mainstream education were a possible deterrence for the students' and EdTs' receptivity towards AT adoption. Additionally, the EdTs indicated that AT use in the DAS classroom is typically guided and does not fully allow for independent learning. The perceived limitation of AT as being less effective or more time consuming due to support challenges and the pervasive need for guided use could be a deterrence for AT adoption. Other concerns about AT implementation included affordability and the potential social stigma of AT use.

Table 2. Sample of Responses Regarding Limitations for AT Implementation

Lack of permissibility in school	*"I'm quite apprehensive when I ask my kids to type their essay on a laptop or iPad, because once they are so used to typing essay, they lost the touch of using pen and hand to write, and that will affect their speed when they're doing the examinations, during the examinations." (EdT01)* *"So I think a lot of the things that we try, or rather, what we have implemented over here, we have moved along with edu-technology, but the question is always, are they allowed to do the same in school. Like what EdT06 said, the assessment differs you see. We encourage the use of AT, but are they allowed to use the same AT for tests and exams?" (EdT04)*
Affordability	*"To have a device which needs them to purchase it, if students are on the lower economic scale, are they going to be able to purchase it?" (EdT04)*
Social Stigma	*"Give colors and make it more trendy. Because, you know why? I'm afraid that people will laugh at them when they wear this device." (EdT01)*

4) Feedback on AT Introduced

The EdTs were asked for their feedback on C-Pen and the mobile app to get a better understanding of the features and functions that could be incorporated when developing our AT device (see Table 3). The EdTs indicated the importance of an AT being able to scan individual words and longer chunks of text or sentences

continuously. Some EdTs suggested that the AT should also provide learning features such as the word definition and examples in the forms of images, sentences or even videos. Other EdTs, however, expressed that depending on the child's proficiency, an assistive reading device that could focus on single word recognition instead would be ideal, as the additional definitions and examples provided might not be necessary. The overall recommendation was for the device to provide options for the user to access different learning features as needed. Device output should incorporate both auditory and visual stimuli to facilitate multisensory learning. Auditory output should also be adjustable for aspects such as speed, volume, accent or gender of the voice output. Depending on the age group, a reward or feedback system would be useful for student motivation and engagement. The EdTs indicated that AT development should consider its applicability in the local context. The audio output of the device should also be customized for the local context as different accents could affect the intelligibility and comprehension of AT. The EdTs also indicated that different languages should be ideally accounted for to address the multilingual needs in the Singapore context. An AT that recognized multiple languages or offered language translation features was suggested.

Other considerations included the affordability, durability and physical appeal of the device. The EdTs voiced their difficulties of using the finger-worn camera to focus on a specific word. An intuitive device for student use was recommended to reduce the need for extensive guidance or support when using the device.

Table 3. Sample of Responses Regarding Feedback on AT Introduced

Adapting for local Singapore contexts	"Sometimes they can't make out what it says. It boils down to the accent." (EdT02
	"Can it be dual language? Like translated to Malay or Mandarin? Cos most of them are Mandarin-speaking or Malay-speaking. So when you point to the word, it gives the meaning, and you can select the option where it can be translated to Mandarin or Malay? Any other language?" (EdT02)
	"That is also not a local accent." (EdT04)
Additional Learning Features	"Probably, yea, if there's more functions, it'd be better, like meanings, context, clues" (EdT02)
	"I think you're saying this as a device that helps in word recognition, right? Further than that, it doesn't have a definition to it; an explanation part. If there can be some exploration on that side?" (EdT03)
	"Yea, again, so putting it in context, and if I'm going to read a text, and then there is this one word that I don't know and I scan it and it gives me all the other information. I'm going to be losing whatever that I've read earlier on. I'm not going to be following the story. So, I agree with EdT06. A reader should just function as a reader…" (EdT04)

	"So you were saying that if it's word by word, I think, yea, it will be very useful maybe for the preschool kids if they want to learn, maybe not preschool, maybe upper primary when they want to learn sight words on their own at home, they can go through it. But, probably, like they were saying the definition part, if there is a function where they can switch off the definitions and then maybe only when they need the definition, they can switch it back on, something like that, but I don't know whether it would be too complicated. Sometimes, they know they meaning of the word, but they're just unable to read the word, for the upper primary that is." (EdT08)
Reward System	*"Oh! How about motivation? Like there's something that says...ok but that's for preschool, because they are really rewarded by motivation right? So if you say, "Oh you did it!", you know usually apps have this, if they get that formation correctly then, "You did it! Wow well done!" I think that helps my kids." (EdT03)* *"But older kids they don't like ya?... They may say its childish." (EdT01)*
Physical Appeal	*"Attractiveness" (EdT02)* *"Appealing" (EdT03)* *"I think the main thing is that it has to be compact. Easy to keep. Not cumbersome, not chunky." (EdT02)*
Ease of Use	*"Camera to finger is very cumbersome ...As it is sometimes, writing from left to right is already very difficult for them (the students), so to toggle, and looking at EdT05's struggles with pointing, and this is an adult here, struggling with pointing the camera at the word, with a child, it's going to be even more challenging." (EdT04)*
Affordability	*"So, I mean, this will be helpful for them, but if it's going to cost, I don't think they have, we have access to it." (EdT05)*

Part 2. User Feedback Study (UFS)

Methods

Participants

The same students who participated in the OS also participated in the UFS.

Procedure

The study was carried out at either the start or end of the respective regular intervention sessions. Each session lasted for ten minutes to ensure that students did not miss out on their class time or to minimize the duration of staying back. Students were asked about their watch-wearing preferences and habits, and their general use and attitude towards technology and learning. The researcher introduced the two form

factors of the AT that we were developing – a wearable smartwatch and a mobile application. Students were then asked to try on the wearable smartwatch by themselves and to use the mobile application to identify a list of printed words. Questions about the ease and comfort of use of the device, likes and dislikes, as well as explicit preferences and reasons for either the wearable or the mobile app were then asked.

Materials

2) *Wearable FingerReader*

The Zeblaze Thor 4 Pro 4G, which is a commercially available smartphone watch, was modified to serve as a form-factor design prototype. The Thor 4's in-built camera unit was extended from the main watch body and retrofitted into a 3D-printed ring. This version of the wearable FingerReader prototype did not have the word recognition software installed.

2) Mobile Application

A mobile application for word recognition was developed and installed on a smartphone. A Galaxy J4+ Dual-SIM SM-J415F/DS operating on Android OS version 8.1 was used. Students were able to use the smartphone's in-built camera to capture the image of the word and read the identified words on the screen out loud.

Results

Familiarity and liking towards mobile phones over watches: Overall, the mobile phone was more familiar to students and all students enjoyed using it. Six students indicated that they liked wearing a watch, as it was useful for telling the time. Students who liked or were indifferent (n=2) to wearing watches indicated that they wore watches occasionally, due to it being more expensive or only if they "*felt like it*". Five students who did not like wearing watches cited that wearing a watch was uncomfortable and it "*hurt (their) hand*", was "*quite hot*" or would "*have a mark*". Watch wear was also considered unnecessary as they could use a mobile phone for telling time instead. Comparatively, all students expressed liking or were comfortable using smartphones and/or tablets. All students had indicated prior experience of using a smartphone and/or a tablet device, typically for gaming, video-watching, web-browsing, communication and social interactions.

Comfort and ease of use of mobile app over wearable: The use of the mobile phone was more intuitive and comfortable compared to the wearable smartwatch. Following the experimenter's demonstration of the mobile application, only three students required additional instruction or guidance on how to focus the camera on the worksheet. The remaining students did not have any difficulties with using the mobile app. All students indicated that the mobile phone was comfortable to use.

Conversely, students had more difficulties wearing the watch on their own. Nine students required assistance from the researchers in adjusting the watch-strap and the camera-ring attachment. As the camera was extended from one port, the wearable design could only cater for right-hand wear. Students who preferred wearing the

watch on their left hand (n=8) tended to wear the watch upside down, thus requiring further assistance in adjusting the fit and orientation of the device. Students also indicated that the wearable was not comfortable to wear. The comments made about the comfort of the wearable were as follows (Table 4):

Table 4: Sample of Comments on the Comfort and Ease of Wear of the Wearable Device

Comfort	• *"(The wire is) too long"* • *"(The ring) is pulling my finger out"* • *"It feels a bit strange"* • *"It feels disturbing…I don't like to put things on my hand, so it feels like something new for me when it's like that…can I take it off?"* • *"This feels so weird…my finger…it's a bit uncomfortable because the finger keeps pressing on my (child gestured to ring component and finger)""* • *"It's very hard (to move my finger around) because…usually I can move all the way, but this thing keeps (gestured to wire)…it's like controlling me, it's like when I want to move, then oh, cannot."* • Found it light (n=2), heavy (n=7) or were indifferent to the weight of the watch (n=4)
Ease of wear	• *"Very big…I don't think I can wear it"* • *"What kind of watch is this? It only works with adults' hands, not my hand"* • *"Usually I wear watch, but now I don't, so I might have difficulties wearing this"*
Ease of Use	• (Mobile app was) *"more easier and simpler to use"*

Student feedback on wearable device and mobile app: Students were explicitly asked which form factor they preferred and to provide their reasons for liking and/or disliking each version (see Table 5). An equal number of students preferred the wearable smartwatch (n=5) and the mobile phone (n=5), while three students indicated they liked both versions. Students who liked the mobile phone indicated that the app installed on it would be a helpful reading tool.

Additionally, a mobile phone was "*easier and simpler to use*" than the watch. A key deterrent for using a mobile app was the fact that the use of mobile phones was typically prohibited in school. One child also indicated that the additional features of a mobile phone could result in greater distraction as compared to a wearable's singular function.

With regards to the wearable device, one student preferred the wearable as it was more convenient – "*Easier to use the watch because you don't have to walk to get your phone and then take a picture*". Another student indicated that he liked the wearable as it allowed for word recognition to be more focused – "*because it only points to one word*". The remaining two students were unable to provide specific reasons for their preference. Other reasons for disliking the use of the wearable were

lack of familiarity of the device, discomfort of wear, and possible social stigmatization.

Table 5: Sample of Student Feedback on Wearable Device and Mobile App

Factors	Student Feedback on Wearable Device and Mobile App
Usefulness of Mobile App	*"It's helpful…If you cannot read, then you can take your phone and you can take a picture and it helps you to read".*
Concerns over aesthetics of the wearable	*"People would think that you're different…you're strange…because who would wear something like this that is connected to a watch. This looks like a ring, and this looks like a watch, who will wear a ring that is connected to a watch?*

Conclusion

As part of our device development process, our study aimed to understand the current landscape of dyslexia in Singapore, particularly pertaining to AT. Understanding the existing difficulties and challenges faced in existing dyslexia intervention, and the limitations of incorporating AT in interventions would allow us to develop AT as an effective problem-based solution. EdT and student responses towards AT and our specific device prototypes also provided first-hand feedback on the stakeholders' requirements for AT.

The challenges faced by the EdTs in the Singapore intervention classroom were found to be similar to those experienced in typical dyslexia intervention sessions. The need for intensive and explicit instruction from EdTs (Vaughn et al., 2003; Firth et al, 2012) was limited by the lack of time the students could attend remediation. Better familial and school support has been associated with better academic and socio-emotional outcomes for dyslexic individuals (Chen, 2005; Horn, Denessen, Bakker, van den Bergh & Voeten, 2010). However, the lack of reinforcement of concepts and strategies learned outside of the DAS classroom in the home and school environment also hinders the child's learning progress. Developing AT with differing levels of support access would allow students to become independent learners despite lacking familial, school or institutional support and resources (Moar, Currie, & Drewry, 2011).

Despite the awareness for the potential of AT-based intervention in overcoming the barriers of reading and literacy and socio-emotional or behavioural challenges, there are constraints that limit effective AT implementation in both intervention and mainstream classrooms. Taking into account the feedback provided by the EdTs and the students with regard to our device prototypes, the development of a mobile app would be more suited to circumvent the aforementioned challenges of AT and non-AT dyslexia intervention than a wearable device.

The fear of possible social stigmatization from using AT could also deter individuals from adopting it (Daley & Rappolt-Schlichtmann, 2018; Parette & Scherer, 2004). Fostering social acceptability is thus important for promoting sustained AT use (Landulfo et al., 2015). Development and use of a mobile app would likely be more socially acceptable compared to a wearable. A wearable would be more conspicuous and novel-looking compared to a generic mobile phone. This is supported by our findings where concerns were voiced on the aesthetic of the wearable device but not on the mobile phones.

Additional limiting factors for AT-implementation include the lack of skilled personnel for training support or the lack of knowledge on how best to incorporate the use of AT (de Witte et al., 2018; LoPresti, Bodine & Lewis, 2008). The need for guided AT use and user training for educational institutions and parents poses manpower and time limitations. The additional time and manpower support needed for adopting a specialised device like a wearable FingerReader are factors that hinder effective AT accessibility (de Witte et al., 2018; LoPresti et al., 2008). A mobile app would require little to no training time due to its ubiquitous familiarity.

The lack of affordability of AT could also prevent individuals from accessing such AT, especially those from lower socioeconomic backgrounds who already lack resources to begin with (Borg et al., 2015; Rohwerder, 2018). As the market for AT development is relatively niche, developers of novel AT, especially local and smaller technology companies, face possible difficulties of economics of scale (de Witte et al. 2018). The comparative higher cost of developing and manufacturing a wearable device thus limits the number of individuals who can afford it. In contrast, the widespread ubiquity of mobile phones or tablets make them a more affordable option. Users could also download a mobile app from available app stores at a fraction of the price or even for free.

For future directions for our AT development, we propose that the development of a mobile app would be the most suited to addressing the barriers for AT implementation due to its intuitiveness, familiarity, affordability, and perceived social acceptability. Positive aspects of intervention, such as feedback or a reward system would also be more easily incorporated in a mobile app via gamified elements. Multi-sensory learning could also be customized to each individual's preferences in a mobile app, and this could also allow for increased user-engagement and knowledge retention. A mobile phone with the app would also allow for more versatile use than a functionally specific wearable. Future software improvements and upgrades would be more easily accessible on a mobile phone than on a wearable device as users would only have to download updated app versions from the app store. Software improvements for a wearable might not be as easily accessible without having to purchase a new device, as updated versions of the software might not be optimised or compatible with older hardware versions. The flexibility of being able to improve and adapt the mobile app software would allow us to better cater to users' needs effectively. Developing a mobile app that could overcome the other limitations, such as bridging or reducing the necessity for communication between home and school environment would be ideal. Taking into account the other featural and functional requirements listed by the EdTs, the results of these three set of studies would serve as a guideline for future development of a mobile app that is optimally suited for dyslexia intervention.

Acknowledgements

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