Watch Your Language: Using Smartwatches To Support Communication

Humphrey Curtis
Department of Informatics
King's College London
London, UK
humphrey.curtis@kcl.ac.uk

Timothy Neate
Department of Informatics
King's College London
London, UK
timothy.neate@kcl.ac.uk

ABSTRACT

With an ageing population and increased prevalence of people living with complex communication needs there is a growing need to design scalable high-tech augmentative and alternative communication (AAC) apps to support agency and social participation. For end-users it is currently difficult to regulate the prominence of most mainstream high-tech AAC devices and tablet-based apps – they are socially conspicuous, offer poor portability, are aesthetically unconsidered, and obstruct vital non-verbal communication pathways. In response to this, we leverage participatory design techniques to design and evaluate two discreet and inconspicuous AAC smartwatch apps. We engage with a community of people living with the language impairment aphasia, to collaboratively build and iterate both a smartwatch app for 'public' communication: *Watch Out* and 'private' cognitive support: *Watch In*. Following this, we evaluate both apps during an experience prototyping workshop with an actor and subsequent focus group. We report results from communication interactions with both apps, interviews and feedback responses. Participants were not only successful in using both AAC smartwatch apps but, critically, the wearable and discreet intervention did not restrict users' agency and non-verbal communication.

CCS CONCEPTS

• **Human-centered computing → Accessibility technologies**.

KEYWORDS

Smartwatches, AAC, Alternative and Augmentative Communication, Accessibility, Discreet and Wearable Devices

ACM Reference Format:
Humphrey Curtis and Timothy Neate. 2023. Watch Your Language: Using Smartwatches To Support Communication. In *The 25th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '23), October 22–25, 2023, New York, NY, USA.* ACM, New York, NY, USA, 21 pages. https://doi.org/10.1145/3597638.3608379

Humphrey Curtis and Timothy Neate. This is the accepted version of the paper, hosted by the authors. Definitive version published at ASSETS and found here: https://doi.org/10.1145/3597638.3608379

1 INTRODUCTION

Augmentative and alternative communication (AAC) encapsulates a diverse range of tools, strategies and techniques to support individuals with complex communication needs (CCNs) in self-expression [29, 56]. Yet, adoption of AAC remains low and abandonment common [57, 91, 93, 97]. Recent research has highlighted that AAC devices detract socially and have the potential to exacerbate communication breakdowns [8, 35, 62]. Key AAC design shortcomings include that they are not intuitive to use[1], too large and socially prominent[2] [73]. Instead, AAC device design has predominantly focused on accurately outputting verbal dialogue for clear and unambiguous communication exchanges[3] [9, 35, 62, 94]. Yet, we argue that there is undeniably more nuance and ambiguity beyond strictly *accurate* speech when communicating in person. Indeed, most AAC devices fail to support non-verbal communication pathways [33–35, 75], which make up a vital part of communication [55]. Consequently, our work considers the importance of *total communication*, which people with CCNs already leverage to effectively communicate[4] [75]. This expansionist framing of communication is rarely considered in the design of AAC and perhaps consequential of the proportionally smaller number of AAC devices co-designed with communities living with CCNs [17, 18].

Against this context, over the last two decades, smartwatches have become *much* more socially prominent. Estimations suggest that Apple has sold 100 million smartwatches alone [12, 83]. Equally, the growing functionality of smartwatches means that they are almost as feature-rich as their counterpart smartphones [69]. Moreover, smartwatches serve an aesthetic purpose – acting as desirable artefacts[5] [64, 69]. Additionally, they are also generally *always available* at a glance and therefore have the potential to serve as a potential just-in-time support tool for people with CCNs [30, 64, 92], or as a quick-access trigger for existing AAC applications. For instance, Proloquo2Go now supports a watch companion app which allows users to quickly access functionalities of their tablet AAC [77]. Despite these technologies, previous work has not *co-designed* AAC smartwatch apps *directly* with communities with CCNs. In this paper, we present the first contribution which seeks to design AAC smartwatch applications for people with CCNs. We work directly

[1]With extensive operating instructions for the adopting family and community [8].
[2]Often, not viewed as aesthetically desirable by their users [73].
[3]Research has sought to make speech-generating devices (SGD) that appropriately support paralinguistics i.e., vocal intonation, humour and sarcasm.
[4]Subtle natural cues in body language, eye gaze, facial expression and the usage of props to augment verbal speech and enrich overall self-expression has been termed *total communication* [75].
[5]Smartwatches such as the Apple Watch can afford the wearer positive connotations of fitness and health. Even operating as a fashion accessory with watch straps designed by luxury fashion brands such as Hermès [2, 12].

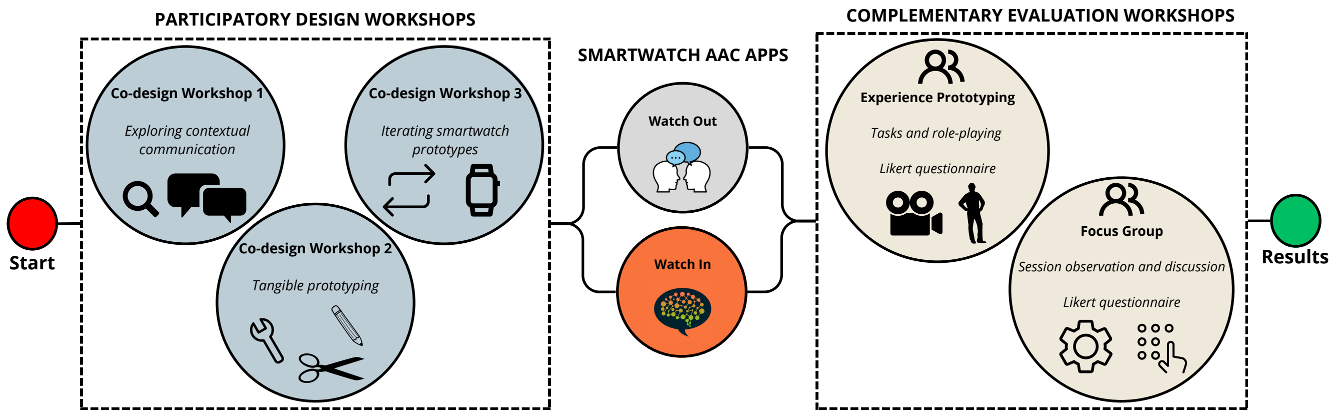


Figure 1: Research chronology from start to results: research began with three participatory design workshops in Section 3 to develop the *Watch Out* and *Watch In* smartwatch AAC apps outlined in Section 4. Followed by complementary evaluation of both apps during an experience prototyping workshop outlined in Section 5 and a further focus group outlined in Section 6.

with people with aphasia – a language impairment which often follows a stroke. Through a range of participatory approaches (see Figure 1 for a chronology) we build upon an *expansionist* notion of technology-supported communication, which seeks not just to support verbal output but also complement wider total communication strategies. Overall, we:

(1) Co-design two AAC smartwatch apps in collaboration with communities with CCNs, specialists and stakeholders – specifically, speech and language therapists (SLTs) and people living with aphasia.
(2) Provide insights from three co-design sessions with people with aphasia which used a myriad of accessible techniques for exploration of contextual communication challenges, before transitioning to tangible low-fidelity prototyping and culminating in AAC app wireframes.
(3) Report results from an evaluation of two AAC smartwatch apps during an accessible experience prototyping workshop with an actor and subsequent focus group, coupled with results from interviews and questionnaires.
(4) Offer guidance for future research regarding accessible co-design of AAC smartwatch interventions for people living with CCNs and older adults. Plus, a collective evaluation of the methods and participatory design techniques used within this research.

2 RELATED WORK

2.1 Social Engagement and Smartwatch Interventions

Historically, the form factor of AAC is large, prominent, publicly conspicuous and predominantly designed to be mounted to the frame of a wheelchair [18, 35]. Critically, this large form factor can restrict agency as devices are inconvenient to transport and detrimental for social engagement [66, 71]. Research by Bennett et al. [6], has found that prominent assistive devices can portray the user as vulnerable or incapable [66]. Equally, we have previously found that people with CCNs actually *desire* less prominent device form factors – *even* wearable AAC [18, 71]. Furthermore, for daily usage, the bulky and heavy size of tablet-based AAC apps is inconvenient 'on the go' and can be difficult to quickly access especially if the user has a physical impairment such as hemiplegic paralysis [8, 35, 53]. Rather, AAC devices should be designed to *maximise* social engagement and agency[6] supporting users ability to engage in communal activities. For instance, AAC interventions should accommodate user's agency to exercise, visit restaurants and use public transport [63]. Equally, AAC should support children's agency to physically play with other children [35]. However, current tablet-based AAC designs offer a rigid and prominent form factor – restricting user customisation and personalisation for the public domain [8, 35].

Overall, there has been considerable growth in AAC apps downloadable for mainstream computer devices i.e., laptops, tablets or smartphones [29]. Positively, these technologies are highly scalable and mainstream devices do *not* socially signal the users underlying disability [71]. At the same time, research has increasingly considered smartwatch apps as a potentially beneficial assistive technology intervention. For instance, Jain et al. [36] effectively designed a smartwatch app to support sound awareness for DHH users – deploying a deep learning sound classification model on watch hardware. Elsewhere O'Brien et al. [64] repurposed a smartwatch to provide just-in-time (JIT) support for autistic children. Turning to the commercial sphere, Proloquo2Go is currently the only AAC smartwatch app available on the App Store to our knowledge. It provides two options: firstly, operating as a switch to support cross device interactions with a partner device (i.e., tablet) or secondly, to provide both voice and text output for pre-written phrases [77]. Despite a lack of commercial development, smartwatches have many unrealised advantages for AAC technology: they provide portability, a non-medical aesthetic and do not restrain the users embodied expression by forming a physical barrier [22, 35, 37, 71]. Equally, Apple has designed mainstream tools to increase the accessibility of smartwatch input interactions – Assistive Touch enables one

[6]Pre-existing research finds social engagement decreases *significantly* with disability across age ranges and communities [21, 46, 67].

hand input via pinches and clenches [1, 68]. Plus, a motion based pointer controllable by tilting the display [1].

2.2 Total and Non-Verbal Communication

Communication is significantly more complex than purely verbal dialogue – interlocutors rely on nuanced complex and context-dependent cues to communicate meaning [75]. Non-verbal body language, haptics, gestures, facial expressions, proxemics (i.e., personal space) and eye-gaze are used to augment speech and enrich overall self-expression [75]. Furthermore, communicators can leverage physical props, appearance and low-tech devices to successfully complement embodied forms of communication[7] [75]. These non-verbal strategies are termed *total communication* [75]. For people with CCNs, research has established the heightened importance of total communication strategies to communicate meaning – in which people with CCNs creatively leverage *all* naturally available communication pathways beyond purely verbal speech [75]. Further advantages of total communication strategies include that they are more personal, spontaneously accessible for a person with CCNs and easier to quickly learn than sign language or a new AAC device [75].

Yet, both communication partners and technology can detrimentally undermine total communication strategies. For example Neate et al. [59], identified the challenge presented for total communication by pandemic-driven videoconferencing technologies amongst people with aphasia. Regarding specifically AAC devices, research finds that they *significantly* compromise non-verbal and total communication strategies – even promulgating eventual device abandonment. Research by Ibrahim et al. [33, 35], investigated AAC usage amongst children with severe speech and physical impairments (SSPIs) and found that AAC devices undermined embodied pathways to communicate. Specifically, the AAC manifested as a physical barrier with communication partners – obfuscating naturalistic non-verbal expression [8, 34, 35].

Elsewhere, our systematic review previously found *just* 1.4% of AAC devices are designed to enhance non-verbal communication [17]. Indeed, AAC devices do *not* actively encourage total communication strategies they are instead designed for dialogue construction and voice synthesis. Meanwhile, it is challenging for the user to *regulate* the prominence of their AAC during communication exchanges – the rigid form factor results in an inability to shape-shift and take *more* discreet forms limiting opportunities for spontaneous communication interactions [18, 35]. Ideally, AAC should have the capacity to support a diversified set of interactions for their user [18, 35]. Towards this goal, promising research by Valencia et al. [89, 90] has sought to enhance AAC users non-verbal interactions via co-designed physical expressive objects.

2.3 Participatory Design with People with Aphasia

Aphasia is an acquired language impairment most commonly caused by stroke [4, 7]. However, aphasia can be caused by other forms of damage to the language centers of the brain. It can affect reading, writing, speech and comprehension [4, 7]. Importantly, aphasia is classified as an *invisible disability*, which can make navigating public environments more challenging [16]. Aphasia affects approximately one third of stroke survivors yet less than 10% of the population know of the condition [16]. People with aphasia can have hemiplegic paralysis on one side of their body, which limits its dexterity [7]. Typically, people with aphasia's communication abilities vary significantly [4]. For instance, some people with aphasia might find speaking more challenging than writing or vice versa. The number of people living with aphasia will likely increase due to the ageing global population [16]. Increasingly, people with CCNs such as aphasia face barriers to long-term speech and language therapy due to health systems facing increased service demands [10, 32, 49]. Conversely, research has found AAC interventions can support people with CCNs communication and ability to live independently [39].

To improve upon the design of high-tech AAC devices we elected to involve end-users and stakeholders *directly* within the design process [78]. Co-designing with people with aphasia can be challenging due to problems with communication, providing consent and cognitive fatigue [98]. Yet, previous scholarship has improved the accessibility of participatory approaches to develop technologies that support people with aphasia's agency and autonomy [61, 98]. For instance, Obiorah et al. [63] successfully co-designed three AAC apps to support dining in restaurants for people with aphasia. Other influential methodologies included, Wilson et al. [98] tangible design languages. They facilitated people with aphasia's *voice* in design via the usage of: short, direct tasks and tangible physical artefacts [98]. For example, Story Grids[8] supported workshop participants multimodally ranking communication environments in terms of challenge and noise [98]. Other influential co-design approaches, include Raman et al.'s multi-method techniques for collaboration with young people with learning disabilities [74]. Initially, they used topic coasters to capture details from conversations (e.g., scenario setting, people involved and key issues) and ideated solutions with participants by envisaging 'Superheros' and 'Super Tools' using tangible templates [74]. Finally, they employed artefacts, prototypes and role-playing[9] to test concepts and iterate on emergent insights [74].

3 PARTICIPATORY DESIGN OF AAC SMARTWATCH APPS

We began with three co-design workshops on AAC smartwatch apps with people with aphasia. To start, we explored contextual communication challenges within different public contexts before transitioning towards tangible low-fidelity prototyping and finally, iteration of the smartwatch apps.

3.1 Procedure

To make the workshops more accessible we followed Mack et al. [48] guidelines throughout the research process – we operated in a familiar space for participants, used accessible consent procedures, monitored participants' needs and endorsed flexible attendance.

[7] Clark and Chalmers [14], extended mind theory (EMT) posits that environmental objects can even serve the cognitive process and function as extensions of the mind.

[8] An adaptation of the Talking Mats AAC, whereby individuals with CCNs express themselves via symbols, photographs and categories.

[9] For further research on role-playing and experience prototyping please refer to Buchenau and Suri [11] and Szklanny et al. [85] – this research informed our simulation of usage contexts and promoted engagement with the smartwatch apps.

Ethical approval for this research was granted by the King's College London Health Faculties Research Ethics Subcommittee. Participants with aphasia were supported to access the information sheets and led through the consent process by an SLT. The workshops were video and audio recorded for qualitative data and analysed inductively to identify recurrent themes [68].

3.1.1 Setting. Participants were recruited from Aphasia Re-Connect, a charity, which supports people with aphasia by providing a social community and group therapy. We conducted our research during the weekly face-to-face group drop-in at the Roberta Williams Speech and Language Therapy Centre. All participants were familiar with the location and most arrived independently using public transport.

3.2 Participants

Four people with aphasia were employed as co-designers. All four had moderate to severe aphasic language difficulties as a result of stroke, and two had right-side paralysis from hemiplegia. Ages ranged from 51 to 69 years old. One SLT was employed as a co-designer and to support the workshops. Complete participant information is presented in Tables 1 and 2 (i.e., all Co-designers are CD in the Attendance columns). The three co-design workshops each lasted 1.5 to 2 hours. The co-designers with aphasia worked alongside the SLT and researchers to extensively ideate and provide feedback on AAC ideas and prototypes. Their participation was facilitated through accessible co-design techniques for people with aphasia. The workshops were mostly group-based but also included some individual use of technologies and pair-based co-design activities. All participants were paid at a rate of 20 GBP per hour. All participants' names are aliases.

3.3 Co-design Workshop One: Exploring Contextual Communication

Illustrated by Figure 2, workshop one explored participants' communication experiences in different public contexts. We wanted our co-designers to feel empowered to share their unique stories about varying experiences with communication partners across multiple contexts. To improve workshop accessibility, we adopted a highly tangible approach during participant discussions [98]. This consisted of using 20 laminated tangible context cards in both visual/text format – each card represented different public communication contexts (e.g., cinema, supermarket etc.). Using shuffled decks participants spontaneously shared stories when prompted by each card context. Furthermore, the tangibility of the card served as an invaluable affordance that participants leveraged to scaffold narratives. Throughout this process, the researchers and SLT probed for additional meaningful details about each scenario (e.g., people involved, key issues, feelings and emotions). Once the entire deck had been thoroughly explored we proceeded to a group activity based on Wilson et al. [98] Story Grids. Here, a whiteboard grid structure was created to rank each conversation context. The vertical dimensions of the grid gave frequency of visiting a context (Never to Daily) whilst the horizontal dimension rated the degree of difficulty presented by communication within this setting (Easy to Hard). This activity was especially successful in generating group discussion about participants' routines, what they found difficult, points of consensus and notable differences. Instead of reaching group consensus, the context cards were colour-coordinated so participants could pin their unique perspective from living with aphasia. Shown in Figure 2, the whiteboard communication grid provided a tangible, manipulable representation of overall communication for the participants across different contexts.

3.3.1 Findings from Exploration. Some communication contexts were identified as very challenging by our co-designers. In particular, public and busy locations with many strangers i.e., public transport, pubs, bars, concerts, stadiums, hospitals and GPs. During these stranger-based communication interactions, participants noted it can be exacerbating to repeatedly explain to strangers *"what is aphasia"* as it is an invisible disability. Instead, participants actively avoid this repetitive conversation by rather expressing that they have had *"a stroke"*, which is more publicly recognisable terminology. Elsewhere, Brian and Rick acknowledged their routine of visiting the hospital due to underlying health conditions i.e., an autoimmune disorder and hypertension. During these visits, Rick specifically acknowledged his trouble with short-term memory loss – commonly forgetting critical *"doctor's prescriptions"* and leaving *"something on the hob"* at home. All co-designers admitted that their fluctuating communication abilities caused tremendous frustration. Whilst, staffing changes at hospitals, layout changes of supermarkets and rising preference for supermarket self-checkouts, *"Jill: is very hard"* to successfully navigate. Indeed, our co-designers rely upon communication with familiar doctors who provide sufficient, *"Brian: time to get comfortable"* and shop clerks to find items. Indeed, for our co-designers internalised anxiety from the social pressure of being rushed to *normalised* communication speeds triggers substantially worse dialogue and self-expression.

3.4 Co-design Workshop Two: Tangible Prototyping

The second co-design workshop transitioned from contextual communication difficulties towards supporting our co-designers to define and ideate low-fidelity solutions using craft materials. Initially, we printed A1 diagrams of the whiteboard communication grids to provide a formalised reproduction to prompt collective ideation. Co-designers then reflected on the printed communication grid and specific problems faced within these contexts. These problems were outlined in a bullet point format. Following this, we prompted participants to envisage a 'super' tool that could assist them with these communication problems and enhance their pre-existing total communication abilities [74]. We then divided into smaller sub-groups of 2 or 3 with each group selectively choosing a small set of these acknowledged communication problems to solve. One researcher/SLT was assigned to each smaller group to support ideation of divergent solutions. Equivalently, previous co-design research by Neate et al. [60, 61, 86] used low-fidelity tangible craft and paper-based wire-framing materials to successfully ideate with participants with aphasia. Amongst the smaller groups, the SLT/researcher would mediate discussions and appropriately use closed 'yes/no' questioning to support prototyping activities (e.g., drawing, writing and cutting) of a high-volume of participants' solutions. Low-fidelity prototypes were also successfully used by our co-designers to tangibly supplement their dialogue and expression. Starting with abstract *imagined*

Table 1: Overview of participants with aphasia across co-design workshops, the experience prototyping workshop and focus group. Assessed by an SLT are participants' aphasia, speaking, reading, hearing, and writing – scaled: Mild, Moderate and Severe. Also, we noted participants' Hemiplegia and personal technology refers to participants' day-to-day devices or AAC.

PWA (Gender - Age)	Aphasia	Attendance	Difficulties	Personal Technology
Brian (M - 57)	Moderate	CD, EPW	Speaking: Moderate Reading: Severe Writing: Moderate Physical: Hemiplegia	Smartphone
Rick (M - 51)	Moderate	CD, EPW	Speaking: Moderate Reading: Moderate Writing: Severe	Smartphone Smartwatch
Isaac (M - 69)	Moderate	CD, EPW	Speaking: Moderate Reading: Mild Writing: Moderate	Smartphone
Jill (F - 53)	Severe	CD	Speaking: Severe Reading: Severe Writing: Severe Physical: Hemiplegia	Smartphone Smartwatch
Patrick (M - 49)	Moderate	EPW	Speaking: Severe Reading: Moderate Writing: Moderate	Smartphone Smartwatch
Jack (M - 69)	Mild	EPW	Speaking: Moderate Reading: Mild Writing: Mild	Smartphone
Jacob (M - 65)	Moderate	FG	Speaking: Moderate Reading: Moderate Writing: Severe	Smartwatch
Hannah (F - 61)	Severe	FG	Speaking: Moderate Reading: Severe Writing: Severe Physical: Hemiplegia	Smartphone
Steve (M - 52)	Severe	FG	Speaking: Moderate Reading: Severe Writing: Severe Physical: Hemiplegia	Smartphone
Joseph (M - 80)	Severe	FG	Speaking: Severe Reading: Severe Writing: Severe Physical: Hemiplegia	Flip phone

Table 2: Overview of SLT Focus Group participants. Role refers to SLTs professional experience spent working with people with aphasia and respective family members who supported participation.

Participants (Gender)	**Attendance**	**Role**
Peter (M)	CD, EPW	SLT - 3 years
Sarah (F)	FG	SLT - 40 years
Emilia (F)	FG	Family member - Joseph's wife

PWA: People with aphasia EPW: Experience prototyping workshop CD: Co-designer FG: Focus group
SLT: Speech and language therapist M: Male F: Female NB: Non-Binary N/S: Not Specified

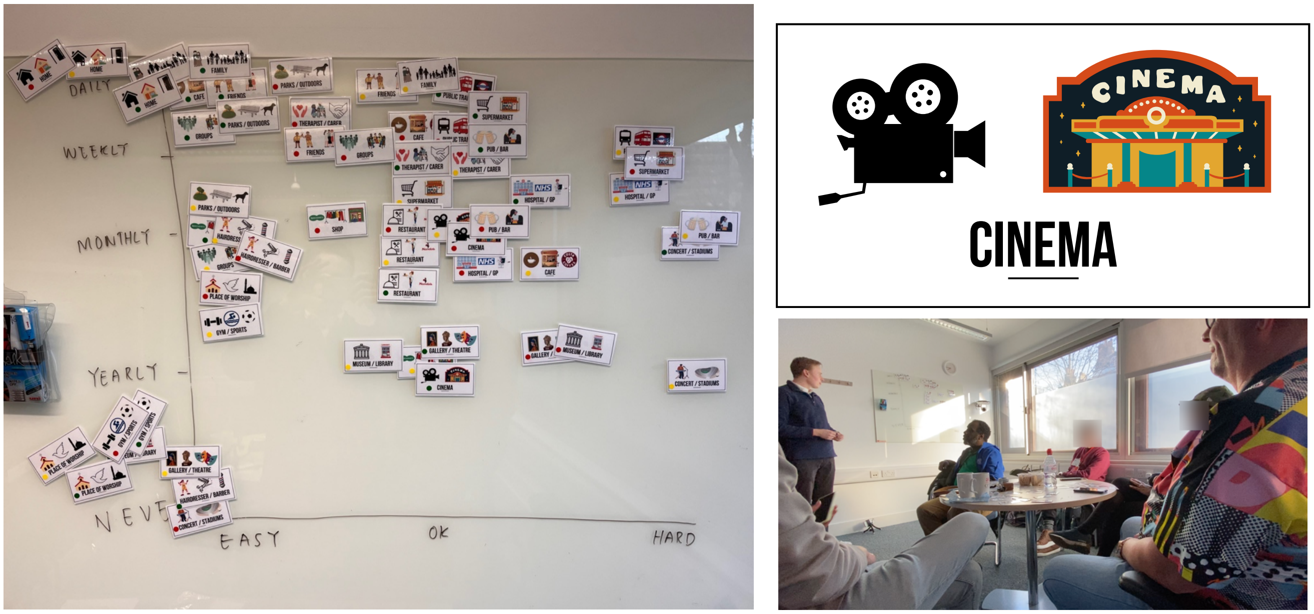


Figure 2: Figures from co-design workshop 1 in Section 3.3, which explored contextual communication experiences in different public contexts. From left to right, image of finalised whiteboard communication grid to rank each communication context, picture of tangible context card for 'cinema' and image of co-designers during session.

solutions each group slowly transitioned towards wireframing *more* focused smartwatch apps during the workshop. Equally, during prototyping the researcher/SLT could be extemporaneously enquiring over participants' design choices, the accessibility of envisaged interactions and types of multimodal communication support from the AAC. The low-fidelity wireframing process naturally finished once participants were satisfied with their final designs. Lastly, depicted in Figure 3, the workshop ended with demonstrations of each finalised smartwatch wireframe application and envisioned functionality.

3.4.1 Outcomes from Prototyping. Pictured in Figure 3, low-fidelity prototyping led to three wire-framed smartwatch apps which we delineate by their main co-creator.

Jill's AAC. Jill's AAC smartwatch app centres on solving her daily word-finding challenges. Jill uses an AAC app (*SpokenAAC*[10]) daily on her iPhone to find words. Frustratingly, her premium trial on *SpokenAAC* was due to expire so she was very motivated to design *free* AAC. Co-designed with the recruited SLT, her app starts with a quadrant of icons for navigation. Navigating to the first feature provides an alphabet picker – supporting her phonetic search of the first letter of a dictionary of words. For Jill, she typically recalls the first letter and phonetic sound. For instance, during recall of the word *"dog"* Jill would typically recall *"d"* or the first phoneme *'/d/'* sound, which she simultaneously makes with her tongue and mouth. Therefore, the picker search was deemed most accessible versus the small keyboard or vocal input offered by the smartwatch. Indeed, Jill has right-side hemiplegia thus her larger iPhone screen is preferable for *more* dexterous input interaction. However, she wears an Apple watch daily due to its health monitoring (e.g., step count), ability to manage incoming calls, send messages and control music – without retrieving her phone from a pocket/bag. Upon finding the desired word within her co-designed smartwatch AAC, she wanted to tap to trigger text-to-speech and present the word coupled with multimedia i.e., an image, icon and video. Navigating to the second feature, Jill desired a chronological search history feature as she repeatedly has trouble forgetting the same words over time.

Brian and Isaac's AAC. Co-designed with a researcher, Brian and Isaac's AAC smartwatch app considered the problem of informing strangers about their underlying aphasia in public environments. Their app design begins with a quadrant of navigation icons i.e., the expression *"Please speak more slowly"* with a tortoise icon to indicate slowness. Following navigation, Brian and Isaac designed for each expression to be displayed in large text and an icon. In terms of interaction, they proposed the expression to be externally synthesised each time you tapped the screen. In terms of expressions most useful for communicating with strangers – Brian and Isaac initially considered: *"Please speak more slowly"*, *"Could you please let me have your seat"*, *"Please give me time to answer"* and *"I have had a stroke and aphasia"*. Equally, Brian and Isaac proposed the ability to rotate the screen to support presentation to onlooking communication partners – with the smartwatch acting as an outward prop to supplement communication.

Rick's AAC. Rick's AAC smartwatch app revolves around his problems with short-term memory loss and mindful breathing during dialogue. Contextually, Rick is a dedicated smartwatch adopter

[10]https://spokenaac.com/

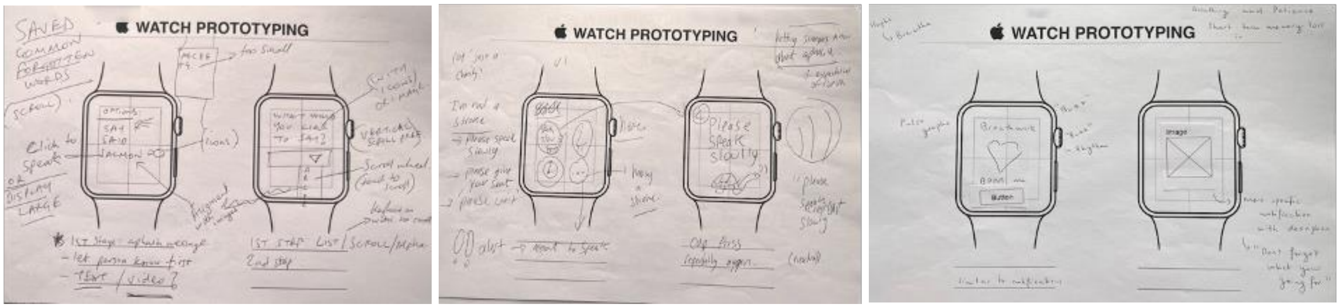


Figure 3: Three wireframes developed in collaboration with co-designers outlined in Section 3.4.1. From left, Jill's AAC app is envisaged to support phonemic word-finding, Brian and Isaac's AAC app centres on an outward public communication displays and Rick's private AAC app supports short-term memory loss and *more* mindful breathing.

Figure 4: Images from co-design session 3 outlined in Section 3.5. On the left, participants discuss and trial the deployed prototypes on an Apple Watch. On the right, participants critique A4 printouts of each app.

having worn a smartwatch for eleven years. Regarding the home screen, he wanted a scrollable list of features for initial navigation. Co-designed with a researcher, his first feature centred on transcription enabling him to verbally record notes and excerpts of conversations. Presently, Rick finds it very challenging to elucidate critical details from earlier conversations such as prescription/medication doses from his doctor or pharmacy. Typically, he requires the support of his brother for these critical conversations. Once, an excerpt of the conversation was transcribed he requested the text to be played back via voice synthesis upon tap. During conversations, Rick finds he gets out of breath due to the anxious pressure of worrying about his mind blanking mid-sentence consequently, his second feature considered breathwork. In particular, Rick advocated for some form of haptic cues to breathe via a pulsing vibration on the wrist in a sequential rhythm. Although he was concerned about device battery loss he said that a mindful breathing feature would be discreetly supportive and prevent him from getting too *"frustrated"* at his broken dialogue and remind him to *"not rush"* when speaking.

3.5 Co-design Workshop Three: Iteration of Prototypes

Shown in Figure 4, using the wireframes of co-designers smartwatch AAC we built three proof of concept Apple Watch AAC apps prior to the third co-design workshop. The three apps contained most of the core features envisaged by participants from the previous co-design workshop. The three apps were deliberately deployed on two devices of different sizes: an Apple Watch Series 8 (45mm) and Apple Watch SE 2 (40mm) to appropriately test font and icon size. Each participant with aphasia and the SLT tested the collection of apps with support from a researcher. Furthermore, we performed light testing with Apple's Assistive Touch activated amongst co-designers, especially those with hemiplegic paralysis. We immediately held an open discussion about each app whether it achieved what our co-designers envisaged and suggested changes. To support this process, we provided participants with a navigable A4 prints of the three apps – so participants could annotate and critique each application.

3.5.1 Findings from Iteration. Overall, participants were very satisfied with the implementation of their wireframes. Turning to suggested changes for Jill's AAC app our co-designers suggested a

(a) Using request for seat expression and options for: voice synthesis, reverse display for onlooker and buzzer

(b) QR code to provide more information on aphasia

(c) Trigger recognisable blue accessibility badge

(d) Customisation of voice gender

Figure 5: The *Watch Out* on wrist and demonstration of functionality.

page where an SLT or family member could add new words to the dictionary – supporting the ability to add unique names, nouns and place names. Equally, we collectively agreed the app's initial dictionary should be based on commonly forgotten words suggested by our co-designers plus Palmer et al. [65] dataset on frequently used words by people with aphasia. Turning to Rick's AAC app, he initially requested that we automatically add reminders of recorded dialogue transcripts to remind him later in the day. Furthermore, the group appreciated the graphic used to visually support deep breathing.

Finally, our co-designers decided it was best to merge Rick and Jill's app into a singular smartwatch AAC offering more *private* cognitive support. For Brian and Isaac's *public* AAC app, we implemented a looping transition through the dialogue to significantly increase font size on the watch display for public readability. Regarding changes to Brian and Isaac's AAC app, our co-designers suggested a red screen to be more eye-catching and Brian proposed adding an audible buzzer to draw public attention. Equally, it was collectively agreed that the functionality to display a blue disability badge would improve public recognition. Importantly, Jill insisted upon a settings page to configure the gender of the voice synthesis. Finally, it was collectively suggested by our co-designers to implement a specific Aphasia information page, which could be used to improve public awareness via QR code.

4 THE WATCH OUT AND WATCH IN APPS

Watch Out and *Watch In* are co-designed AAC iOS applications designed to support communication for people with aphasia. *Watch Out* is designed to support *public* face-to-face interactions of key expressions as a non-verbal display and verbal voice synthesizer. In contrast, *Watch In* is a *private* cognitive support designed to support short-term memory loss, word finding and mindful breathing. Both smartwatch apps are designed to reinforce users pre-existing total communication abilities and agency.

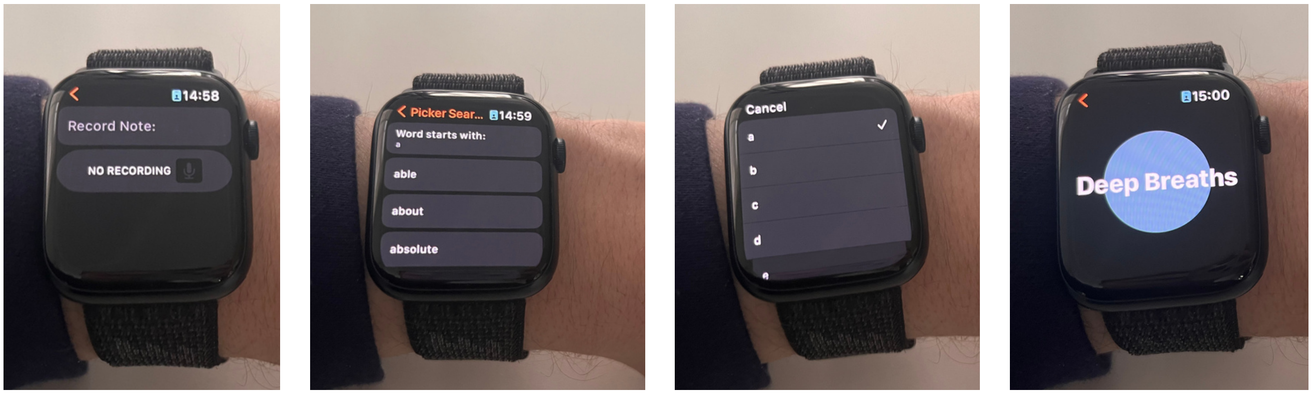
4.1 Watch Out

An app that converts the wearer's smartwatch into a multimodal public display[11] to communicate with strangers and pictured in Figure 5. Initially, the app opens on a list view of pages for eight different verbal expressions. The app enables non-verbal users to reach out to communication partners and strangers to output key dialogue, especially in an emergency. Our co-designers came up with expressions that would be most essential to use 'on the go'. These expressions included: asking for help, requesting a seat, informing that you have an invisible disability and requesting to speak more slowly. Upon selecting the desired expression, the user transfers to a page where the dialogue repeatedly iterates in a looping motion. Here, the user has four further options. Firstly, a bottom left icon to sound a buzzer to draw attention to the smartwatch. Secondly, a central icon to pull up a blue disability badge. Thirdly, a button to rotate the screen for more accessible presentation directly to onlookers – with the display serving as a non-verbal prop [75]. Fourthly, the user can tap the text to have a voice synthesizer deliver the dialogue expression. Elsewhere, the user can customize the voice gender. Plus use a page that provides a QR code for communication partners to scan with their phone to be directed to a relevant Stroke.org[12] website for further information about aphasia.

4.2 Watch In

Serves as private cognitive support for people with aphasia's memory, word finding and mindful breathing. *Watch In* initially opens on a list view of available pages and is pictured in Figure 6. Firstly, the *Transcribe* feature, allows people with aphasia to record essential conversational excerpts using the smartwatch microphone. Once a note is saved, the user can play back the note using text-to-speech at any point, thus supporting memory. Equally, notifications for each note can be enabled to prompt the user of unread excerpts later in the day. Secondly, the *Picker* lets users search through a

[11]For smartwatches as a public display, refer to the design space of Pearson et al. [69].
[12]https://www.stroke.org.uk/what-is-aphasia/aphasia-and-its-effects



(a) Transcribe notes and conversations to improve memory

(b) Picker based search of dictionary for word-finding

(c) Picker interaction

(d) Haptic breathing exercises

Figure 6: The *Watch In* on wrist and demonstration of functionality.

dictionary of words using the very first letter supporting word finding and recall. The search is designed in light of the phonological awareness of our co-designers with aphasia and their ability to verbalise the first phoneme of forgotten words. Thirdly, the *Breathe* functionality provides a discreet looping three-second on-wrist haptic for mindful breathing. Finally, *Update* enables SLTs or family members to add new words to the underlying dictionary.

5 WORKSHOP WITH WATCH OUT AND WATCH IN APPS

Following feedback and iteration of both smartwatch apps with our co-designers. Both the *Watch Out* and *Watch In* were evaluated via experience prototyping and role-playing using both AAC apps with an unfamiliar actor [11, 52]. Participants then completed a feedback questionnaire and exit interview.

5.1 Procedure

We wanted to determine the efficacy of our AAC in simulated 'real-world' scenarios, therefore we asked our participants to use both AAC smartwatch apps in a role-playing scenario with an actor/stranger. The experience prototyping tasks are outlined in Figure 7. Initially, a researcher and SLT would introduce and demonstrate both smartwatch apps to each participant. Following this, participants would have supervised exploration of each app for 2-3 minutes on an Apple Watch Series 8. Afterwards, each participant would receive instruction concerning the three tasks they had to complete with a role-playing actor/stranger using both apps. The tasks would take approximately 5-10 minutes to complete. For task one, the participant had to enter the room and use the *Watch Out* expression to ask the actor for a seat. For task two, the participant had to introduce themselves and mention they had aphasia. At which point the actor would ask, *"What is aphasia?"* and they would respond by showing the QR code within the *Watch Out* app. Finally for task three, the participant had to navigate to the *Watch In* application and use the *Transcription* feature to record the actor's response to a question. At all times, one researcher was present within the room to video record the experience prototyping and support participants' app interactions. Proceeding role-playing participants would have an immediate exit interview in Section 5.3.2 – ascertaining their feelings about the AAC and experience prototyping. Then complete a feedback questionnaire in Section 5.3.3 on the apps and their usability whilst performing tasks. All participants were paid 20 GBP for participating.

5.1.1 Setting. The workshop took place within the context of an Aphasia Re-Connect charity support group at the Roberta Williams Speech and Language Center. Ethical approval for this research was granted by a King's College London Health Faculties Research Ethics Subcommittee. Participants with aphasia were recruited from the charity. Equally, participants were supported to access the information sheets and guided through the consent process by an SLT. The workshop was video and audio recorded for analysis.

5.1.2 Data Analysis. Video analysis was used to investigate the class-based interactions performed by each participant during the role-playing tasks outlined in Figure 7. As participants had varying levels of verbal speech, analysis enabled us to identify interactional phenomena associated with a range of communication modes including looking behaviours, gesture, proximity, voice tone and voice loudness. We took a whole-to-part inductive approach to video analysis whereby videos were viewed multiple times and indexed to identify shorter segments involving usage of the smartwatch AAC apps and verbal dialogue. Initially, videos were broadly transcribed and time-marked using NVivo 12. In order to investigate the participants' non-verbal and total forms of communication we used social semiotic approach that centred on investigating unique communication styles (i.e., the use of eye-gaze or expressive bodily gestures e.g., thumbs up or pantomime). Alongside the video segments and transcripts, we extracted stills from the videos. Still images i.e., Figures 8, 9 and 10 emphasised the consideration of important spatial elements and environmental factors whereas video footage enabled

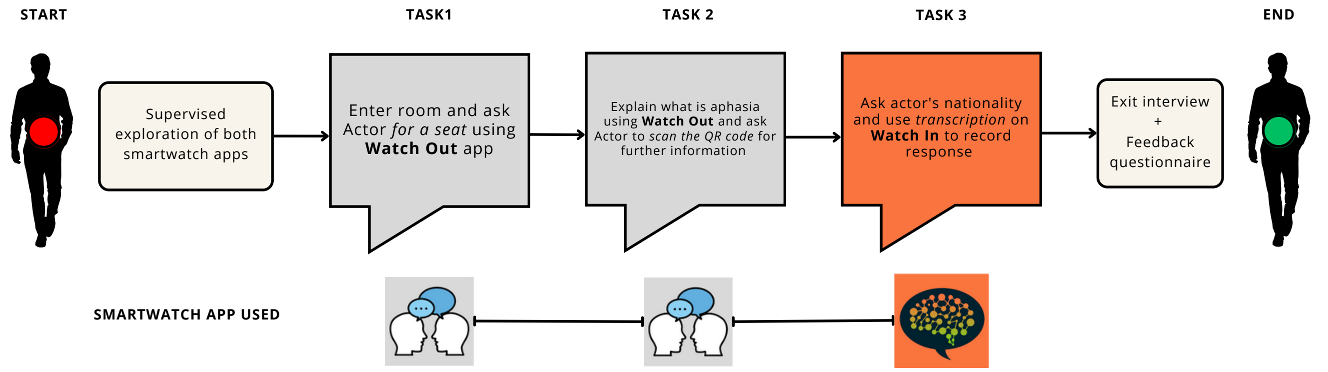


Figure 7: Experience prototyping procedure including role-play tasks one to three that participants performed with both the *Watch Out* and *Watch In* apps with an actor.

us to delineate utterances of talk, movement and the uptake of non-verbal modes. Videos were watched multiple times to exhaust the different possible interpretations of events. This process resulted in Table 3's, four core interaction categories and 15 sub-categories. Data was compiled from feedback questionnaires in Section 5.3.2 and transcripts from the exit interviews were thematically analysed in Section 5.3.3 to explore perspectives on the apps.

5.2 Participants

Noted in Table 1, five participants with aphasia took part in the experience prototyping workshop (i.e., all experience prototype workshop participants are EPW in the Attendance column). Participants had a range of aphasic language difficulties as a consequence of stroke. Due to the cognitive demands of completing the tasks and simultaneously communicating with a stranger/actor using two unfamiliar smartwatch apps – some of our co-designers participated in the workshop to support co-interpretation of the utility of the finalised AAC apps [82]. Speaking ability was severely limited for one participant and moderately limited for the remaining four participants. Some participants experienced mild to moderate difficulties in understanding spoken language and one participant had vision difficulties limiting his ability to read all text within the app. Participant ages ranged between 49 and 69 years old. Two participants were pre-existing smartwatch users. All participants were at least six months post-stroke and had spoken English fluently prior to their stroke. One participant had hemiplegic weakness which restricted the use of their right arm and leg. All participants' names are aliases.

5.3 Results

5.3.1 Interaction Analysis. Outlined in Table 3, we coded video footage and performed an analysis of participants' multimodal communicative interactions during the three tasks with both smartwatch apps. We coded the amount of times the researcher had to assist, participants' verbal dialogue, watch interactions and non-verbal communication. In total, we coded 244 instances with the researcher assisting watch-based navigation on 17 occasions. Overall, participants favoured using dialogue (N=34) and bodily gestures (N=36) i.e., thumbs up, nodding, raising arms, pantomime and shrugging to communicate with the actor during the tasks. Participants regularly altered the loudness (N=4) and tone of their verbal dialogue (N=6) to communicate with the actor – typically for emphasis e.g., *"Excuse me!"* and *"Wow!"*. Importantly, the AAC smartwatch apps did not overwhelmingly interfere with these natural pathways of communication with almost equivalent instances of eye-gaze on the watch (N=33) and actor (N=30) respectively. Participants mainly used the smartwatch as a prop for communication (N=14) by showing the actor the display – even supplementing this interaction with dialogue e.g., *"I am now recording your response for my [short-term] memory"* and body language. Frequently, participants used the smartwatch as a prop to reinforce the delivery of their verbal message e.g., *"Can I have a seat?"* coupled with showing the message on the smartwatch i.e., Figure 8 with Patrick showing the relevant display before saying *"Thank you"* and a thumbs up.

Whilst, performing dexterous navigation interactions with the smartwatch participants regularly used conversational fillers (N=33) e.g., *"Err"* and *"Umm"* to signal to the actor for patience whilst they navigated on the smartwatch – an example includes Brian's use of conversational fillers during Task 3 i.e., Figure 10. Equally, the smartwatch AAC encouraged participants to regularly alter their proxemics (N=15) shifting their personal space in relation to the actor. For instance, participants would move their arm deliberately physically closer to the actor to reveal the smartwatch display and communicate its message i.e., Figure 9 with Isaac leaning closer to the actor to support scanning of the QR code. The researcher had to assist interactions on the smartwatch on multiple (N=17) occasions. Particularly, for the third task (N=11) which involved navigating to the separate *Watch In* app and use the Transcribe feature. For three participants that do not use a smartwatch it was at times cognitively and visually challenging to simultaneously communicate with a stranger and interact with unfamiliar smartwatch apps. Nonetheless, multiple participants were optimistic and emphasised that it would take, *"Rick: time to get used to it"*. Less frequently, participants used the watch voice synthesis (N=10) and instead preferred using their own verbal dialogue (N=34). Finally, the use of the buzzer (N=3) and blue disability badge (N=0) was less popular during role-playing with the actor.

Table 3: Interaction analysis of participants' verbal, non-verbal and smartwatch-based interactions during the completion of tasks with *Watch Out* and *Watch In* apps.

Interaction	Instances	Task 1	Task 2	Task 3	Total
Researcher assists interaction	Count	3	3	11	17
Watch interactions	Rotate display for actor	3	0	0	3
	Watch blue disability badge	0	0	0	0
	Watch buzzer for attention	3	0	0	3
	Watch voice synthesis	1	6	3	10
	Eye-gaze on watch	11	12	10	33
Verbal communication	Participant dialogue	9	14	17	34
	Change in loudness	1	1	2	4
	Change in tone	3	1	2	6
	Use of conversational fillers	10	11	12	33
Non-verbal communication	Bodily gestures	6	13	17	36
	Use of watch as prop	6	5	3	14
	Proxemic i.e., manipulation of personal space	5	6	4	15
	Haptic i.e., use of touch	0	0	0	0
	Eye-gaze on actor	10	10	10	30
Total		**71**	**82**	**91**	**244**

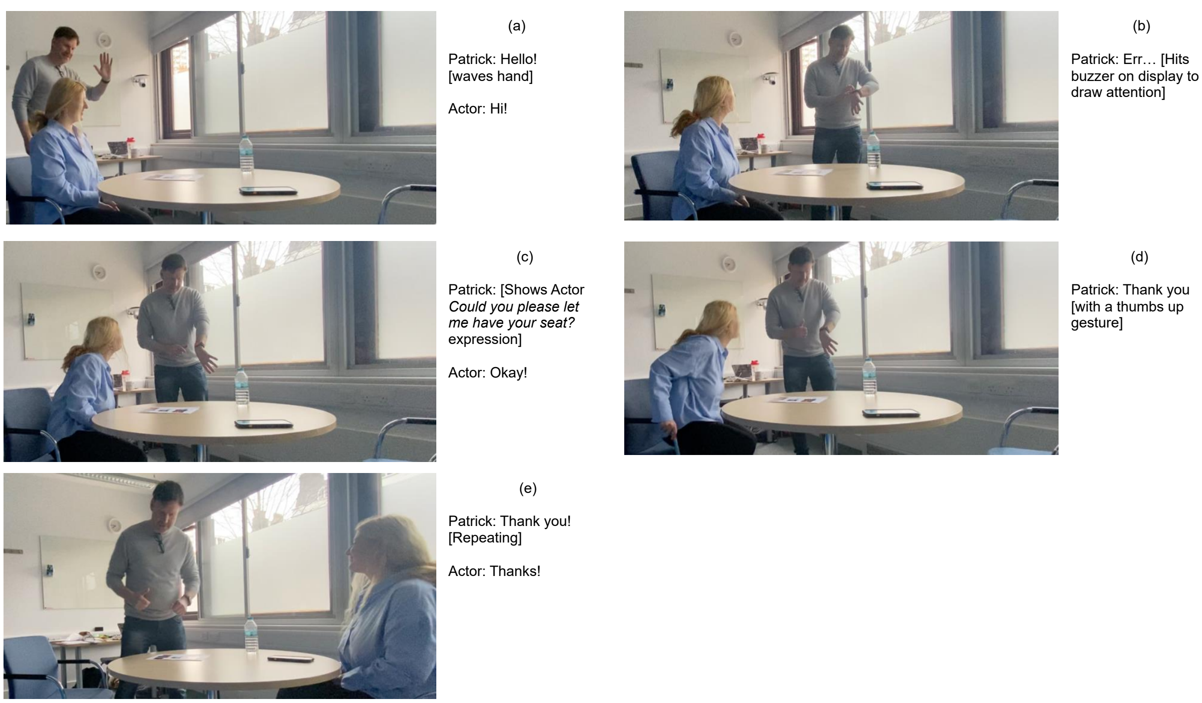


Figure 8: Interaction between Patrick and actor for *Task 1* using the *Watch Out* app to ask for a seat. Patrick repeatedly uses gesture i.e., wave (a) and thumbs up (d)–(e) to reinforce his related dialogue. Equally, Patrick alters his proxemic distance to move closer to the actor in frames (b) and (c) to show the relevant smartwatch display.

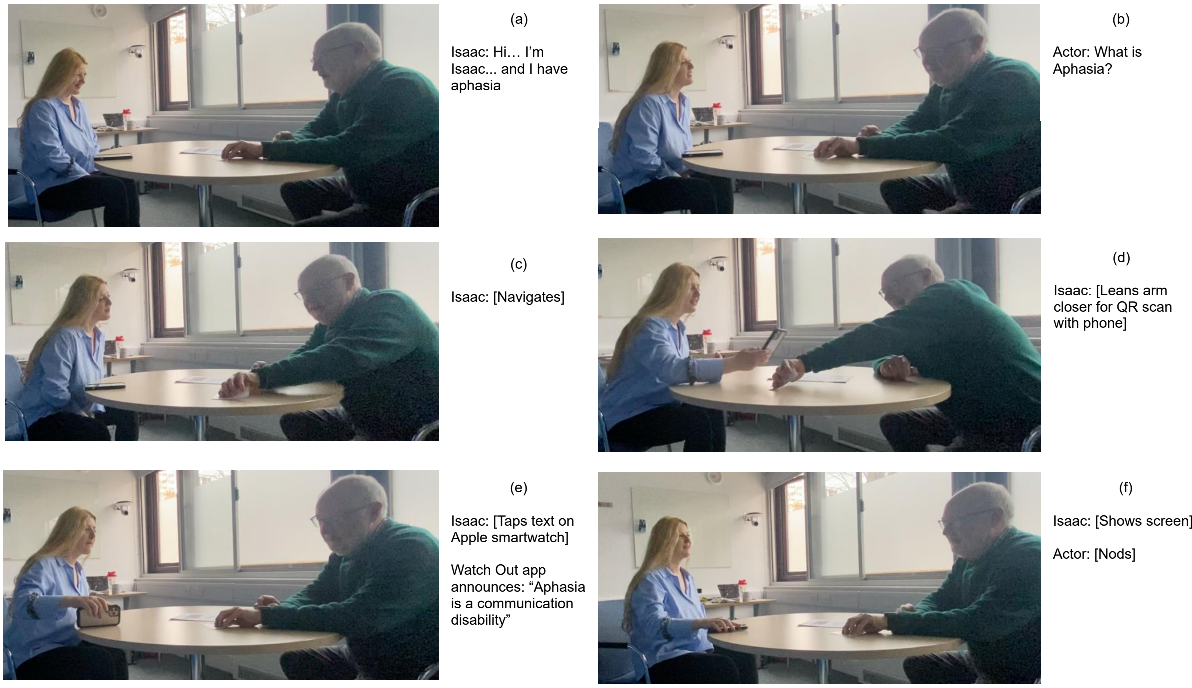


Figure 9: Interaction between Isaac and actor for *Task 2* using the *Watch Out* app to explain what is aphasia. Initially, in (c)–(d) Isaac alters proxemics to shift arm closer to the actor to share the smartwatch QR code. Whilst Isaac in frame (e) manages to use the text to speech of the app to explain that aphasia is a disability and provides simultaneous eye contact (f).

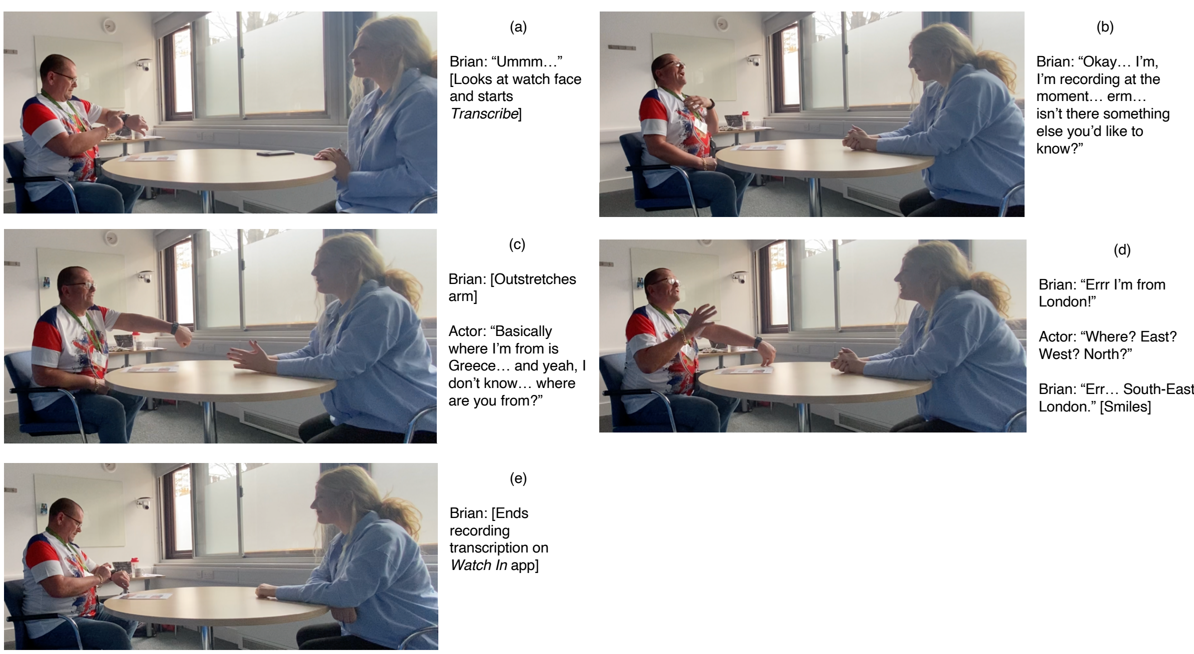


Figure 10: Interaction between Brian and actor for *Task 3* Transcribe task using *Watch In*. Initially, Brian uses conversational fillers to supplement smartwatch navigation in (a). Furthermore, Brian remains very non-verbally expressive (b) and even uses bodily gesture whilst speaking and recording in (d).

Table 4: Likert responses to experience prototying and role-playing with *Watch Out* and *Watch In* apps. Plus, Likert response evaluating role-playing session.

Question	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1) I would use the *Watch Out* app to "ask for a seat"	1	0	0	2	2
2) Did the *Watch Out* "asking for a seat" app make you feel more confident	0	0	0	0	5
3) I would use the *Watch Out* app to let people know I have aphasia and provide the QR information	0	0	1	1	3
4) Was showing the QR information with the *Watch Out* app comfortable	0	0	0	1	4
5) I would use the *Watch In* app to transcribe conversations	0	0	1	0	4
6) Transcribing dialogue with the *Watch In* app was easy	0	0	1	2	2
7) I enjoyed today's session	0	0	0	0	5
Total	**1**	**0**	**3**	**6**	**25**

5.3.2 Likert Results. Results from asked feedback questions are presented in Table 4. In total for questions regarding both smartwatch apps, there was 20 instances of 'strong agreement' in positively phrased questions, 6 instances of 'agreement' and 3 instances of 'neutrality'. This indicates the overwhelming majority of feedback for the smartwatch apps was positive. Furthermore, all participants strongly agreed that they enjoyed experience prototyping and role-playing with an actor.

5.3.3 Exit Interviews. Following role-playing and experience prototyping, participants were immediately interviewed by a researcher for feedback on both apps and the workshop. Concerning the *Watch Out* app, all participants emphasised that the app would give them *"more confidence"* with their communication abilities. Despite the confidence boost, Jack admitted he still generally felt *"very shy"*. In terms of changes, Brian and Patrick agreed that they wanted the voice synthesis *"louder"*. Patrick also believed the voice synthesis was *"too quick"* and may cause a stranger to be, *"irritable and annoyed with me"*. Regarding the QR feature, Rick positively felt that, *"people are seeing QR codes in more places"* and would help raise awareness as, *"nobody knows what aphasia is!"*. Equally, Rick emphasised that he would start using the app *"straight away"* – he had faced denial of his disability on the bus as, *"[Strangers] think I am a strong man who should get up! [...] Making me feel upset"*. Likewise, Patrick emphasised that he sometimes does not ask for a seat on the tube when he actually *"needs one"*.

Turning to the *Watch In* app, Brian, Patrick and Isaac were concerned about the privacy of recording people's dialogue and emphasised that you would have to let them know beforehand. However, Rick said that he would be, *"fine using the app [to transcribe]"* as his memory loss is *"so terrible!"*. Equally, Brian conceded that it would be useful, *"for the doctors"* and *"remembering appointments"*. More generally Jack and Brian found the smartwatch hard to use without the correct prescription glasses. Regarding the workshop, Rick positively noted that it felt like you were, *"really having to speak to a stranger"*. In contrast, Patrick felt that our actor was *more* understanding than a stranger in *real life*. Outside of the apps, Patrick said he was apprehensive about the Apple watch running out of battery. Yet, his aspiration is to be, *"more fluent"* and *"have that confidence to fall back onto... if my fluency drops... [the apps are] a really good safety net!"*. Currently, Patrick strategically carries a water bottle which he deliberately drinks as a distraction to, *"have a pause and more time to think"* – he also performs *"breathing techniques"* and *"talks slower... to let my brain catch up"*. In a similar vein, Isaac emphasised how he was *"very impressed"* with both apps and that would they would serve as a useful *"fall back!"* when he struggled with his communication.

6 FOCUS GROUP WITH WATCH OUT AND WATCH IN APPS

Pictured in Figure 11, further focus groups with participants with aphasia were held to support accessible engagement with the *Watch Out* and *Watch In* apps.

6.1 Procedure

The focus group lasted 1.5-2 hours and was structured as follows: initially, participants arrived and seated themselves around a large central table, a researcher and SLT introduced and demonstrated both the *Watch Out* and *Watch In* apps using an Apple Watch Series 8 (45mm) and Apple Watch SE 2 (40mm). Sequentially, participants were presented with either app – encouraged to engage and test. One researcher and SLT supervised and supported participants' engagement. After 15-20 minutes of usage, participants each completed a short feedback survey. Next, the SLT plus researcher facilitated a group discussion about the app, documenting participants' comments and garnering consensus about potential future refinements to each app. All participants were paid 20 GBP for participating.

Figure 11: Images from focus groups with participants. Top left, Joseph and Emilia compare the *Watch Out* set of expressions with his low-tech pocket-sized communication book. Top right, Jacob and Hannah trial *Transcribe* on the *Watch In* application. Bottom left, Hannah tests the functionality of the QR code. Bottom right, Steve with right-side hemiplegia reverses the expression, *"Please give me time to speak"* and gestures to the research team.

6.1.1 Setting. The focus group took place within the context of an Aphasia Re-Connect charity support group at the Roberta Williams Speech and Language Center. Ethical approval for this research was granted by a King's College London Health Faculties Research Ethics Subcomittee. Participants with aphasia were recruited from the charity. Equally participants were supported to access the information sheets and guided through the consent process by an SLT. The focus group was video and audio recorded for analysis.

6.1.2 Data Analysis. Workshop outcomes were analysed by compiling data from the feedback questionnaires, analysing transcription from discussion and undertaking structured observation of the video data of the group members using the *Watch In* and *Watch Out* app. Transcripts were analysed thematically to explore positive and negative perspectives about each app, comments about the implications of constraints and suggestions for future refinements. Interactions were logged on the paired smartphone using an additional logger application – capturing extra data for dissemination.

6.2 Participants

Noted in Tables 1 and 2, the focus group involved 4 participants with aphasia, one family member and one SLT who had not taken part in the earlier experience prototyping session (i.e., all focus group participants are FG in the Attendance columns). Three participants had hemiplegic limb weakness, which restricted the use of their right arm and leg. Ages ranged from 52 to 80 years old. Of note, most participants wanted to engage with the co-designed smartwatch apps but did *not* feel comfortable experience prototyping with an actor. Therefore, we adjusted our sessions to support maximum engagement amongst our pool of participants with aphasia. Furthermore, one participant's wife, Emilia also participated in the focus group as Joseph felt more comfortable with her support and proxy engagement. All participants' names are aliases.

6.3 Results

Results are drawn from the feedback questionnaire, transcript of group discussion, transcript with a participant with severe aphasia/family member and dissemination from logged interactions.

6.3.1 Likert Results. The feedback questionnaire was delivered during the session and results are presented in Table 5. There was 36 instances of 'strong agreement' in positively phrased questions – 23 instances for the *Watch Out* app and 13 instances for the *Watch In* app. In sum, there was 19 instances of 'agreement' – 3 instances

Table 5: Likert responses from focus groups with *Watch Out* and *Watch In* apps. Plus, Likert response evaluating workshop.

Question	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Watch Out					
1) I think the *Watch Out* app would support my communication	1	0	1	2	1
2) The *Watch Out* app was easy to use	0	0	0	0	5
3) I enjoyed using the *Watch Out* app	0	1	1	0	3
4) I would use the *Watch Out* app to communicate with strangers	0	1	1	0	3
5) It helped when the *Watch Out* app spoke aloud	0	0	0	0	5
6) The *Watch Out* app would be useful for communicating that I needed assistance, a seat or the bathroom	0	0	2	0	3
7) The *Watch Out* app would help me let others know I have had a stroke and aphasia	0	0	1	1	3
Sub-total	*1*	*2*	*6*	*3*	*23*
Watch In					
1) I would use the *Watch In* app to communicate with strangers	1	0	1	2	1
2) I think that the *Watch In* app would support my language abilities and confidence	0	1	1	2	1
3) The *Watch In* app was easy to use	0	0	1	3	1
4) I enjoyed using the *Watch In* app	1	0	0	2	2
5) Transcription in the *Watch In* app would help my memory	0	1	0	2	2
6) Deep breathing in the *Watch In* app would help my speaking	0	0	2	1	2
7) Search in the *Watch In* app would help me find words	0	0	1	2	2
8) Picker in the *Watch In* app would help me find words	0	0	1	2	2
Sub-total	*2*	*2*	*7*	*16*	*13*
I enjoyed today's session	0	0	0	1	4
Total	**3**	**4**	**13**	**20**	**40**

for the *Watch Out* app and 16 instances for the *Watch In*. Whilst, there was 13 instances of 'neutrality' – 6 instances for the *Aphasia Phases* and 7 instances for the *Watch Out* app. Overall, this indicates that the majority of feedback concerning the smartwatch AAC apps was positive. Our points of 'strong disagreement' came from one participant who was *not* a smartphone user and preferred to remain technology-free. Nonetheless, the participants all collectively enjoyed the focus group with 4 points of 'strong agreement' and 1 point of 'agreement'.

6.3.2 Session Observation and Discussion. All five participants with aphasia wore watches and one was a pre-existing smartwatch user. During the session, three participants expressed interest in purchasing a smartwatch. Group consensus preferred the larger 45mm watch face of the Apple Watch Series 8 to mitigate vision difficulties whilst using both apps. Whilst, Joseph, Steve and Hannah who all have hemiplegia successfully navigated the app with the velcro strap affording wrist adjustments for extra comfort. Specifically, Joseph uses *Tactus Therapy*[13] on his iPad to practice speaking and carries a pocket-sized communication book[14] – in public Joseph is *very* reluctant to use his iPad therapy apps and does not own a smartphone. Regarding the *Watch Out* app three participants were very positive about the app and its synthesis of key dialogue. Initially, Emilia was *very* enthusiastic about *Watch Out* whereas her husband Joseph was *not* keen to loose his agency and instead preferred his beloved watch of 60 years – despite Emilia's suggestion Joseph could wear the smartwatch on the other wrist. As a regular conversation partner with Joseph, Emilia believed the app was, *"so intuitive and logical"* and remarked that, *"it's so small and easy and*

[13]https://tactustherapy.com
[14]Joseph's communication book also contained matching expressions to the apps such as, *"I have had a stroke"*.

does so many different things". Joseph non-verbally was less enthusiastic at which point Emilia noted he is, *"as technology resistant as possible"*. Emilia could foresee the app would be very useful for Joseph to request, *"a seat from a stranger when... [his] leg was hurting"* and to support situations where Emilia receives, *"phone calls from restaurants*" regarding, *"problems Joseph is [independently] having"*.

Otherwise, there was collective enthusiasm for the ability to convert to a female voice – supporting previous research, which highlights the significance of customisable AAC [8, 17]. Yet, many remarked on the American accent of the voice synthesis e.g., *"Hannah: the accent is different"* – currently British female voice is not accessible in the WatchOS voice synthesis APK. The group believed the *Watch Out* QR code would be understood due to frequent public scanning of QR codes for menus in restaurants throughout national Coronavirus lockdowns. Whilst, Steve remarked that the watch would have helped recently when a stranger on the, *"bus couldn't understand me [...] I was told to move!.. and I wasn't happy"*. Equally, Jacob felt that the app *"would help tremendously!"*. Suggested improvements to the *Watch Out* included making the voice sound *"as human as possible"*, sections, *"including medical information, age and [family] contact information"* and a section for conversations starters particularly, *"communication strengths – as [Joseph can be] a real charmer once he's built up [non-verbal] rapport"*. Indeed, Joseph's ability to speak 5 languages pre-stroke is, *"something he really likes to share with people"*.

Turning to *Watch In*, three participants were positive about the smartwatch app. The speech-to-text performed impressively even recognizing Spanish words prompting Jacob to remark, *"it performed very well"*. Steve emphasised he would like to try it with his family members that have, *"a strong Irish accent"*. Initially, Emilia was surprised at the accuracy of the speech-to-text. She could foresee the Transcribe feature being useful for recording excerpts of her dialogue that Joseph could play to people. For instance, if Joseph was visiting the doctor alone, she could record for him to use, *"I have a pain in my tummy, its been fluctuating for a few days – when you go to the doctor you know you can just press play and you start correctly interacting with each other"*. Joseph cannot read so he was resistant to the text and its small size on the *Watch In* app. Importantly, Emilia noted that at Joseph's favourite restaurants, *"where people know him and have built up a rapport over time – they completely understand his gestures usually – they know what he likes to order"* so could see the potential of the *Watch In* in unfamiliar settings with strangers.

In terms of changes, Hannah critiqued that the watch sometimes voice synthesised too quickly and Steve suggested that the face was hard to read due to his vision difficulties. The three participants successfully used the app to find keywords – Hannah found *"cat"*, Steve *"horse"* and Jacob *"bus"*. Indeed, Steve noted that in, *"time you'd learn it better"* and that he typically remembers words via recalling the first letter or phoneme. Jacob felt that the breathing would help him to be *more* mindful. Other recommendations from our participants included that Steve found the *Watch In* app especially useful if he, *"lived on my own without my family"*. Whilst, Hannah wanted future reminders for appointments activated from the Transcription feature. Finally, Jacob wanted the watch to read the, *"time aloud"* upon face tap. Meanwhile, Emilia noted that for Joseph, *"face to face [communication] he is quite territorial about I suppose"* suggesting that he does not want AAC interventions to compromise his agency to communicate with his natural total forms of communication. Nonetheless, Joseph can sometimes feel *very* frustrated about his aphasia and people *not fully* understanding him.

7 DISCUSSION

Our findings reveal key insights on the potential of using smartwatches as AAC to support communication. In this section, we discuss the efficacy of our two smartwatch applications: *Watch Out* and *Watch In*, future directions for AAC research and lastly, insights concerning accessible participatory design.

7.1 Efficacy of the *Watch Out* and *Watch In* Smartwatch Applications

The speed and adequacy with which participants were able to use *both* smartwatch apps to supplement their pre-existing communication strengths, coupled with the observations and self-reported data – strongly indicated that both smartwatch applications were effective in supporting people with aphasia's communication. Through three participatory design workshops, our co-designers transitioned from exploring contextual communication challenges to tangible prototyping and iterating apps deployed on smartwatches. The eventual designs served our co-designers differing needs by offering 'public' support of dialogue with *Watch Out* and 'private' cognitive support with *Watch In*. Unlike the large form-factor of *most* high-tech AAC devices, the smartwatch encourages discretion and portability [8, 18, 35]. Particularly, in physically demanding communication environments for people with aphasia i.e., busy or crowded public transport, coffee shops and bars [19, 21, 67].

The wearable assistive technology of the smartwatch mitigates potential problems from carrying or even dropping a tablet or smartphone *'on the go'* – especially for users with aphasia that have bodily paralysis, right-side hemiplegia, use an arm brace and walking stick day-to-day [96]. Equally, the Apple smartwatch affords increased customisability of strap colours, watch face, design aesthetics and socio-cultural perceptions of health/fitness – without *necessarily* revealing the wearers underlying disability [25]. Previous research has repeatedly underlined the significance of social perceptions for assistive technology and their public interactions [24, 25, 46, 71, 72, 79]. For AAC, social perceptions are especially significant given these are assistive technologies designed to support human-to-human communication and social engagement. Indeed, our co-designers and participants have a *very* strong sense of autonomy and agency thus the AAC technology should *certainly not* interfere with their communication strengths or become the locus of public attention [8, 35].

During our experience prototyping workshop, we had 17 instances of researcher assistance across both AAC smartwatch apps – these input difficulties occurred due to the small interface size of the smartwatch i.e., 40–45mm display causing 'fat finger' problems [80] and vision challenges[15] [76]. However, operating both apps with Assistive Touch was *too* difficult – the repeated use of "clench" for selection was quickly deemed fatiguing and *even* uncomfortable [1].

[15]Smartwatch font size was maximised throughout.

Although not ready for our use case at this stage, we can see the future potential of research towards making input interactions on smartwatches *more* accessible through personalised hand gestures or discreet wrist/hand input interactions i.e., [84, 95, 99] – particularly if gesture recognition improves with further sensors on the watch band [15]. Elsewhere, studies on increasing the accuracy of smartwatch input interactions have considered: the recognition of different finger functions [27], using pressure-based inputs [20] and by enabling multi-device/cross-device interactions[16] [13, 31]. Imperatively, this research *must* consider *accessibility* by *directly* engaging communities with disabilities rather than *just* testing with the general population or proxies [47]. For example, Malu et al. [50, 51] appropriately performed an analysis of the most accessible smartwatch interactions including bezel-based inputs amongst ten participants with upper body impairments and in another study amongst people with vision impairments [100].

Data from interaction analysis with both AAC smartwatch apps report that both the *Watch Out* and *Watch In* interventions did *not* restrain access to multimodal communication [35, 41, 75]. On the contrary, the 'public' *Watch Out* even encouraged our participants with aphasia to alter their proxemics and non-verbally shift towards the actor to 'share' the watch display. These communicative interactions offer *much* promise as they support an increasingly *interdependent* framing of the assistive technology in which both communication partners *directly* interact with the AAC – supporting the co-construction of meaning rather than a sender-receiver model of communication [6, 28, 35]. For instance, the *Watch Out* QR code encourages the communication partner to scan the watch face – a gesture that supports *both* physically interacting with the assistive technology rather than perpetuating social distancing and stigma [6, 54]. Furthermore, the expression pages of the *Watch Out* application can be appropriated as props with the display rotatable to present to communication partners and multimodally supplementable with personal gestures, verbal dialogue or eye-gaze [28, 35, 75, 81] – this design deliberately augments users pre-existing communication strengths [63, 89, 90].

In contrast, *Watch In* provides discreet 'private' cognitive support to the wearer – supporting memory with transcription, haptic-based mindful breathing and providing a phonemic searchable dictionary. In particular, the co-designed AAC smartwatch app further supports the design of AAC that is not strictly orthographic (text) and graphic (symbol) based for communication [9]. During our studies, two participants repeatedly emphasised that their recollection of words centered on the first phoneme – whilst the picker was found to be the most accessible smartwatch input interaction. These findings bolster support for initiatives to design phoneme-based AAC such as the work of Trinh et al.[17] [9, 87, 88]. Indeed, phoneme-based AAC has even been shown to improve literacy and search prediction for users with CCNs [9, 87, 88]. Equally, offering a history of previously searched words was important amongst our co-designers living with aphasia as specific words can be *repeatedly* challenging to recall [38]. Based on the counts of researcher assistance, Watch In was found to be a more complex app, which would require *more* learning to develop familiarity. Ultimately, *Watch In* serves as a discreet confidence boost for the wearer and neatly supports their pre-existing communication abilities.

[16] Apple has begun to offer cross-device interaction through Continuity in MacOS [3].

[17] Significantly, phoneme-based AAC systems importantly grant users the agency to generate novel words.

7.2 Future Directions for AAC Research

AAC is potentially an *essential* support for many living with CCNs, yet presently faces low-rates of adoption and high-rates of abandonment [43, 44, 57]. Indeed, a core problem for AAC interventions includes that they predominantly fail to build on the *usually* embodied and multimodal communicative competencies of their end-users [8, 35]. Instead, *most* AAC devices are typically complex requiring detailed instructions on how the user, friends and families should adjust and adopt these technologies, which ultimately provide an unfulfilling sender-receiver style of communication [8, 29, 53]. Rather, high-tech AAC technologies should build on the embodied strengths of their users by enhancing rather than restricting their pre-existing multimodal and non-verbal forms of communication [8, 35]. Echoing research by Ibrahim et al. [35], we agree that AAC devices that can have their status/visibility regulated via shifting in shape/function will ultimately provide *more* fulfilling and adaptable interventions for end-users with differing and evolving CCNs[18].

We strongly encourage the design and development of AAC devices that *augment* the end-users' unique communication style and needs. If this is performed correctly, the AAC device will serve more as a useful "safety net" in challenging communication instances rather than a *permanent* assistive technology, which will likely hinder the users agency [8, 40]. As Dietz et al. [23] correctly assert AAC should serve as an empowering tool to encourage people with CCNs to pursue life-affirming activities – imbuing confidence and providing support during communicative breakdowns [5]. Rather than replacing the users' natural style of communication through outputting voice synthesis, these devices can look to *even* operate as a supplemental non-verbal prop or provide discreet cognitive functionality [89, 90].

Consequently, AAC must offer multiple forms of input/output interaction to be adaptable and configurable dependent on the user, environment, context and communication partner. Equally, AAC designs should more readily consider the role of the communication partner i.e., cues that can be signalled to co-construct communication in that *very* instance [26, 40, 42, 81]. If this is the case, AAC technologies will better follow an *interdependence* framing of assistive technology. AAC designs should also always consider the greater socio-cultural norms of device usage and the individual's natural desire to blend in such considerations are extremely important for long-term adoption and usage [25, 71, 72, 79].

Increasingly, well-adopted wearable technologies such as smartwatches offer aesthetics, customizability and more positive social connotations. Indeed, there has been significant growth in AAC apps designed to be downloaded and configured on either a smartphone or tablet [29]. However, there are comparatively fewer accessible AAC apps that are deployed on smartwatches. We encourage future AAC research to continue to explore the potential of smartwatch interventions. Particularly, as smartwatches increase in adoption, improve in accessibility and have *more* available bodily

[18] Indeed, for people with aphasia their communication needs are ever evolving – for instance, dialogue abilities can significantly vary each day.

sensors/services [69]. At the same time, smartwatches also critically do not detriment end-users ability to easily navigate a multitude of public settings as they are lightweight and portable. Plus, their public status is regulatable given their smaller size and ability to be concealed [35].

7.3 Accessible Participatory Design Techniques

This work provides further evidence for *more* direct engagement and the co-design of human-centred high-tech AAC technologies directly with people living with CCNs. Much like previous research, employing people with aphasia as co-designers for insightful smartwatch AAC was successful [18, 58, 60, 86]. Using guidelines such as those from Mack et al. [48] to anticipate and adjust, ensured our participants felt empowered throughout the co-design process. Equally, we recommend using a range of methodologies and honing on the *most* accessible. Throughout the co-design process, we promoted tangibility with physical props, liberally used multimedia (i.e., both text/images) and validated co-designers' insights by building their unique ideas – thereby engendering collective confidence.

In particular, the pairing of Raman and French [74] context cards and Wilson et al. [98] communication grids – provided a fulfilling group exercise that let our co-designers share stories, feelings and emotions before turning to creative prototyping of AAC. Indeed, the use of multi-vocal and multi-method co-design approaches supported conceptual decision-making, communication and genuine participation [74]. Consequently, tangible prototyping resulted in the development of three low-fidelity wireframes that could be deployed on Apple smartwatches for iteration and critical feedback. Reflecting upon this process, we can evidently see the merits of previous research, which has iterated co-designed AAC with people with CCNs over multiple sessions [18, 63].

Performing an experience prototyping workshop with the finalised AAC smartwatch apps provided an immediate usability assessment of the apps and their effectiveness as an intervention. Currently, assessing the success of AAC is particularly challenging aside from field deployments – yet experience prototyping with an actor really helped simulate many essential factors of communication [11, 52]. Initially, the tasks were cognitively demanding for our participants with aphasia: they had to simultaneously communicate with an actor and perform dexterous smartwatch interactions on completely unfamiliar apps. To improve accessibility, all engagement was appropriately supervised by a researcher to verbally assist smartwatch interactions when needed.

Impressively, one participant successfully completed all tasks without any researcher's assistance. Overall, participants self-reported that they thoroughly enjoyed experience prototyping and role-playing. Furthermore, the simulation afforded by experience prototyping helped evaluate the quality of communication experiences and feelings engendered by using the AAC prototypes under deliberately pressured conditions [11]. Additionally, the experience prototyping activities successfully supported participants' ability to identify and communicate emergent issues with the smartwatch AAC. Plus, reflect on conditions where the AAC would be most useful. Ultimately, we recommend experience prototyping to effectively evaluate AAC interventions provided cognitive exertion can be mitigated[19] [98].

8 LIMITATIONS

This study represents the first participatory design of AAC smartwatch applications to support the communication of people with CCNs – specifically, people living with aphasia. Nonetheless, there are several limitations to this research. Initially, this work represents a relatively small sample size and limited context – results should be interpreted on the basis of a Western context and densely populated city with public transport. Amongst this group, there was widespread technology literacy – almost all participants owned a smartphone and the majority of participants were very comfortable using a smartphone and three participants owned a smartwatch. Significantly, people with disabilities are *very* diverse, therefore not all people with aphasia and more generally CCNs would be able to capably use the AAC smartwatch apps and produce equivalent results [70]. Another limitation is that we did not develop apps using *all* available smartwatch sensors. Perhaps future research may look to leverage the available physiological and GPS sensors on the smartwatch for: biofeedback [45], personalised hand gestures [99] or context-driven AAC [39]. Equally, future research may look to even compare smartwatch AAC directly with counterpart smartphone or tablet AAC. Turning to methods we performed an initial evaluation of the smartwatch AAC using experience prototyping. However, short to medium-term field deployment in the real-world conditions would provide more concrete findings as to the intervention success of the AAC smartwatch apps. Indeed, our participants reported that they felt slightly more comfortable during role-playing as the actor was aware they were going to use smartwatch apps to support their communication.

9 CONCLUSION

With the ever-increasing prevalence of smartwatches, it is timely to investigate their potential as an assistive technology particularly to support communication amongst people living with aphasia. Consequently, in this work, we begin with three co-design workshops – hiring four co-designers with aphasia and an SLT. Building upon previous successful co-design work with people with aphasia, we used conversation cards and communication grids to establish context followed by tangible prototyping culminating in smartwatch wireframes. Outputs from this enabled us to create and iterate the *very first* co-designed two iOS smartwatch AAC apps – *Watch Out* and *Watch In*. Initially, *Watch Out* provides 'public' support for non-verbal users with eight useful expressions and can be appropriated as a prop. In contrast, *Watch In* serves as a 'private' cognitive support for people with aphasia's memory, word finding and mindful breathing. To evaluate both apps we then held a task-based experience prototyping session with an actor and focus groups – providing results from interaction analysis and questionnaires. We provide insights from the design process and evaluation to inform the design of future AAC technologies that do not restrict

[19] Importantly, we appropriately adjusted our co-design methods to enable those uncomfortable with role-playing to instead participate in a *more* accessible focus group with both smartwatch apps.

the user's agency and better support multimodal communication. Furthermore, we also provide key considerations for the design of future smartwatch applications with older adults and people with CCNs, embodied communication and accessible participatory design techniques. Beyond this, we demonstrate the potential for wearable devices particularly smartwatches to serve as a scalable, mainstream and aesthetic intervention for enhancing communication.

ACKNOWLEDGMENTS

Many thanks to our participants and Dr Sally McVicker from Aphasia Re-Connect. We would also like to thank Dr Rita Borgo for her support, comments and advice throughout the establishment and writing of the paper. Many thanks to Ms Melina Petsolari for their significant help and support during the experience prototyping workshop. We also thank the anonymous ASSETS 2023 reviewers for their valuable input. This work was supported in part by a UKRI EPSRC Studentship.

REFERENCES

[1] Apple Accessibility. 2023. Use Assistivetouch on Apple Watch. https://support.apple.com/en-gb/guide/watch/apdec70bfd2d/watchos

[2] Apple. 2023. Apple Watch Hermès. https://www.apple.com/uk/apple-watch-hermes/

[3] Apple. 2023. MacOS - continuity. https://www.apple.com/uk/macos/continuity/

[4] National Aphasia Association. 2022. Home. https://www.aphasia.org/

[5] Edna M Babbitt and Leora R Cherney. 2010. Communication confidence in persons with aphasia. *Topics in Stroke Rehabilitation* 17, 3 (2010), 214–223.

[6] Cynthia L Bennett, Erin Brady, and Stacy M Branham. 2018. Interdependence as a frame for assistive technology research and design. In *Proceedings of the 20th international acm sigaccess conference on computers and accessibility*. ACM Press, New York, USA, 161–173.

[7] Marcelo L Berthier. 2005. Poststroke aphasia: epidemiology, pathophysiology and treatment. *Drugs & aging* 22 (2005), 163–182.

[8] Filip Bircanin, Bernd Ploderer, Laurianne Sitbon, Andrew A Bayor, and Margot Brereton. 2019. Challenges and opportunities in using augmentative and alternative communication (AAC) technologies: Design considerations for adults with severe disabilities. In *Proceedings of the 31st Australian Conference on Human-Computer-Interaction*. ACM Press, New York, USA, 184–196.

[9] Rolf Black. 2011. The Phonicstick: a joystick to generate novel words using phonics. In *The proceedings of the 13th International ACM SIGACCESS conference on Computers and accessibility*. ACM Press, New York, USA, 325–326.

[10] Caterina Breitenstein, Tanja Grewe, Agnes Flöel, Wolfram Ziegler, Luise Springer, Peter Martus, Walter Huber, Klaus Willmes, E Bernd Ringelstein, Karl Georg Haeusler, et al. 2017. Intensive speech and language therapy in patients with chronic aphasia after stroke: a randomised, open-label, blinded-endpoint, controlled trial in a health-care setting. *The Lancet* 389, 10078 (2017), 1528–1538.

[11] Marion Buchenau and Jane Fulton Suri. 2000. Experience prototyping. In *Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques*. ACM Press, New York, USA, 424–433.

[12] Marta E Cecchinato, Anna L Cox, and Jon Bird. 2015. Smartwatches: the good, the bad and the ugly?. In *Proceedings of the 33rd Annual ACM Conference extended abstracts on human factors in computing systems*. ACM Press, New York, USA, 2133–2138.

[13] Xiang'Anthony' Chen, Tovi Grossman, Daniel J Wigdor, and George Fitzmaurice. 2014. Duet: exploring joint interactions on a smart phone and a smart watch. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM Press, New York, USA, 159–168.

[14] Andy Clark and David Chalmers. 1998. The extended mind. *analysis* 58, 1 (1998), 7–19.

[15] CNET. 2023. Apple Watch Straps may someday track your hand gestures. https://www.cnet.com/tech/mobile/apple-watch-straps-may-someday-track-your-hand-gestures/

[16] Chris Code, Ilias Papathanasiou, Silvia Rubio-Bruno, María de la Paz Cabana, Maria Marta Villanueva, Line Haaland-Johansen, Tatjana Prizl-Jakovac, Ana Leko, Nada Zemva, Ruth Patterson, et al. 2016. International patterns of the public awareness of aphasia. *International journal of language & communication disorders* 51, 3 (2016), 276–284.

[17] Humphrey Curtis, Timothy Neate, and Carlota Vazquez Gonzalez. 2022. State of the Art in AAC: A Systematic Review and Taxonomy. In *Proceedings of the 24th International ACM SIGACCESS Conference on Computers and Accessibility*. ACM Press, New York, USA, 1–22.

[18] Humphrey Curtis, Zihao You, William Deary, Miruna-Ioana Tudoreanu, and Timothy Neate. 2023. Envisioning the (In) Visibility of Discreet and Wearable AAC Devices. In *ACM Conference on Human Factors in Computing Systems*. ACM, ACM Press, New York, USA, 1–20.

[19] Ruth JP Dalemans, Luc De Witte, Derick Wade, and Wim van den Heuvel. 2010. Social participation through the eyes of people with aphasia. *International journal of language & communication disorders* 45, 5 (2010), 537–550.

[20] Rajkumar Darbar, Prasanta Kr Sen, and Debasis Samanta. 2016. PressTact: Side pressure-based input for smartwatch interaction. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. ACM Press, New York, USA, 2431–2438.

[21] Bronwyn Davidson, Tami Howe, Linda Worrall, Louise Hickson, and Leanne Togher. 2008. Social participation for older people with aphasia: The impact of communication disability on friendships. *Topics in stroke rehabilitation* 15, 4 (2008), 325–340.

[22] Milad Dehghani and Ki Joon Kim. 2019. The effects of design, size, and uniqueness of smartwatches: perspectives from current versus potential users. *Behaviour & Information Technology* 38, 11 (2019), 1143–1153.

[23] Aimee Dietz, Sarah E Wallace, and Kristy Weissling. 2020. Revisiting the role of augmentative and alternative communication in aphasia rehabilitation. *American journal of speech-language pathology* 29, 2 (2020), 909–913.

[24] Lucy Dunne, Halley Profita, and Clint Zeagler. 2014. Social aspects of wearability and interaction. In *Wearable Sensors*. Elsevier, University of Minnesota, USA, 25–43.

[25] Heather A Faucett, Kate E Ringland, Amanda LL Cullen, and Gillian R Hayes. 2017. (In) visibility in disability and assistive technology. *ACM Transactions on Accessible Computing (TACCESS)* 10, 4 (2017), 1–17.

[26] Alexander Fiannaca, Ann Paradiso, Mira Shah, and Meredith Ringel Morris. 2017. AACrobat: Using mobile devices to lower communication barriers and provide autonomy with gaze-based AAC. In *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing*. ACM Press, New York, USA, 683–695.

[27] Hyunjae Gil, DoYoung Lee, Seunggyu Im, and Ian Oakley. 2017. TriTap: identifying finger touches on smartwatches. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. ACM Press, New York, USA, 3879–3890.

[28] D Jeffery Higginbotham. 2009. In-person interaction in AAC: New perspectives on utterances, multimodality, timing, and device design. *Perspectives on Augmentative and Alternative Communication* 18, 4 (2009), 154–160.

[29] D Jeffery Higginbotham, Howard Shane, Susanne Russell, and Kevin Caves. 2007. Access to AAC: Present, past, and future. *Augmentative and alternative communication* 23, 3 (2007), 243–257.

[30] Jiahui Hou, Xiang-Yang Li, Peide Zhu, Zefan Wang, Yu Wang, Jianwei Qian, and Panlong Yang. 2019. Signspeaker: A real-time, high-precision smartwatch-based sign language translator. In *The 25th Annual International Conference on Mobile Computing and Networking*. ACM Press, New York, USA, 1–15.

[31] Steven Houben and Nicolai Marquardt. 2015. Watchconnect: A toolkit for prototyping smartwatch-centric cross-device applications. In *Proceedings of the 33rd annual ACM conference on human factors in computing systems*. ACM Press, New York, USA, 1247–1256.

[32] Gareth Iacobucci. 2017. A service under pressure. *BMJ* 356 (2017), 2 pages.

[33] Seray Ibrahim, Asimina Vasalou, Laura Benton, and Michael Clarke. 2022. A methodological reflection on investigating children's voice in qualitative research involving children with severe speech and physical impairments. *Disability & society* 37, 1 (2022), 63–88.

[34] Seray B Ibrahim. 2020. *Communication and Non-Speaking Children with Physical Disabilities: Opportunities and Reflections from Design-Oriented Research*. Ph. D. Dissertation. UCL (University College London).

[35] Seray B Ibrahim, Asimina Vasalou, and Michael Clarke. 2018. Design opportunities for AAC and children with severe speech and physical impairments. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. ACM Press, New York, USA, 1–13.

[36] Dhruv Jain, Hung Ngo, Pratyush Patel, Steven Goodman, Leah Findlater, and Jon Froehlich. 2020. SoundWatch: Exploring smartwatch-based deep learning approaches to support sound awareness for deaf and hard of hearing users. In *Proceedings of the 22nd International ACM SIGACCESS Conference on Computers and Accessibility*. ACM Press, New York, USA, 1–13.

[37] Hayeon Jeong, Heepyung Kim, Rihun Kim, Uichin Lee, and Yong Jeong. 2017. Smartwatch wearing behavior analysis: a longitudinal study. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 1, 3 (2017), 1–31.

[38] R Jokel, J Cupit, E Rochon, and C Leonard. 2009. Relearning lost vocabulary in nonfluent progressive aphasia with MossTalk Words®. *Aphasiology* 23, 2 (2009), 175–191.

[39] Shaun K Kane, Barbara Linam-Church, Kyle Althoff, and Denise McCall. 2012. What we talk about: designing a context-aware communication tool for people with aphasia. In *Proceedings of the 14th international ACM SIGACCESS conference on Computers and accessibility*. ACM Press, New York, USA, 49–56.

[40] Shaun K Kane, Meredith Ringel Morris, Ann Paradiso, and Jon Campbell. 2017. " At times avuncular and cantankerous, with the reflexes of a mongoose" Understanding Self-Expression through Augmentative and Alternative Communication Devices. In *Proceedings of the 2017 acm conference on computer supported cooperative work and social computing*. ACM Press, New York, USA, 1166–1179.

[41] Teresa lacono, Pat Mirenda, and David Beukelman. 1993. Comparison of unimodal and multimodal AAC techniques for children with intellectual disabilities. *Augmentative and Alternative Communication* 9, 2 (1993), 83–94.

[42] Janice Light. 1989. Toward a definition of communicative competence for individuals using augmentative and alternative communication systems. *Augmentative and alternative communication* 5, 2 (1989), 137–144.

[43] Janice Light and David McNaughton. 2012. The changing face of augmentative and alternative communication: Past, present, and future challenges. , 197–204 pages.

[44] Janice Light, David McNaughton, David Beukelman, Susan Koch Fager, Melanie Fried-Oken, Thomas Jakobs, and Erik Jakobs. 2019. Challenges and opportunities in augmentative and alternative communication: Research and technology development to enhance communication and participation for individuals with complex communication needs. *Augmentative and Alternative Communication* 35, 1 (2019), 1–12.

[45] Fannie Liu, Chunjong Park, Yu Jiang Tham, Tsung-Yu Tsai, Laura Dabbish, Geoff Kaufman, and Andrés Monroy-Hernández. 2021. Significant otter: Understanding the role of biosignals in communication. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. ACM Press, New York, USA, 1–15.

[46] Stephen J Macdonald, Lesley Deacon, Jackie Nixon, Abisope Akintola, Anna Gillingham, Jacqueline Kent, Gillian Ellis, Debbie Mathews, Abolaji Ismail, Sylvia Sullivan, et al. 2018. 'The invisible enemy': disability, loneliness and isolation. *Disability & Society* 33, 7 (2018), 1138–1159.

[47] Kelly Mack, Emma McDonnell, Dhruv Jain, Lucy Lu Wang, Jon E. Froehlich, and Leah Findlater. 2021. What do we mean by "accessibility research"? A literature survey of accessibility papers in CHI and ASSETS from 1994 to 2019. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. ACM Press, New York, USA, 1–18.

[48] Kelly Mack, Emma McDonnell, Venkatesh Potluri, Maggie Xu, Jailyn Zabala, Jeffrey Bigham, Jennifer Mankoff, and Cynthia Bennett. 2022. Anticipate and adjust: Cultivating access in human-centered methods. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*. ACM Press, New York, USA, 1–18.

[49] Azeem Majeed, Edward John Maile, and Andrew B Bindman. 2020. The primary care response to COVID-19 in England's National Health Service. *Journal of the Royal Society of Medicine* 113, 6 (2020), 208–210.

[50] Meethu Malu, Pramod Chundury, and Leah Findlater. 2018. Exploring accessible smartwatch interactions for people with upper body motor impairments. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. ACM Press, New York, USA, 1–12.

[51] Meethu Malu, Pramod Chundury, and Leah Findlater. 2019. Motor Accessibility of Smartwatch Touch and Bezel Input. In *Proceedings of the 21st International ACM SIGACCESS Conference on Computers and Accessibility*. ACM Press, New York, USA, 563–565.

[52] Elena Márquez Segura, James Fey, Ella Dagan, Samvid Niravbhai Jhaveri, Jared Pettitt, Miguel Flores, and Katherine Isbister. 2018. Designing future social wearables with live action role play (larp) designers. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. ACM Press, New York, USA, 1–14.

[53] M Shannon McCord and Gloria Soto. 2004. Perceptions of AAC: An ethnographic investigation of Mexican-American families. *Augmentative and alternative communication* 20, 4 (2004), 209–227.

[54] David Mcnaughton and Diane Nelson Bryen. 2007. AAC technologies to enhance participation and access to meaningful societal roles for adolescents and adults with developmental disabilities who require AAC. *Augmentative and alternative communication* 23, 3 (2007), 217–229.

[55] Albert Mehrabian. 2017. *Nonverbal communication*. Routledge, New York, USA.

[56] Sally Millar, Janet Scott, et al. 1998. What is augmentative and alternative communication? An introduction. *Augmentative communication in practice: An introduction* 1 (1998), 3–12.

[57] Alison Moorcroft, Nerina Scarinci, and Carly Meyer. 2020. 'We were just kind of handed it and then it was smoke bombed by everyone': How do external stakeholders contribute to parent rejection and the abandonment of AAC systems? *International journal of language & communication disorders* 55, 1 (2020), 59–69.

[58] Timothy Neate, Aikaterini Bourazeri, Abi Roper, Simone Stumpf, and Stephanie Wilson. 2019. Co-created personas: Engaging and empowering users with diverse needs within the design process. In *Proceedings of the 2019 CHI conference on human factors in computing systems*. ACM Press, New York, USA, 1–12.

[59] Timothy Neate, Vasiliki Kladouchou, Stephanie Wilson, and Shehzmani Shams. 2022. "Just Not Together": The Experience of Videoconferencing for People with Aphasia during the Covid-19 Pandemic. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*. ACM Press, New York, USA, 1–16.

[60] Timothy Neate, Abi Roper, Stephanie Wilson, and Jane Marshall. 2019. Empowering expression for users with aphasia through constrained creativity. In *Proceedings of the 2019 CHI conference on human factors in computing systems*. ACM Press, New York, USA, 1–12.

[61] Timothy Neate, Abi Roper, Stephanie Wilson, Jane Marshall, and Madeline Cruice. 2020. CreaTable content and tangible interaction in Aphasia. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. ACM Press, New York, USA, 1–14.

[62] Christopher S Norrie, Annalu Waller, and Elizabeth FS Hannah. 2021. Establishing context: AAC device adoption and support in a special-education setting. *ACM Transactions on Computer-Human Interaction (TOCHI)* 28, 2 (2021), 1–30.

[63] Mmachi God'sglory Obiorah, Anne Marie Marie Piper, and Michael Horn. 2021. Designing AACs for people with aphasia dining in restaurants. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. ACM Press, New York, USA, 1–14.

[64] Amanda M O'Brien, Ralf W Schlosser, Howard Shane, Oliver Wendt, Christina Yu, Anna A Allen, Jacqueline Cullen, Andrea Benz, and Lindsay O'Neill. 2020. Providing visual directives via a smart watch to a student with Autism Spectrum Disorder: an intervention note. *Augmentative and Alternative Communication* 36, 4 (2020), 249–257.

[65] Rebecca Palmer, Helen Hughes, and Tim Chater. 2017. What do people with aphasia want to be able to say? A content analysis of words identified as personally relevant by people with aphasia. *PloS one* 12, 3 (2017), e0174065.

[66] Phil Parette and Marcia Scherer. 2004. Assistive technology use and stigma. *Education and training in developmental disabilities* 39, 3 (2004), 217–226.

[67] Susie Parr. 2007. Living with severe aphasia: Tracking social exclusion. *Aphasiology* 21, 1 (2007), 98–123.

[68] Gail V Pashek. 1997. A case study of gesturally cued naming in aphasia: Dominant versus nondominant hand training. *Journal of Communication Disorders* 30, 5 (1997), 349–366.

[69] Jennifer Pearson, Simon Robinson, and Matt Jones. 2015. It's About Time: Smartwatches as public displays. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. ACM Press, New York, USA, 1257–1266.

[70] Helen Petrie. 1997. User-centred design and evaluation of adaptive and assistive technology for disabled and elderly users. *it-Information Technology* 39, 2 (1997), 7–12.

[71] Halley P Profita. 2016. Designing wearable computing technology for acceptability and accessibility. *ACM SIGACCESS Accessibility and Computing* 114 (2016), 44–48.

[72] Halley P Profita, Abigale Stangl, Laura Matuszewska, Sigrunn Sky, and Shaun K Kane. 2016. Nothing to hide: Aesthetic customization of hearing AIDS and cochlear implants in an online community. In *Proceedings of the 18th International ACM SIGACCESS Conference on Computers and Accessibility*. ACM Press, New York, USA, 219–227.

[73] Graham Pullin. 2009. *Design meets disability*. MIT press, Cambridge, Massachusetts, USA.

[74] Sneha Raman and Tara French. 2022. Participatory design in sensitive contexts: A proposal for a conceptual framework. *The Design Journal* 25, 5 (2022), 752–767.

[75] Pirkko Rautakoski. 2011. Training total communication. *Aphasiology* 25, 3 (2011), 344–365.

[76] Reza Rawassizadeh, Blaine A Price, and Marian Petre. 2014. Wearables: Has the age of smartwatches finally arrived? *Commun. ACM* 58, 1 (2014), 45–47.

[77] Samuel Sennott and Adam Bowker. 2009. Autism, aac, and proloquo2go. *Perspectives on Augmentative and Alternative Communication* 18, 4 (2009), 137–145.

[78] Tom Shakespeare et al. 2006. The social model of disability. *The disability studies reader* 2 (2006), 197–204.

[79] Kristen Shinohara and Jacob O Wobbrock. 2011. In the shadow of misperception: assistive technology use and social interactions. In *Proceedings of the SIGCHI conference on human factors in computing systems*. ACM Press, New York, USA, 705–714.

[80] Katie A Siek, Yvonne Rogers, and Kay H Connelly. 2005. Fat finger worries: how older and younger users physically interact with PDAs. In *INTERACT*, Vol. 5. Springer, ACM Press, New York, USA, 267–280.

[81] Kiley Sobel, Alexander Fiannaca, Jon Campbell, Harish Kulkarni, Ann Paradiso, Ed Cutrell, and Meredith Ringel Morris. 2017. Exploring the design space of AAC awareness displays. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. ACM Press, New York, USA, 2890–2903.

[82] Katta Spiel, Laura Malinverni, Judith Good, and Christopher Frauenberger. 2017. Participatory evaluation with autistic children. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. ACM Press, New York, USA, 5755–5766.

[83] Nick Statt. 2020. Apple now sells more watches than the entire Swiss watch industry. https://www.theverge.com/2020/2/5/21125565/apple-watch-sales-

2019-swiss-watch-market-estimates-outsold

[84] Ke Sun, Yuntao Wang, Chun Yu, Yukang Yan, Hongyi Wen, and Yuanchun Shi. 2017. Float: one-handed and touch-free target selection on smartwatches. In *Proceedings of the 2017 chi conference on human factors in computing systems*. ACM Press, New York, USA, 692–704.

[85] Krzysztof Szklanny, Marcin Wichrowski, and Alicja Wieczorkowska. 2022. Prototyping Mobile Storytelling Applications for People with Aphasia. *Sensors* 22, 1 (2022), 14.

[86] Carla Tamburro, Timothy Neate, Abi Roper, and Stephanie Wilson. 2020. Accessible creativity with a comic spin. In *Proceedings of the 22nd International ACM SIGACCESS Conference on Computers and Accessibility*. ACM Press, New York, USA, 1–11.

[87] Ha Trinh, Annalu Waller, Keith Vertanen, Per Ola Kristensson, and Vicki L Hanson. 2012. Applying prediction techniques to phoneme-based AAC systems. In *Proceedings of the Third Workshop on Speech and Language Processing for Assistive Technologies*. ACM Press, New York, USA, 19–27.

[88] Ha Trinh, Annalu Waller, Keith Vertanen, Per Ola Kristensson, and Vicki L Hanson. 2012. iSCAN: A phoneme-based predictive communication aid for non-speaking individuals. In *Proceedings of the 14th international ACM SIGACCESS conference on Computers and accessibility*. ACM Press, New York, USA, 57–64.

[89] Stephanie Valencia, Michal Luria, Amy Pavel, Jeffrey P Bigham, and Henny Admoni. 2021. Co-designing socially assistive sidekicks for motion-based aac. In *Proceedings of the 2021 ACM/IEEE International Conference on Human-Robot Interaction*. ACM Press, New York, USA, 24–33.

[90] Stephanie Valencia, Mark Steidl, Michael Rivera, Cynthia Bennett, Jeffrey Bigham, and Henny Admoni. 2021. Aided Nonverbal Communication through Physical Expressive Objects. In *Proceedings of the 23rd International ACM SIGACCESS Conference on Computers and Accessibility*. ACM Press, New York, USA, 1–11.

[91] Mieke van de Sandt-Koenderman. 2004. High-tech AAC and aphasia: Widening horizons? *Aphasiology* 18, 3 (2004), 245–263.

[92] Marin Vuković, Željka Car, Melita Fertalj, Ida Penezić, Valerija Miklaušić, Jasmina Ivšac, Nina Pavlin-Bernardić, and Lidija Mandić. 2016. Location-based smartwatch application for people with complex communication needs. In *2016 International Multidisciplinary Conference on Computer and Energy Science (SpliTech)*. IEEE, IEEE, Split, Croatia, 1–7.

[93] Annalu Waller. 2019. Telling tales: unlocking the potential of AAC technologies. *International journal of language & communication disorders* 54, 2 (2019), 159–169.

[94] Annalu Waller, Rolf Black, David A O'Mara, Helen Pain, Graeme Ritchie, and Ruli Manurung. 2009. Evaluating the standup pun generating software with children with cerebral palsy. *ACM Transactions on Accessible Computing (TACCESS)* 1, 3 (2009), 1–27.

[95] Hongyi Wen, Julian Ramos Rojas, and Anind K Dey. 2016. Serendipity: Finger gesture recognition using an off-the-shelf smartwatch. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. ACM Press, New York, USA, 3847–3851.

[96] Renata Whurr and Marjorie Lorch. 1991. The use of a prosthesis to facilitate writing in aphasia and right hemiplegia. *Aphasiology* 5, 4-5 (1991), 411–418.

[97] Kristin Williams, Karyn Moffatt, Jonggi Hong, Yasmeen Faroqi-Shah, and Leah Findlater. 2016. The cost of turning heads: A comparison of a head-worn display to a smartphone for supporting persons with aphasia in conversation. In *Proceedings of the 18th International ACM SIGACCESS Conference on Computers and Accessibility*. ACM Press, New York, USA, 111–120.

[98] Stephanie Wilson, Abi Roper, Jane Marshall, Julia Galliers, Niamh Devane, Tracey Booth, and Celia Woolf. 2015. Codesign for people with aphasia through tangible design languages. *CoDesign* 11, 1 (2015), 21–34.

[99] Xuhai Xu, Jun Gong, Carolina Brum, Lilian Liang, Bongsoo Suh, Shivam Kumar Gupta, Yash Agarwal, Laurence Lindsey, Runchang Kang, Behrooz Shahsavari, et al. 2022. Enabling hand gesture customization on wrist-worn devices. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*. ACM Press, New York, USA, 1–19.

[100] Hanlu Ye, Meethu Malu, Uran Oh, and Leah Findlater. 2014. Current and future mobile and wearable device use by people with visual impairments. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM Press, New York, USA, 3123–3132.