ABSTRACT

Title of Document: THE COST OF TURNING HEADS: THE DESIGN AND EVALUATION OF VOCABULARY PROMPTS ON A HEAD-WORN DISPLAY TO SUPPORT PERSONS WITH APHASIA IN CONVERSATION

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Symbol-based dictionaries could provide persons with aphasia a resource for finding needed words, but they can detract from conversation. This research explores the potential of head-worn displays (HWDs) to provide glanceable vocabulary support that is unobtrusive and always-available. Two formative studies explored the benefits and challenges of using a HWD, and evaluated a proof-of-concept prototype in both lab and field settings. These studies showed that a HWD may allow wearers to maintain focus on the conversation, reduce reliance on external support (e.g., paper and pen, or people), and minimize the visibility of support by others. A third study compared use of a HWD to a smartphone, and found preliminary evidence that the HWD may offer a better overall experience with assistive vocabulary and may better support the wearer in advancing through conversation. These

studies should motivate further investigation of head-worn conversational support.

THE COST OF TURNING HEADS: THE DESIGN AND EVALUATION OF VOCABULARY PROMPTS ON A HEAD-WORN DISPLAY TO SUPPORT PERSONS WITH APHASIA IN CONVERSATION

By

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Foreword

Statement of Co-Authorship

All work in this thesis was conducted under the supervision of Dr. Leah Findlater. Dr. Karyn Moffatt also provided guidance on all three studies, and Dr. Yasmeen Shah did so for the third study.

I am the primary contributor to all aspects of this research, with the exception of the controlled comparison study in Chapter 4. For that study, Jonggi Hong designed and created the remote control used as part of the head-worn display prototype and incorporated code from Meethu Malu.

Large parts of Chapters 2 and 3 are updated versions of the following published paper, for which I wrote the first draft before collaboratively editing it with all co-authors:

> Williams, K., Moffatt, K., McCall, D., & Findlater, L. (2015) Designing Conversation Cues on a Head-Worn Display to Support Persons with Aphasia. *Proceedings of CHI 2015*, 231-240.

Dedication

To Pembroke Whitfield Williams Jr. (1948-2015)—Dad: for teaching me how to read the wind when it cannot be seen on the water or in the leaves.

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At times it can be impossible to fully acknowledge and express appreciation for all of the help and support that contributed to a project, and this is one of those times. Researching this thesis required the coordination and cooperation of a vast network of people with diverse expertise, connections, and interests in advancing the creation of technology to support persons with aphasia. I am deeply grateful to every person who contributed, from the individuals who passed along contact information to those who took the time to discuss in depth what they knew of aphasia and technology’s impacts. This thesis would not have been possible without these people, and I regret that I am incapable of listing them all here.

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Inclusive Design Lab, Jonggi Hong designed and built the remote control in the third study, and Theo Lorraine-Hale coded a few transcripts from the second study for validation. Both pushed me to explain and justify my research in its early stages, and I thank them for teaching me in part how to collaborate as part of a student team. I would also like to thank Meethu Malu and Uran Oh for their continued support and feedback on this work in its different stages. From the Aphasia Research Center (ARC), I would like to thank Angela Baker for discussing with me some of the limitations she encountered during speech-language therapy, and also the ARC's members for helping me whenever I stopped by.

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Chapter 1: Introduction

“What you read and what you experience in life are not two separate worlds, but one single cosmos. Every life-experience, in order to be interpreted properly, evokes certain things you have read and blends into them.”

- *Italo Calvino (Preface to The Path to the Spiders’ Nest)*

Assistive technology to support communication for persons with aphasia is often needed mid-conversation. As aphasia is an acquired language disorder that impacts speaking, challenges with finding a needed word often arise when talking with an unfamiliar conversation partner. Symbol-based dictionaries provide a resource for pieces of dialogue or vocabulary to supplement what is conveyed to the partner. Yet, they are commonly housed on external devices and when used, divert attention away from the conversation to retrieve the desired support. By providing a wearable design with a glanceable display, head-worn displays (HWDs) may better assist a person with aphasia focusing on the conversation while unobtrusively controlling support.

1.1 Motivation and Research Problem

Persons with aphasia encounter a sudden loss of language skills after a lifetime of competent communication as the result of damage to the brain from stroke or traumatic head injury. Aphasia can impact reading, writing, speaking, and even aural comprehension, and thus, it can limit a person’s ability to conduct daily conversation. The impacts on language are particularly evident in public or community settings where conversation partners may not know anything about aphasia. Persons with aphasia are often perceived as incompetent and are excluded from conversation and decision-making due to impaired language skills [2,23]. Conversational success often depends on the facilitation skills and cooperation of the conversational partner [3,23]. Yet in public settings, unfamiliar partners are not likely to assume the role of a language resource [23] as may be required to jointly establish meaning during conversation [9,20,30].

To address aphasia's impacts on language, assistive communication technologies may prove supportive such as Augmented Alternative Communication (AAC) [2,49]. These approaches often consist of a dictionary made up of icons, pictures or written words [49], and are typically provided either on a dedicated device (e.g., Dynavox) or as a mobile application (e.g., Lingraphica). However, adoption of AAC by persons with aphasia remains low [45]. While the causes are complex, evidence suggests that these devices do not fit well into conversation [20]. Unlike sensory aids such as eye glasses [43,51], AAC devices are obtrusive when employed by the user. For example, the synthesized voice of speech-generating devices—a popular form of AAC—tends to replace the user's own natural voice [49]. Or, attention is explicitly diverted to accessing and operating the device rather than attending to communication, such as speaking role, appropriate verbal inflection, monitoring for errors, or continuing the dialogue's pace [20,48,49].

A head-worn display (HWD) may enable a fundamentally different communication experience than existing tools. A head-worn display is a self-powered computer and display worn on a person’s head [4]. In this thesis I will focus on Google Glass (see Figure 1) as an example of a head-worn display. It consists in a semi-transparent, monocular display connected to a titanium frame in the shape of glasses with wi-fi and Bluetooth capability. The wearable form of a HWD such as Google Glass could enable a person with aphasia to better maintain focus on their communication partner while unobtrusively controlling conversational support. This thesis will examine this potential by asking whether the design of a HWD is more suited to conversation than external AAC devices like a mobile phone.

Figure 1 - Depiction of how head-worn vocabulary prompts may enable minimal departure from conversation to retrieve communication support and facilitate concentration on the conversational partner for persons with aphasia. The prompt ‘Listen to Music’ is shown being accessed on Google Glass to support conversation about personal interests.

1.2 Research Questions

Future conversation support tools need to address the issues with current AAC devices enumerated above: 1) replacing the user’s natural voice, 2) diverting attention away from the conversation, and 3) being readily available mid-conversation. By providing private access to device content and a glanceable display in a wearable design, HWDs are a promising alternative.

This thesis investigates the potential of HWDs to support persons with aphasia in conversation by addressing the following research questions:

1. How do individuals with aphasia respond to the idea of using vocabulary prompts on a HWD?
2. Are there any major physical accessibility challenges posed by HWD for individuals with aphasia?
3. To what extent can persons with aphasia use vocabulary prompts on a HWD to support conversation with unfamiliar partners?
4. How do vocabulary prompts on a HWD compare to those on a phone in terms of supporting engagement in conversation, being readily available, and enhancing a person with aphasia's contribution?

1.3 Approach

Working closely with 25 persons with aphasia, three studies created and evaluated a design for head-worn vocabulary prompts to assess the feasibility of HWDs for communication support and their potential benefits over mobile phones. Employing storyboards as a design probe, an initial interview elicited feedback and design ideas for a vocabulary prompting application on an HWD from 8 persons with aphasia. Guided by findings from that study, a proof-of-concept prototype was evaluated with 14 persons with aphasia to gauge the feasibility of using a HWD in conversation with an unfamiliar partner in a lab and market setting. Combined, the interview and *in situ* studies showed that participants responded positively to the idea of head-worn vocabulary prompts and were able to successfully complete the conversation tasks. These two formative studies also found that busy contexts challenging persons with aphasia to respond quickly are likely to be when HWDs would prove most supportive. To verify these findings, a follow up study with 17 persons with aphasia compared use of a HWD in conversation to use of a mobile phone in terms of overall experience, support for focus, and the ability to progress through conversation accurately and quickly. Findings from this controlled study provide preliminary verification of the two formative studies' results, but a follow-up study with greater statistical power is needed to conclusively determine whether HWDs are more supportive in conversation than a mobile phone.

1.4 Contributions

This thesis worked closely with 25 persons with aphasia over the course of 3 studies to design and evaluate a head-worn vocabulary prompting application to support communication. From this research, this thesis contributes:

1. A proof-of-concept prototype for presenting vocabulary prompts on a head-worn display
2. A qualitative evaluation of this prototype based on use in lab and field settings
3. Identification of potential contexts of use for which head-worn vocabulary prompts may be most beneficial, and

4. A preliminary assessment of how vocabulary prompts on a HWD compare to those on a mobile phone under controlled conditions.

1.5 Overview

The thesis is organized into the following chapters. A review of related work on aphasia, communication support, and related technology is summarized in the second chapter. The third chapter covers two formative studies consisting of an interview study and an *in situ* study evaluating use of a proof-of-concept prototype in field and lab settings. Next, a preliminary, controlled study comparing a head-worn display to a mobile phone as a communication support tool is covered in the fourth chapter. Finally, the last chapter considers the findings of all three studies together and how they contribute to the central questions and motivations of this research. The final discussion outlines possible future lines of research and approaches to supporting conversation for persons with aphasia resulting from this work.

Chapter 2: Related Work

The design of head-worn displays (HWDs) to support communication for individuals with aphasia draws on related work covering aphasia, communication support both with and without technology, and HWDs as assistive tools. As such, this chapter provides a review of human-computer interaction research on communication support technology for individuals with aphasia and related lines of research as appropriate. We first characterize aphasia and its sociolinguistic impacts before describing methods to include individuals with aphasia in conversation. Given this background, we then cover related research on HWDs for targeted populations and communication, design techniques relevant to aphasia, computerized communication support, and modelling and evaluating technology use mid-conversation.

2.1 Aphasia and Conversation

Aphasia is an acquired language disorder that occurs from damage to the central nervous system [8,50]. It ranges in severity from mild complications in the selection of the appropriate word to complete loss of the ability to comprehend or formulate language. A typology has emerged which classifies the presentation of aphasia according to different combinations of deficits in naming, fluency, repetition, auditory comprehension, grammatical processing, reading, and writing [8,50]. Aphasia affects people of all ages. However, the most common cause of aphasia is cerebrovascular accident—also known as stroke—and so, the prevalence of aphasia increases with age [8].

Creating opportunities for persons with aphasia to participate in conversation and decision-making includes making available appropriate resources to empower a person with aphasia to initiate discussion of complex topics [33]. Picture-based support tools have traditionally been used [33], but there is growing recognition that textual artifacts are increasingly important for initiating interaction in an information society [3,22]. How the relationship between persons with aphasia and textual artifacts is constructed can have profound implications for inclusion: shaping the ability to work [43], political representation [22], and quality of life [41,51]. Creating a route for persons with aphasia to intellectually access the textual resources needed to effectively coordinate with conversation partners will be central to the design of this relationship.

Conversation partners put pressure on individuals with aphasia to capitalize on efficiency for the sake of continuing the forward momentum of discussion. Long delays in formulating a response present opportunities for the partner to take over the person with aphasia’s turn at talk and can highlight deficits in aphasic speech [61]. Some researchers hypothesize that persons with aphasia adapt in their speech by concentrating on high information words such as nouns and dropping low information words such as function words and verbs in order to save face as a competent speaker [19,61].

Research into the design of photo-based systems to support communication have highlighted how photographs support the ability of a person with aphasia to efficiently communicate complex information such as progress on a personal project like gardening or acquiring a needed item for a hobby [1]. Central to this approach is the ability for individuals with aphasia to quickly convey a complex conception of who they are and their relationship to their environment. Interviews with speech-language pathologists indicated that navigation of dictionary-based support tools like Lingraphica may be enough to deter persons with aphasia from using the technology, and that a point-and-speak approach may be more desirable [44]. Using a pen-based technology, researchers found that associating recordings of object names to a personal living room photo empowered participant person with aphasia to name the objects herself. However, the participant found it challenging to extend the technique to her actual living room. These findings suggest that photo-based methods may be limited in their extension to naming in the natural world. By using augmented reality techniques that overlay images on the environment within the wearer's line of sight, HWDs may be able to address some of these limitations.

2.2 Head-Worn Cognitive and Communication Support

The physical device design of communication support technologies is part of a complex interplay between sociolinguistic facets of communication and the physical orientations required for perceptual access. Galliers, et al. argue that the ergonomics of device design for those with aphasia is often neglected in device research [16]. Yet, others argue that a focus on physical access to AAC devices has swamped concerns for social interaction during communication [20]. For example, a clear view of the conversation partner's face may substantially impact the ability of a person with aphasia in both comprehending and formulating language. Facial expressions, eye contact, and lip reading provide important feedback on whether conversation partners have a shared understanding [16,44]. Speech entrainment techniques which emphasize a speaker's mouth movement and concurrent pronunciation have been shown to be therapeutic in helping an individual with aphasia regain speech [15]. HWDs may provide a physical design that is potentially suited to balancing social cues with device use during conversation.

To the author's knowledge, no research has investigated how HWDs might support a person with aphasia in finding needed words mid-conversation. One project used a head-worn camera (without a visual display) to capture content for later use in storytelling [34]. A few studies have looked at HWDs to support older adults [27] and persons with cognitive decline [18]; these efforts have identified a number of potential application areas, including short-term memory aids, experience capture, and instructions (e.g., for cooking). In addition, a study of Google Glass with persons with Parkinson's disease found no serious accessibility challenges due to motor impairments [36], a consideration that is also important for persons with aphasia, who often have right-side hemiparesis (weakness or paralysis).

To a limited extent, HWDs have been previously explored to support AAC. However, the user studies were brief and did not involve persons with aphasia. One study focused on the algorithm to predict needed vocabulary, but did not have a user study [57]. Another involved two individuals with cerebral palsy, but it did not evaluate subjective indicators of how well communication went while using the device, and objective measures were limited to symbol selection error rate without a description of how the measure was determined [58].

More broadly, the effect of delivering information via a head-worn display during conversation has been studied with unimpaired individuals, but whether these findings extend to the design of AAC remains an open question. One study on the timing and modality of information delivery during conversation found that it should be delivered visually in batches when the wearer is not speaking [42]. Another study showed that delivery during conversation negatively impacted eye contact and attention [35]; however, the information shown was not relevant to the conversation and the display was located just below the wearer's line of sight. It is unclear how these findings will translate when the information plays a direct role in the conversation, as with the approach proposed here.

When delivered information has a direct role in conversation it can impact the wearer's conversation quality and efficiency, but these techniques have not been employed in HWD design for persons with aphasia. Speech, doubling as a response to a conversation partner and as an input technique to HWDs, has been proposed to accommodate social propriety and minimize the demands on the wearer [32]. The user study revealed that the wearer had the most difficulty with negotiating both communication with their conversation partner and manipulating the HWD, and the dual-speech technique did not support maintenance of both tasks. One to two word feedback to the wearer in short intervals supported active change in the wearer's speaking during a public speaking task and was found preferable to information visualizations for its interpretability while speaking [54]. These studies demonstrate potential for symbol-based dictionaries on a HWD to provide support while speaking, but they highlight the need for careful design so that delivered information can be incorporated in conversation dynamics.

2.3 Design and Aphasia

The work of several researchers has yielded a set of guidelines for including individuals with aphasia in the design process, and this thesis is informed by these guidelines when appropriate. These guidelines include working one-on-one with participants and conducting warm-up activities [17], administering standardized tests and working with community organizations [38], observing conversation techniques used with familiar partners, phrasing questions in a closed manner [10], and using speech-language pathologists as proxies to gain an overview of aphasia needs to counter the substantial variability in individual cases [5]. A study on the design of context-aware applications identified techniques that may be of especial importance to ubiquitous computing applications (applications that are not desk-top based) as investigated here: ensure demonstrations are concrete and personalized, provide clear illustrations of interface changes, and use multiple formats to present scenarios during paper prototyping [24].

A notable supplement to these guidelines is an approach that links language deficits to design methods. For example, some researchers try to identify whether design techniques rely on the ability to attribute mental states to others (theory of mind representation), use numbers, or follow chains of reasoning [17]. They argue that many of the abstract representations and open-ended methods used in co-design, participatory design, and user-centered design may be inappropriate for individuals with aphasia as they heavily rely on nuanced communication [62]. Instead, they advocate for eliciting feedback with high-fidelity prototypes and the use of ‘tangible design languages’—non-verbal design representations that can be directly manipulated—to ground discussion of design elements [62]. Taking note of the many ways traditional human-computer interaction techniques may be impacted by participants’ language disorder, this thesis’s research designed the studies with the guidance of experts in speech-language pathology, aphasia, and research in human-computer interaction and aphasia.

The best practices for user interface elements for individuals with aphasia and HWDs requires reconciliation. Brandenburg, et. al. compiled a set of design guidelines from desktop and web based technology research to extend to mobile apps [6]. However, the extension of recommendations—like button size, stable screen contents, and two-tree hierarchies for navigation—

to wearable technologies, and specifically HWDs is not straightforward. In some cases, they may conflict with best practices for HWD: black text on a white background is recommended for user interfaces (UIs) for individuals with aphasia but white text on a black background is recommended for HWDs. These considerations coupled with findings from studies on HWD information delivery emphasize a role for design techniques that consider how assistive vocabulary on a wearable UI would support conversation for persons with aphasia.

2.4 Computerized AAC for Aphasia

Research on assistive technology to support aphasia can be strongly influenced by the conception of the language disorder and what is being targeted for assistance. For example, AAC might draw "on a theory of the underlying language deficit; and, importantly, the efficacy of this device may provide a test of this theory" [31]. This has led some researchers to categorize assistive technologies as "disorder oriented" or "communication oriented" [49]. This division in part reflects early political movements emphasizing a social model of disability instead of a medical model: emphasizing the way society is organized to include or exclude its members [43]. Further, it fits with the World Health Organization's framework distinguishing *impairment, disability, and handicap* [14]. This research is focused on how technology can be designed to supportively mediate the relationship between textual artifacts and persons with aphasia, further discussion about how this research fits within the above framework is beyond the scope of this thesis. This thesis asks, *how can HWD support individuals with aphasia in conversation with unfamiliar communication partners?*

To this end, some research has focused on supporting people with aphasia in activities of daily living (e.g., daily planning [5,38] and cooking [55]). Some systems focus on storytelling, by enabling access to prerecorded stories that can be used to introduce topics (e.g., TalksBac [59]). Others provide mechanisms for capturing and accessing photos for use in later conversation [1,34]. We review these applications, and then discuss the decision to focus on symbol-based dictionairies and the role of HWDs.

Storytelling has recently been a dominant approach in human-computer interaction research on aphasia. At its heart, storytelling taps into the ability of individuals with aphasia to “grasp the rules of narrative structure and to be aware of the boundary between fact and fiction” [50]. Storytelling is used in assistive technology design to support persons with aphasia in making independent contributions to conversation, yet also effectively realizing social goals such as establishing closeness. As a design technique for technology, it has been argued that storytelling supports indirect communication styles, individual expression, and establishing social proximity [10,60]. Further, narrative provides for reusable language and can serve as the basis for high-tech AAC systems by enabling access to prerecorded stories that can be used to introduce topics (e.g., TalksBac [27]).

Storytelling applications have essentially used a linear, temporal order to support a personal narrative through pre-recording [60] or creation of a timeline for the story [10]. However, central to the power of personal narrative is the ability to revise narrative plots so as to make them relevant to the current telling. However, personal identity is often reconstructed after life-changing events and this is reflected in *turning points* that cause storytellers to revise their narratives and in some cases adopt chaotic orders [37]. Further, conversational partners challenge storyteller's narrative arc: "the primary storyteller at the dinner table has an end in view…but has to negotiate her way through the questions and comments of other speakers that may lead to a respecification of her intended ending, which may indeed change the meaning of her story" [37]. Storytelling approaches create room for the conversation partner's role in co-constructing personal narrative [10,34], but little attention has been paid to the need to renegotiate personal narrative in response to the partner. To make progress in this area, it will be important to gain an understanding of how use of assistive technologies are balance with maintaining focus on the conversation.

Another popular line of work is the use of symbol-based dictionaries of words and phrases (e.g., Lingraphica or Proloquo2Go)—an approach that we use in this thesis. These tools typically provide audio and pictures paired with text, and address the problem that individuals with aphasia generally know what they wish to say, but may experience difficulty in expressing the specific words needed. A primary challenge, however, is providing fast access to vocabulary that is typically organized in deep, cumbersome hierarchies. Manual customization is commonly supported, but effortful. Another approach is to reduce navigation time by organizing vocabulary based on semantic associations [40], or dynamically adapting it based on the user's location or conversational partner [24]—some research has begun to explore automated means of generating these contextual predictions [11].

While these approaches provide promising directions for content organization, they ignore how the form factor of the device may impact the user's ability to efficiently integrate support into conversation. For many individuals, the audio and visual stimuli are sufficient for prompting speech. However, because that support is audible and visible to others, the system tends to dominate, replacing rather than augmenting the user [29]. Moreover, use requires that the user turn their attention away from the conversation, which is not only socially awkward, but can impede the use of facial cues as an aid to comprehension. We conjecture that the time to pull out the tool along with the negative implications of turning focus away from the partner compound the effect of navigation time on communication success. We thus explore the use of a head-worn display as an alternative form factor that is also compatible with automated approaches to efficient vocabulary organization.

2.5 Conversation Structure and AAC Evaluation

Modeling experimental task on primitive language tasks could inform research questions about conversational dynamics. These primitive language models are called language games. They are based on modeling a primitive language between a builder and an assistant in which the builder is building with building stones—block, pillar, slab, and beam—and the assistant is to pass the stones in the order required by the builder. According to the language game model, this is the practice of language use: one party calls out the words and the other acts on them [63]. Language games were used as the experimental task to evaluate ACES, a language distortion software system to promote empathy with individuals with aphasia [19]. The experimental task assigned dyads to two communication roles following the language game design—a writer and a doer—and the participants were to coordinate building a physical structure. This model lends itself to information-theoretic measures such as surprisal and game-theoretic notions of signaling to inform design assumptions of common knowledge between two speakers [13].

Language games have recently been incorporated into therapeutic settings to support therapists in shaping the spoken output of individuals with aphasia [46]. The game materials, rules, and reinforcement induce the use of vocabulary that is typically neglected because it is not easily accessible to the individual and so becomes learned nonuse [46]. Emphasizing that language is embedded in activity, and that conversation partners act on what is said supports interactive communication in addition to storytelling such as requests, thanking someone, advising, bargaining, asking and answering, warning, and arguing [47].

2.6 Conclusion

Individuals with aphasia experience a sudden loss of language skills and, with that loss, confront the task of constructing a new sociolinguistic identity.

Central to this task is the desire to independently express themselves in conversations with unfamiliar partners that are dynamic and support self-image. Including individuals with aphasia in the early stages of the design process requires rethinking design methods so that participants can substantively evaluate and critique design ideas. A challenge to the design of assisted communication is to understand how balancing assistive technology with engagement in conversation fits into the conversational task and its part in an ecology that emphasizes efficient communication of high value language. The physical device design must accommodate demands of perceptual access and decision-making that trades on higher quality speaking and normative expectations for conversational roles.

Chapter 3: Formative Studies

The ability of head-worn displays (HWDs) to provide a clear view of a conversation partner coupled with private perceptual access to the device's content could support speakers with aphasia in balancing use of assistive technology with maintaining conversation. We conducted two studies to inform the design of head-worn vocabulary support and to assess the potential impacts of such support. Study 1 was an interview study to elicit feedback on the general idea from 8 participants. It included an introduction to and brief use of Google Glass, and presentation of two narrative storyboards as a design probe. Guided by findings from that study, we created a proof-of-concept prototype on Google Glass—that we call GLAAC (Glass AAC)—and evaluated it with 14 participants with aphasia. In Study 2, participants used GLAAC during conversations in a lab setting with the researcher and *in situ* with unfamiliar conversation partners at a local market.

Combined, the studies show head-worn vocabulary prompts to be a feasible approach to conversation support. Findings from the *in situ* study, in particular, suggest that the near-eye display contributed to keeping participants' attention on their conversation partner and helped them stay engaged in the conversation task while seeking out support. While some participants discussed concerns with the HWD's input, there was generally a positive response to using head-worn vocabulary in busy contexts where environmental pressures challenge those with aphasia to respond quickly.

These two formative studies contribute (1) a proof-of-concept prototype for presenting vocabulary prompts on a head-worn display; (2) a qualitative evaluation of this prototype based on use in lab and field settings; and, (3) identification of potential contexts of use for which head-worn vocabulary prompts may be most beneficial.

3.1 Study I – Formative Interviews

We conducted an interview study with 8 participants with aphasia to gauge initial reaction to vocabulary prompts on a head-worn display and to perform a preliminary assessment of the accessibility of Google Glass for persons with aphasia.

3.1.1 Method

The study included basic tasks on Glass, and semi-structured interviews with storyboards as a design probe.

3.1.2 Participants

Language ability varies greatly with aphasia, and we predict that our approach will be most useful to persons with good auditory comprehension and mild to moderate verbal production deficits. However, as this first study relied heavily on discussion of the design probe, we targeted recruitment at the higher end of that range. Participants were screened by a licensed speech-language pathologist based on two standardized tests: (1) the Communication Activities of Daily Living (CADL-2), to assess the impact of impairment on daily communication [21], and (2) the Western Aphasia Battery

Figure 2 - Example frames from the storyboards used as a design probe in Study 1: two frames from the grocery store scenario showing a woman searching for cheddar cheese, and three frames from a man with a migraine visiting the doctor.

(WAB), which assesses type and degree of aphasia [26]. Criteria for participation included a minimum of the 50th percentile for the CADL-2, and for the WAB, 7/10 for auditory verbal comprehension and 5/10 for information content of spontaneous speech.

Eight participants were recruited at a local community organization for individuals with aphasia.[1] They ranged in age from 45 to 72 (*M* = 59.8, *SD* = 8.5); one was female. All participants acquired aphasia from a stroke that resulted in right-side hemiparesis (weakness). As a result, all participants were left-handed post stroke; pre-stroke, S5 was left-handed and S4 was ambidextrous.

3.1.3 Storyboards

Two storyboards depicting everyday conversational tasks were used as a design probe, to elicit feedback on the idea of glanceable, head-worn vocabulary prompts:

- *Grocery store* (Figure 2). A woman visits a grocery store while wearing a head-worn display preloaded with her grocery list. At the store, she cannot locate the cheddar cheese nor can she express the words "cheddar cheese" to ask a clerk where it is. She activates the device, navigates a

[1] A ninth participant withdrew.

hierarchy to the entry for cheddar cheese, and taps to play text-to-speech. After practicing saying “cheddar cheese” on her own, she seeks a clerk and successfully asks for help with finding the cheese.

- *Doctor’s office* (Figure 2). As a man approaches a clinic, the head-worn device automatically loads personalized medical prompts in response to the clinic’s proximity. Once in the examining room, the man points to his head and the doctor guesses that he has a headache. But, to be more specific, the man accesses two prompts on the head-worn display to help him say that it is a “migraine” and that he wants the medication “Zomig”.

The storyboards were initially hand-drawn, revised with image manipulation software, and augmented with comic-book grammar to convey text-to-speech features, GPS triggers, projected displays, and gestural interaction. Finalized panels were printed on paper for a low-fidelity look-and-feel to encourage critical discussion.

3.1.4 Interviewing and Communication Technique

Because communication is inherently difficult with aphasia, past work has proposed guidelines for including individuals with aphasia in the design process. Accordingly, our method employs aspects such as working one-on-one with participants [17,24,34] and phrasing questions in a closed manner when necessary [23]. The lead researcher was also trained in *supported conversation*, a set of methods designed to create opportunities for an individual with aphasia to contribute to the conversation [23]. While we primarily asked open-ended interview questions, we used supporting materials to adapt to each participant's needs: pictures, visual scales with close-ended alternatives to the open-ended questions, paper and pen, and finally, markers, sticky notes, and transparent sheets to annotate the storyboards.

3.1.5 Procedure

We developed protocols in consultation with clinicians, such as an aphasia-friendly consent process; our institutional review board (IRB) approved these protocols. Study sessions were one hour long, and participants were compensated for their time. Following informed consent, participants were asked demographic questions as well as questions about their current conversation support strategies. The following two parts were then completed:

Part 1: Google Glass Use. The researcher introduced Glass and demonstrated directional swipes (forward, back, and down) and taps on the arm of the device. During this demonstration, participants viewed the effects of the input via screencast on a paired Bluetooth phone. Next, participants put on Glass. After the participant had tried out and confirmed that they understood each gesture, the following set of tasks was presented (~10 minutes): (1) navigate to a photo album, (2) view a recent New York Times article, (3) activate the audio feature to have the headline text read aloud, and (4) return to the home screen. These tasks required at a minimum 3 forward, 3 backward, and 1 downward swipe, and 2 taps. After, participants rated each of the following on 7-point scales (easy to difficult): swiping the touchpad, tapping the touchpad, seeing images/text on the screen, and hearing audio output.

Because 3 of the first 6 participants encountered difficulties in using Glass's touchpad, we adjusted the above protocol for the last 2 participants to include a second input option. These participants completed the task set on the Glass touchpad, and then repeated the task set using the Bluetooth-connected phone as a touchpad to control Glass.

Part 2: Storyboard Scenarios. The storyboards were introduced one at a time (grocery store then doctor's office), and participants were asked to give feedback and discuss the role of Glass in each one. Once both storyboards had been shown, participants were asked open-ended questions about whether and how a head-worn display could provide support during conversation.

3.1.6 Data and Analysis

The entire session was video recorded with the exception of S1, for whom only audio was recorded. Open-ended responses were analyzed for themes of interest [7].

3.2 Findings

Participants identified accessibility issues with Glass and offered feedback on the idea of head-worn vocabulary prompts.

3.2.1 Accessibility of Glass

While some participants were able to use Glass with relative ease, others encountered substantial challenges. As a result, ease of use ratings were mixed as shown in Table 1. Based on video analysis, swipes and taps were particularly problematic for 3 participants and the researcher had to step in and control their finger or the device itself to help them complete the tasks. One of the three, S7, was not able to use the touchpad on Glass without the researcher's help, so did not rate its ease of use; he was however able to use the phone as a touchpad and rated its ease of use: swiping, 4; tapping, 1; seeing 2; hearing 1. In total, 6 of the 8 participants expressed a preference for inverting the device's design so that the touchpad and display would be on the left.

Aspect of Use	Mean	SD	Median	Range
Swiping	4.1	1.0	4.0	2–6
Tapping	3.5	2.1	4.0	1–7
Seeing	3.9	1.6	3.5	2–6
Hearing	4.0	2.3	5.0	1–7

Table 1. Study 1 ratings of Google Glass accessibility, including swiping and tapping on the touchpad, seeing the display, and hearing the audio (1=easy; 7=difficult). (N = 7)

In terms of the display, 3 participants gave low ratings for being able to see it, either due to poor eyesight or weakness in the right eye, or a preference for having a display on both sides. Two participants encountered issues with the audio being hard to hear or too fast.

3.2.2 Feedback on Glanceable Vocabulary Prompts

Overall, 7 out of 8 participants spoke positively of the ideas presented in both storyboards. S6 only responded positively to the doctor's office scenario, finding the vocabulary depicted in the grocery store scenario too easy to require support. We summarize the main themes here, particularly focusing on those related to the head-worn form factor.

***Enabling stronger conversational roles*.** Five participants discussed how support during conversation can impact their identity within a group and ability to influence group decisions. Important roles included being a fully informed patient at a doctor's office, providing customer service at work, or asking questions at a board meeting. S1, for example, expressed a desire to return to his previous job as a restaurant owner. To do so, he envisioned using the head-worn display to ask customers for their preferred ingredients while making sandwiches with his hands. As another example, S3 sat on the executive board of a family business, but found his opinion skipped over at meetings when he needed to use paper and pen to communicate. He felt a head-worn display could address this problem.

***Privacy & social perception*.** The privacy of the audio and visual output was seen by two participants as potentially enabling natural speech. S5 liked private access to phonetic cuing because she would still have the opportunity to say the word herself: *"I can't say it…um…but I know what it is…so this device can say it for me, and [then] I'll say it."* S3 wanted access to the audio, text, and visual aspects of the prompts to support his communication without circumventing his place in conversation. When asked why those aspects, he said: *"Because [the prompts are] working now I mean…its…I'm the one asking, not [my wife] or someone else but me."* The ability to retain the ability to speak for oneself while accessing support was important for these participants. Notably, none of the participants raised concerns about privacy or negative social perception when asked about the drawbacks of using Glass.

***Overcoming contextual pressures*.** Six of the 8 participants highlighted situational pressures that make timeliness of support important. S3 was keenly aware of having a limited amount of time to find support because otherwise he may lose his turn to ask a question or steer the topic of conversation during group meetings: *“But I can’t say it, or write it down, or have me a pen and paper…4 or 5 minutes and then that’s it.”* S6 provided the example of wanting to use head-worn support when taking the bus so that he could respond to the bus driver’s requests: *“talk to bus driver, money, what kind of money, $1 okay.”* This hurried context of boarding a bus while retrieving the required fare highlights the potential of glanceable support. Relatedly, 4 participants described how support mechanisms may be unavailable or misplaced at the time they are needed. A wearable, always-available display could mitigate this issue. S2, for example, uses voice recognition on his phone but sometimes misplaces the phone. In this respect, he viewed Glass positively: “*[taps the side of his glasses] click away and the eyes see it and there is no distractions [like] with 'where's my cell phone?”*

***Perceived advantages*.** Participants additionally noted a number of general advantages relative to their current compensatory strategies. Two mentioned trouble with audio-only conversations, noting the need to both hear and see. S6, for example, explained that he does not use a cell phone because he needs to see facial expressions. This points to problems with assistive tools that require the user to look away from their partner to access the support. A head-worn display would allow the wearer to monitor their partner's facial expressions while accessing support.

Another general advantage, raised by 3 participants, was that while writing was useful, it was also time consuming, inefficient, and dependent upon finding a pen. Particularly relevant to our focus on vocabulary retrieval, 4 participants described elaborate support strategies for when precision is needed. S2 described that when he needs a specific medication he relies on the availability of a particular pharmacist who knows him. S3 described telephoning his wife when stuck, who would then list off possible words until finding the right one. Both of these examples point to the potential of AAC vocabulary support as a solution, though a head-worn display may not be necessary.

***Perceived drawbacks*.** Apart from the widespread concern about the right-sided touchpad on Glass, participants raised other issues regarding head-worn vocabulary support including: one participant who did not like the idea of assistive technology in general (whether a tablet, phone or head-worn display), concern by 2 participants about the learning curve for our proposed solution, and 1 participant who did not want more than five prompts on the device, feeling that it could detract from efficient navigation mid-conversation. Note, however, that this lattermost participant changed his mind after also participating in the *in situ* study.

3.2.3 Summary

Overall, participants responded positively to the idea of head-worn conversational support, and thought it might support a stronger role in conversation for the wearer and more efficient communication than current strategies. While the study did reveal accessibility issues with Google Glass, the use of alternative input options alleviated these concerns.

3.3 Study II – Prototype and Evaluation

While the findings from the interview study suggest promise for head-worn vocabulary support, the experience of using a working prototype could be different. For this second study, we built a proof-of-concept prototype called *GLAAC* and asked 14 participants with aphasia to complete conversational tasks with the prototype in a lab setting and at a public market.

3.3.1 Proof-of-Concept Prototype

For the proof-of-concept prototype, we wrote a custom Android application for Google Glass. The design was informed by common participant feedback in the interview study (*e.g.*, the need for a different touchpad placement) and user interface guidelines for individuals with aphasia (*e.g.*, [6,16]). Although the interview study explored the number and types of prompts that should be included in such a tool, these remained open design questions in this second study.

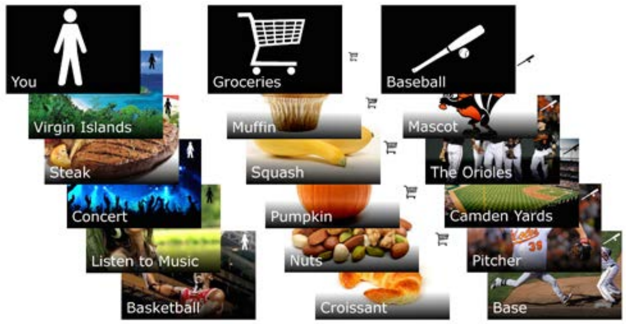

***Figure 3 - Vocabulary in the proof-of-concept prototype for Study 2. This two-level hierarchy consists of three categories (you, groceries, baseball), and five words in each category. Each screen provides an image, text, and audio. The 'you' category was customized in advance for each participant*.**

The prototype consisted of a simple two-level hierarchy of words the user could navigate with swipes and taps (Figure 3). The top-level categories were 'baseball', 'groceries', and 'you', which correspond to the study tasks described below; 'you' was customized to each participant. Each category included five words. Category and word screens consisted of an image, a text label, and an audio prompt (provided by Android's text-to-speech engine). To visually differentiate between category screens and word screens, categories used white icons from the Noun Project [64] on a black background, while words included color photos and had the parent category's icon superimposed on the upper-right corner (Figure 3).

Only one screen in the hierarchy was visible at a time. We used standard Glass interactions for navigation: *forward* and *backward swipes* scrolled through items in the current level of the hierarchy, *tap* moved down a level (*i.e.*, from a category to its specific words), *downward swipe* canceled out of a level (*i.e.*, from a specific word back to its category screen). In addition, we implemented a fifth gesture, a *two-finger tap*, to play audio for the current screen.

Because of the difficulties observed in Study 1 with Glass's right-sided touchpad, we used a Bluetooth-paired Samsung Galaxy S4 phone to control the prototype (Figure 1). Pairing the phone in this way mirrors the Glass display on the phone's screen and allows use of the phone's touchpad to control Glass. We covered the phone screen in black tissue paper that still allowed for touch input while visually hiding the display.. The phone was placed in a sport armband, which could then be attached to the user's right wrist to allow for left-handed control of Glass. While this approach is not designed for long-term use, it allowed us to sufficiently circumvent the accessibility issues with Glass's right-sided touchpad to conduct an exploratory evaluation.

3.3.2 Evaluation Method

We evaluated the proof-of-concept prototype with 14 persons with aphasia to assess usage and response to head-worn vocabulary prompts during conversation.

3.3.2.1 Participants

We recruited 14 participants (3 female) through our partner organization, including the 8 who had participated in the interview study. As this second study relied less on verbal feedback than the interview study, we did not restrict participation to those with high verbal skills. Participants were screened by a licensed speech-language pathologist. Participants ranged in age from 46 to 75 (*M* = 61, *SD* = 8.1). Scores on the CADL-2 ranged from the 31st–99th percentile. Composite scores on the WAB ranged from 51.5–82 (*M* = 68.6), while the sub-component ranges were 5–10 (*M* = 7.6) for information content, and 5.85–9.5 (*M* = 8.1) for auditory verbal comprehension.

3.3.2.2 Procedure

Study sessions were two hours long and were IRB approved. Participants wore Google Glass and controlled it via the paired Samsung phone, which was attached to their right wrist. The researcher introduced the application and how to control it with the touchscreen gestures by using the ‘baseball’ category; this category was chosen because it is a popular conversation topic at the partner organization. Participants then completed tasks in two settings: an autobiographical task in the lab with a researcher, and two shopping tasks at a nearby market with unfamiliar store clerks. Finally, a semi-structured interview was conducted.

***Autobiographical task*.** To provide practice using head-worn prompts, the researcher and participant had a brief conversation (~5 minutes) on a familiar topic and in a quiet environment. To support this conversation, the ‘you’ category was customized in advance based on a short questionnaire covering personal interests administered before the session. The researcher then asked 3 open-ended questions, such as “What would you like to do this weekend?” or “What do you enjoy doing in your spare time?” Participants were asked to use the prompts when responding.

***Market tasks*.** During the second hour, participants visited a nearby market with the researcher to use GLAAC for *in situ* conversational tasks with unfamiliar partners (*i.e.*, store clerks). We chose a setting with an unfamiliar partner as it is a challenging—but important [49]—setting for high-tech AAC design. The tasks were: (1) ask for an out-of-season item that would not be easily found (a pumpkin), and (2) ask whether a particular product (a muffin) contained an allergen (nuts). These tasks were chosen because of their everyday nature and because they would be difficult to accomplish through other compensatory strategies like pointing and gesturing. The ‘groceries’ category contained 5 prompts: 3 (‘pumpkin’, ‘muffin’, and ‘nuts’) to support the tasks, and 2 (‘croissant’, and ‘squash’) as distractors.

Before leaving the lab setting for the market, the researcher explained the goal of each market task by using pictures but without verbally naming the items (pumpkin, muffin, nuts). For example, for the second task participants were instructed to clarify whether ‘this bakery item contains this common allergen.’ Participants were given a chance to ask questions in the lab and again before entering the market.

Semi-structured interview. Finally, upon return to the lab, the researcher asked open- and close-ended questions on the experience of using GLAAC.

3.3.2.3 Data Collection and Analysis

All interaction with the device was automatically logged. The autobiographical task and semi-structured interview were video recorded, while the market trip was only audio recorded due to IRB concern that video was invasive of bystanders’ privacy. Clerks were told about the study in advance, but they were not given detail about the tasks or goals. To supplement the market audio data, the researcher took notes *in situ* and filled out a more thorough observation sheet immediately following the study session. This sheet included topics like whether the participant said the target vocabulary word or whether the device created noticeable disruption during conversation with the clerk.

Semi-structured interviews were transcribed and coded for themes of interest [7], while allowing for new, inductive codes tied closely to the data to emerge. We developed our themes from 22 codes, such as ‘line of vision’, ‘timing of support’, and ‘learning curve’. Speaking turn was used as the basic unit of analysis for coding. However, because supported conversation requires the interviewer to act as a resource for the person with aphasia, a “turn” could cover more than one speaker or even the same speaker multiple times [3]. In cases requiring gestures for interpretation, the video data was also referenced. Finally, to validate our approach, a person independent of the research team used the code set to independently characterize participant-initiated topics and to jointly code a transcript with a member of the research team to verify whether consensus held. The two coders disagreed in 65 of 1034 cases, conflicts were resolved through discussion, and when interviewed on issues of bias, completeness, and characterization of participants’ responses, the independent coder thought the codes were being applied fairly.

3.3.3 Findings

We begin with an overview of the autobiographical and market task results, focusing on the log data use and Likert scale feedback, before covering the themes that arose in the end-of-session interview portion of the study.

Participant numbers for repeat participants are the same as in the interview study.

3.3.3.1 Overall Task Success

***Autobiographical task*.** Overall, participants responded positively to using GLAAC to answer the researcher's questions about their personal interests (7 positive, 4 mixed, 2 neutral, 1 negative). Negative responses were largely directed at the physical form factor, with 9 participants suggesting modifications (*e.g.*, adding physical buttons, improving gesture detection, and moving to the left the touchpad/display). Four participants criticized the limited vocabulary, wanting it customized to their needs or interests. For example, S2 highlighted how our design does not capture his main need for help linking vocabulary: *"…'how', 'is', 'its', 'have', […] a lot of times [my conversation partner] can't help me [with those]."* A summary of log data from interactions with the device is shown in Table 2.[2]

***Market tasks*.** Accessing the word prompts appeared to help participants correctly say the target vocabulary while at the market. Based on observational data, 7 participants used the prompts and said the target vocabulary for both the pumpkin and muffin tasks, while 3 more did so for at least one of the tasks (another participant was successful but did not need the prompts at all). The participant who had scored the lowest on the functional language profile of the CADL (S14) was not successful. However, 5 of 7 participants who scored in the middle of the range were successful with at

[2] Log data is unavailable for S1 due to an application malfunction.

least both tasks—a promising finding particularly given the complexity of using a new device in a busy environment.

Participants rated their use of the prototype at the market highly. The overall average rating of the experience was 7.5 on a 9-point scale, where 9 is positive (*SD* = 1.3, median = 7.5). Participants also felt that they were able to concentrate on conversing with the clerk while using the prototype (*M* = 7.6/9, *SD* = 1.5, median = 8.5), and that the device generally supported rather than disrupted their conversation with the clerk (*M* = 7.1/9, *SD* = 1.4, median = 7.5).

The log data, shown in Table 2, suggests that differences between the lab and market settings impacted use of the device. On average, participants viewed more prompts at the market, spent less time on relevant vocabulary, and interacted with the device both more often and for longer than they did during the autobiographical tasks. This trend is not surprising given the additional distractions in the market setting. Aside from one participant who did not use GLAAC at all during the tasks,[3] all participants viewed the prompt 'muffin' at least once while 11 viewed 'pumpkin' and 9 viewed 'nuts'. On average, each participant activated the 'pumpkin' audio 3.5 times (*SD* = 4.7), but use quickly dropped off for the second task at least partly because the audio was difficult to hear in the noisy environment. Audio use also varied by participant, with 5 participants using it over 6 times, and 4 not using it at all.

[3] This participant was able to complete the tasks without support, as indicated in their feedback and by the researcher's observations.

Despite these successes, some issues arose. Six participants encountered a problem in at least one of their conversations. S7, S9, S12, and S14 tried using the device during conversation but had to walk away before reattempting. The time it took for them to find the needed word caused either the clerk to excuse themselves and promise to return, or the participant to volunteer to take a moment and return. S6, S7, S9, and S10 got stuck with the device interaction at least once, for example, tapping repeatedly when tapping was not applicable or interacting at length with unrelated vocabulary. Of these 6 participants, 3 had problems saying the target vocabulary in both tasks. The others persevered and successfully completed at least one of the tasks.

	Lab		**Market**	
	M	*SD*	*M*	*SD*
Number of prompts used	20.9	12.3	36.7	21.3
Time spent on irrelevant vocabulary (%)	32.3	17.0	69.2	20.0
Number of touch events	26.9	17.5	42.5	26.8
Elapsed time of interaction bursts (s)	1.4	0.2	2.0	0.9
Number of times the most relevant word category was closed	0.7	1.2	3.1	2.2

Table 2. Interactions with GLAAC in the autobiographical (lab) and market tasks.

3.3.3.2 Semi-Structured Interview

Our interview results illustrate how GLAAC was perceived as offering support for maintaining conversational focus, reducing reliance on others to support conversation, managing perceptions, and handling stressful conversations. Important overall feedback was that, though the market was described as a place where it is typically difficult to converse, almost all participants (N = 10) thought that GLAAC had a strong role in such environments. For example, while S3 acknowledged that it was easier to use GLAAC one-on-one in the lab, he stressed it had a larger role in busy, public places like the market.

“Busy place, and friends or enemies, then [GLAAC has] really [a] much livelier [role].”

***Glanceable display*.** Nine participants discussed how the glanceable nature of the display allowed them to maintain visual awareness of their conversation partner. S5, for example, said: *“[My focus was] right on the money…he was standing right there and the…I can see him…and I can see the pumpkin”.* One person, S8, discussed being able to pay attention specifically to his partner’s nonverbal communication: *“Oh, yeah, I could read her.”*

Some scenarios of use for GLAAC envisioned by our participants touched on the ability to immediately access support for time-sensitive exchanges. For example, S8 described how he wanted to be able to be part of a roaring stadium of fans and yell at a soccer player right when they made the wrong play: *“Yeah, ‘You’re doing the wrong f[*%#]in’ thing!’… And they would get it.”* S1 similarly expressed the desire to present his personality, by aspiring to be seen as courteous to hostesses. He felt the prototype could support these quick exchanges.

The quick access to support was also seen as helping the wearer reorient himself/herself mid-conversation. S11 described becoming anxious while talking to the clerk, but glancing at the display got him back on track: *“And the glasses, and then…I could do it. And then, other one, muffin, good.”* Frequently, participants realized they did not have the word they wanted midway through speaking. S8 said:

> *"Oh yeah. I can see it really, it really come to life. I didn't have it, I can, I…right. And I can't even remember now, the prompts, but…yeah, it came to life."*

This quote describes how GLAAC helped with inserting the needed word into speech mid-conversation. Overall, 11 participants described a halt mid-speech, and 9 described seeing the support vocabulary mid-conversation.

***Issues with multi-tasking*.** While the display was regarded positively overall, interacting with it was still seen as demanding by some participants. For the autobiographical tasks, 2 participants described feeling time pressure to respond while trying to read the displayed information: *"Five things, six things [on the display] and I thought, so there was no time for me to see them,"* (S8).

The wrist-based navigation was seen as particularly problematic, with 10 participants commenting that it detracted from speaking. For example, S13 felt as if the wrist navigation added a second task in addition to talking:

> *"Well this…[she mimics the swipe gesture on her wrist]. It's very hard to concentrate. Two things. This conversation, two different things of happening." (S13)*

After finishing the market tasks another participant, S6, explained: *"I like talking to people face-to-face… [but] the eye, the arm, and talking, [are] too much [at once]."*

***Availability of support*.** The market task prompted participants to reflect on how their existing support strategies sometimes fail in similar environments. Similar drawbacks arose as in the interview study. S2 again stressed that the wearable display would be useful because it was always easily available and did not require *"fumbling around."* He mentioned the typical experience of needing to ask for help at the grocery store and having to find a paper and pen.

Four participants currently use social support strategies in these kinds of contexts, but desired more independence. S8's wife goes grocery shopping with him and provides vocabulary support, which S8 combines with gestures, but still he does not speak with the clerk in the way he experienced using our prototype. When leaving the market S8 remarked:

> *"I would never thought to do that myself...I wouldn't. [...] No, I would go with my wife. She would help me and I would have to point." (S8)*

Vocabulary prompts could replace strategies that rely on the availability of a partner to fill mid-conversation gaps. S6 uses a similar approach when at the library: he gets the librarian to list off titles until he signals that she has guessed the correct one. He would prefer to use GLAAC to initiate his own request, *"I would. Nobody [would have to] ask me."* He emphasized that their conversation would be more efficient by eliminating the guesswork: *"Oh, I know what you want,"* enabling them to proceed directly to the desired book.

***Privacy*.** While not a common theme, we were interested in comments about discreet use and privacy. S8 stressed the importance of audio for allowing him to feel in control during a conversation: "*if we had so we can hear at the same time… then it would be easier because we can… [take] control of the situation."* S5 also mentioned privacy, in describing wanting to store contact information and vocabulary, but not wanting anyone but her family to have access to this information. Finally, while our study design did not allow us to directly examine third party perceptions of GLAAC use, one anecdote suggests use was relatively inconspicuous: the researcher incorrectly recorded S4 used GLAAC for the word “nuts” during the market task, yet afterward, S4 clarified that he had been able to say “nuts” but “muffin” was hard. The personal display had concealed the exact words used for support.

3.3.3.3 Summary

The *in situ* study reinforced our findings from the interview study, with observations and feedback from use in the lab and the market highlighting similar themes, including a better ability to maintain focus on the conversation, reduce reliance on the availability of external tools or people, and minimize the visibility of the support by others. Nonetheless, multitasking between accessing the support and engaging in conversation was challenging for our participants and further work is needed to improve input and navigation.

3.4 Discussion

Symbol-based dictionaries could help persons with aphasia find the words they need, but are often seen a last resort because they tend to replace rather than augment the user’s natural speech [8]. Our findings, though exploratory, suggest that head-worn support may mitigate this issue. Participants commented on form-factor related aspects such as being able to keep their conversation partner within their line of sight and how the privacy of the audio and visual prompts could support them in speaking for themselves. It may even be possible to provide fully discreet assistance in the future—

during the market task, even we had difficulty ascertaining when participants were viewing prompts. Despite this promise, our work is only a first step and raises many challenges and questions for future research.

3.4.1 Reflections on Design

***Cognitive demand*.** Manipulating a wearable device may ultimately be less demanding than using a mobile phone for the same support, least of all because it does not need to be retrieved from a pocket or bag. Many participants in the *in situ* study, however, found the multitasking demanding and some even needed to step back and re-orient themselves in the middle of an exchange with a clerk. A lack of familiarity with the device most likely contributed to this cognitive demand, since participants had only briefly used it before being placed in a complex, real-world setting. Even with more practice, further refinement of the input mechanism and vocabulary structure will likely be needed.

***Toward an accessible head-worn display*.** The right-sided touchpad of Google Glass was problematic at times due to right-side motor deficits that are common with aphasia. While we circumvented the motor issues by using a Bluetooth-paired phone as a touchpad, it presented its own problems and a more refined solution is needed for long-term practical use. A wristband with physical buttons to support eyes-free input may be effective. We had also expected the visual display location on the right side to be problematic due to right-side visual deficits, but received only a few complaints during the interview study. Still, other display placements should be explored.

***Scalability*.** A notable limitation of our proof-of-concept prototype was that it included only 15 words in three categories. Because our goal is to provide communication support *during an exchange* it is critical that needed vocabulary be available quickly. Any complete system will need to assess how many prompts are appropriate to include for this use scenario, and how these prompts should be created and managed. The most effective solution will likely combine manual customization and automatic context-based adaptation (*e.g.* [24]) to present a short list of words. The user could, for example, enter their grocery list before leaving home; similar desktop-phone hybrids have previously been explored for aphasia [5].

Target users. Aphasia varies substantially in manifestation and severity. We targeted individuals with relatively intact auditory comprehension and mild speech deficits as we see this profile as likeliest to benefit from head-worn vocabulary support. We also targeted interactions with unfamiliar partners as the primary context for use as this is an underserved area. With intimate partners, in contrast, low- and no-tech AAC solutions (such as pointing, gesturing, and drawing) are often sufficient due to the partner's familiarity with the person and with aphasia.

3.4.2 Reflections on Study Method

Although both studies were exploratory, they played different but complementary roles. The interview study relied heavily on verbal description to collect feedback on early design ideas, which can be challenging for individuals with aphasia [17,24,34]. As such, we recruited participants with high verbal abilities and drew heavily on recommendations for incorporating individuals with aphasia into the design process [24]. The *in situ* study instead focused on use of a working prototype. This approach greatly broadened the range of feedback we received and allowed us to recruit participants with lower verbal abilities, supplementing their feedback with observation. Success in lab or therapy settings has not always translated to less controlled environments [49]. The fact that so many participants completed the market task successfully despite the prototype's rough edges—receiving little training, an unfamiliar conversation partner (clerk), and a noisy setting (market)—is very promising. Due to the complementary successes of both studies, we recommend that this combined method be used more broadly in working with participants with aphasia.

3.4.3 Limitations

Further studies are needed to confirm our findings and to assess detailed impacts on conversation dynamics and long-term use. A main limitation is that we did not employ a control condition in the *in situ* study due to the early nature of the work. As a result, some positive feedback was not clearly attributable to the head-worn form factor; we have tried when possible to note these cases. A comparison may also have mitigated novelty effects, a common concern in design research. A second limitation is that 8/14 participants from the *in situ* study also participated in the interview study. This consistency enabled us to iterate on a well-defined set of user needs, but there is the danger that participants felt more invested in the design than they would have otherwise. Finally, data analysis in both studies relied on participant transcripts, which were sometimes difficult to interpret due to communication difficulties. To lessen this concern we referred to video and observational notes to aid analysis, but the sometimes-cryptic nature of the transcripts made it difficult to perform reliability analysis on the coding.

3.5 Conclusion

We conducted two design investigations of head-worn conversational support for individuals with aphasia. The interview study elicited feedback based on a design probe of two narrative storyboards, and the findings further motivated the potential benefits of a head-worn approach over traditional AAC tools. The *in situ* study evaluated a proof-of-concept prototype in lab and field settings, showing that despite limitations, most participants were able to complete constrained conversation tasks successfully and reacted positively to the experience. While these exploratory studies are only a first step, the findings should motivate further investigation of head-worn conversational support—support that could ultimately improve the wearer’s ability to maintain their sense of identity and use their own natural voice for a range of daily interactions.

Chapter 4: Comparison of a Head-Worn Display to a Mobile Phone

How AAC devices fit within conversation is central to whether or not they prove assistive to a person with aphasia. The set of formative studies described in the previous chapter elicited positive feedback on using HWDs during conversation with unfamiliar partners. Responses suggested that HWDs may better facilitate focus on the conversation partner, support self-expression, and be more readily available than current communication strategies. While a few participants suggested that HWDs may provide better support than a mobile phone, no control condition was employed. Thus, the positive responses from these formative studies are not clearly attributable to the HWD, and the proposed benefit over mobile phones is not supported by actual use.

We address these limitations in this study by employing a mobile phone as a control condition. To do so, we compare a HWD to a mobile phone according to support for focus, self-expression, and availability to assess the impact of the physical design on conversation dynamics and whether the HWD is more supportive.

4.1 Method

4.1.1 Participants

We recruited 17 persons with aphasia (3 females, 14 males) through local aphasia community centers, support groups, speech-language pathologists, listservs, and rehabilitation service providers. They ranged in age from 31 to 78 (M = 56.6; SD = 14.5). We compensated participants $25 for the one and a half hour study. Based on discussion with caregivers and participants' self-report, we screened participants for right-sided visual cuts (loss of vision in the right-sided field of view) and moderate to severe apraxia (problems with the articulation of sounds dependent on the motor system).

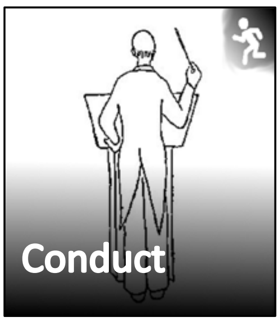

Figure 4 – The figure depicts an example of a vocabulary prompt from the software

4.1.2 Apparatus

To compare the HWD to a mobile phone, we wrote a custom Android application consisting of vocabulary prompts for Google Glass and a Samsung Galaxy Nexus 4G LTE. Within the application, we organized vocabulary into a two-level hierarchy consisting of two categories: actions and objects. We depicted categories using black and white icons from the Noun Project [64], and each vocabulary prompt using a black and white line drawing and associated text from the University of California of San Diego International Picture Naming Project [53]. We associated each vocabulary prompt with its category using the appropriate icon in the upper right corner.

Further iterating on the input mechanism for the HWD, we created a small remote to control the HWD. In the formative studies of Chapter 3, participants criticized Google Glass's right-sided touchpad because of the need to reach across their body with the left hand due to right-sided hemipareisis. Further, participants found the quick mock-up of a gestural control in the *in situ* study—using a touchscreen phone worn on the wrist—distracted from conversation and recommended a button-based control. Following up, we created a remote control by printing the casing with a Makerbot Replicator Desktop 3D printer and using off-the-shelf buttons for the internal components. We powered the remote via an Arduino Uno, and linked it with the HWD via Bluetooth through a Galaxy Nexus mobile phone using the Amarino library [25]. To minimize reading demands and reduce attention diversion to the remote, we labelled the buttons with icons indicating their functions and raised the icons 2mm from the surface of 12mm square buttons to support tactile identification.

For the smartphone, we created an identical button layout on Android to control for navigational variation using square buttons 14mm in size also labelled with icons. Button functions include forward, back, cancel, select, and audio. *Forward* and *Back* buttons (depicted in right or left-facing triangles) cycled through the available vocabulary at each level of the hierarchy. *Select*

Figure 5 – The remote control used in the study task to control the HWD

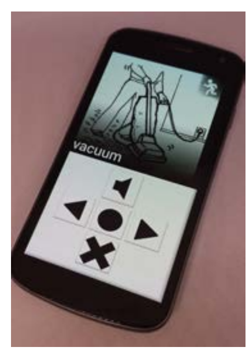

Figure 6 – The smartphone used for the study task

and *Cancel* buttons (depicted with a circle and an X respectively) switched the available level of the hierarchy. The *Audio* button (depicted with an icon of a speaker) activated the text-to-speech reading aloud the vocabulary word shown on the screen.

4.1.3 Procedure

We designed the study to last 90 minutes. Participants initially completed a baseline naming task to gauge the severity of their naming deficits. During this task, participants described each of 40 pictures with one word. Next, we introduced participants to the card game, Go Fish, and played a full game to become familiar with the rules. We then asked participants to complete two task blocks—each task block consisting of a training task and a test task—one for each device. After each task block, we asked participants to rate the supportiveness of the used device on a 7-point scale (1 = poor, 7 = excellent) in facilitating focus on the conversation, focus on the game partner, finding vocabulary quickly, and overall experience using each device. After each choice, participants were asked to explain their rating. After using both devices and rating their supportiveness, participants were asked a series of comparative questions on overall preference, focus, ease of using vocabulary, and ability to control the conversation. Finally, participants were asked a series of open ended questions about the devices' design, public perception of using the device to support communication, and the contribution of design features to shaping other's perceptions of them.

Each experimental condition lasted 25 minutes and consisted in a device familiarization task (10 min.) and a test task (15 min.). We designed the familiarization task to allow the participant to learn about the device and software. To do so, the researcher first introduced a software function—navigating forward, back, activating text-to-speech, selecting a category and changing categories—and then the participant was instructed to use that function. After all functions were introduced, the participant was given time to explore the software for themselves. Finally, the researcher presented 20 pictures in series and asked the participant to locate that picture in the software and say the associated word when they had found it. Participants were cut off at the 10 minute mark whether or not they had proceeded through all 20 pictures.

Go Fish Rules Added to Those of Hoyle Gaming
1) Use the exact target vocabulary for a correct match,
2) Make requests verbally,
3) Restrict attempts at the word to 3 times on the participant's own before the researcher prompted the participant to try and use the device to support the request,
4) Restrict attempts at the word to 3 times using the device, and
5) End the turn after the six attempts.

Table 3 – Depicts a list of rules added to the traditional rules of Go Fish for the test task.

A language game was used for the test task to strike a balance between constraining task dialogue in a targeted manner and simulating natural conversation so as to generalize to everyday life [46]. Following Shah and Virion [52,56], the American card game, Go Fish, structured requests and responses between the researcher and the study participant to simulate conversation while using each device. The object of Go Fish is to match as many pairs of pictures as possible. During the game, each player was dealt five cards and then took turns requesting a card from the other person based on the cards in their own hand. If the opponent had a matching card, the player was able to go again. Otherwise, the player drew a card from the deck. The game proceeded until all cards in the deck had been matched, or 15 minutes had passed, whichever happened sooner. Figure 5 provides a more detailed list of the rules governing the Go Fish Game used in the study task. Participants sat across from the researcher, and stands were constructed to support holding the cards and prevent the partner from seeing a player's hand.

Figure 7 – Go Fish cards from the training task (test cards were not labeled with the vocabulary)

Each Go Fish card consisted of a black and white line drawing matching those in the software. A single deck contained 20 cards consisting in 10 action cards and 10 object cards. Four decks were created for the 2 familiarization tasks and 2 test tasks, and they were counterbalanced across the phone and HWD tasks. Decks were created according to frequency of use in the English language from the picture vocabulary in the picture norming study of Szekely, et. al. [53]. Each word came from each tenth percentile (1^{st}-10^{th} percentile, 11^{th}-20^{th}, etc.) for each category—actions or objects—so that each deck represented the frequency spread in the available public vocabulary.[4] No word was selected twice. The decks were then inspected for number of syllables, and cards were swapped across

[4] Some vocabulary was restricted due to copyright, and our study does not include these.

decks or replaced so that each deck contained the same number of one, two, and three syllable words at an equivalent frequency percentile. Game cards were created with the target word printed on them for the Go Fish training task—unlike the test task cards—so that participants could concentrate on learning the rules of the game rather than naming.

We instructed participants to use the device to support communication as needed for a round of Go Fish, and simply handed over the device (the phone or remote control) without providing any instructions on how to hold it. Participants could adjust the device to suit their preferred hand and reach. Thus, the device was not anchored at a predetermined location to control for distance of retrieval as doing so would be manipulating the availability of the device. However, we did help participants in putting on the HWD and adjusting the focus of the display to ensure all four corners of the screen could be viewed.

4.1.4 Design

The study used a single-factor within-subjects design. The independent variable was the device: HWD or smartphone. Dependent variables included subjective and objective measures of focus on the conversation, conversation quality, availability of the vocabulary, and device preference.

4.1.5 Hypotheses

At a high level, this study examines whether a HWD better supports conversation for individuals with aphasia compared to a mobile phone. A better quality conversation will be marked by a person with aphasia being more engaged in the conversation topic, more aware of their conversation partner, demonstrating greater comprehension, using language to precisely express themselves, and managing their turn in the conversation in a timely manner. High quality conversations are nuanced, but both subjective and objective measures should show evidence of quality. We hypothesize that 3 subjective and 3 objective measures of how the HWD features in conversation will show that a HWD better supports conversation.

4.1.5.1 Hypotheses for Subjective Measures

Overall Experience Using the Device

H1: The experience using the HWD will be rated higher than the phone. The physical design of the HWD will support conversation behaviors such as eye contact and greater focus on conversational content.

Focus on the Conversation Topic (the Game)

H2: The HWD will be rated higher than the phone for supporting focus on the conversation. The near eye-display of the HWD will require minimum departure to use and facilitate resumption of the game and related conversation.

Focus on the Conversation Partner

H3: The HWD will be rated higher than the phone for supporting focus on the conversation partner. The ability to see the conversation partner's face while wearing a HWD will enable the wearer to focus on their conversation partner.

4.1.5.2 Hypotheses for Objective Measures

Proportion of Correct Cards Passed

H4: The proportion of correct cards passed and received will be higher with HWD than the phone. The HWD will minimize diversion of the wearer's visual attention away from the game, and so will facilitate focus and performance on achieving the game's objective of matching cards.

Use of Supporting Vocabulary

H5: The HWD will better facilitate use of supporting vocabulary in conversation compared to the phone. The ability to see a conversation partner while seeing supportive vocabulary will minimize need to keep the supporting vocabulary in short-term memory and so will be easier to insert in conversation.

Time per Turn

H6: Less time per turn will be taken with the HWD than the phone. With the HWD, the wearer is able to glance at the near-eye display and use tactile cues on the remote control to access the target vocabulary. Thus, the required movements to access the device will take less time than turning away and identifying the button edges on the phone.

4.1.6 Measures

Ratings on a 7-point Likert scale (1-poor, 7-excellent) were used to collect subjective measures to verify the overall study hypotheses and gauge the extent to which each device supported focus on the conversation and conversation partner. Three objective measures were used to evaluate the participant's speaking, comprehension, and timely response. 1) The proportion of correct card passes (passed card corresponding to the requested card) to the total matches made during the game was used as a proxy to capture responsiveness to the conversation partner. To measure this, we calculated the proportion of cards passed during the game to the total number of possible matches (20 per deck). 2) The number of vocabulary used from each device to make card requests during the game was used as evidence of the device's support in speaking. To calculate this, we determined the time frame of each turn at play and compared what a person said during that time to the vocabulary being viewed on the device. 3) The average time taken for each turn at play was measured to determine how available each device was in retrieving needed vocabulary during the participant's turn. Time per turn was calculated by averaging across all the time frames a participant took a turn at play during the test task. Log data was collected to help with calculating the number of words used from the device, and also to catch navigational challenges and determine whether audio prompts were used. The entire study was video recorded.

4.1.7 Analysis

Video from the test tasks was divided into segments of turns at play using CHAT/CLAN [65], and the conversations during the test tasks were transcribed. Descriptive statistics were used to summarize the data.

We discovered a software bug in the phone application that significantly impacted our data. Participants used the HWD for five minutes longer than the phone during the test task (15 min. vs. 10 min.). This difference between the amount of time the devices were used impacts the ability to compare a person's use of one device to their use of the other. Longer exposure to the HWD could have aided a learning effect. Through having more time to become familiar with the task and software design, those persons assigned first to the HWD condition may have been better at using the second device than participants assigned to use the phone first. The difference could also bias participants to the HWD condition as they would have been more familiar with it, and so could prefer it when asked the comparative questions, or even have more developed responses for the open-ended questions.

As a result, we *only* analyzed data from each participant's initial condition, discarding that from the second condition. Additionally, for objective measures, we only analyzed the first 10 minutes of gameplay for that initial condition. While these changes allow us to more fairly compare the two conditions, the study design effectively becomes between-subjects and statistical power is reduced. Further, we discarded four participants due to language ability (explained next), which left 6 participants who used the HWD first and 7 participants who used the phone first. Participants C2 and C9 were excluded from the analyses because the log data revealed that they did not use the device during any of their turns. Thus, their subjective ratings and performance data did not reflect actual use of the device during the test task.

Participants C5 and C10 were excluded from the analyses because their baseline evaluation performance revealed that they were at the lowest end of the spectrum of communicative ability for the recruited participants. Further, performance data suggested that their degree and type of language deficits present confounding factors for the study's measures and distort evidence on whether or not the device impacts conversation dynamics. For example, C5 and C10 were able to name 1 and 0 items respectively, of the baseline items compared to M=16.9 and SD=8.6 for all 17 participants.

4.2 Results

Given the issues discussed in the Analysis section, we elected to treat the data as preliminary and provide only descriptive statistics. Nevertheless, these results should be useful for informing refined hypotheses to be tested in future studies.

4.2.1 Subjective Measures

4.2.1.1 Overall Experience Using the Device

We hypothesized that participant would rate the overall experience of using the HWD in conversation higher than that of using the phone. On average, participants rated the HWD a 6.0 (*SD*=0.8, range 5-7) on a 7-point Likert scale (1-poor, 7-excellent), and the phone, a 4.4 (*SD*=1.9, range 1-7). The more positive rating for the HWD suggests that H1 may be supported in a larger study.

4.3.1.2 Focus on the Conversation

We hypothesized that participants would rate the HWD higher than the phone for supporting focus on the conversation. When asked, participants using the HWD rated the device a mean of 5.7 (*SD*=0.9, range 4-7), and those using the phone a mean of 5 (*SD*=2, range 1-7). The range and similarity of ratings across the two conditions suggests that the devices may not have had much of an effect on perceived ability to focus on the conversation.

4.2.1.3 Focus on the Conversation Partner

We hypothesized that participants would rate the HWD higher than the phone for supporting focus on the conversation partner. When asked, participants rated both devices similarly: they rated the HWD a mean of 5.3 (*SD*=1.2, range of 3-7), and the phone a 5.6 (*SD*=1.4, range 4-7). Again, this similarity across the two conditions suggests that H3 may not be a strong hypothesis.

4.2.2 Objective Measures

4.2.2.1 Proportion of Matches

We hypothesized that the proportion of correct cards passed and received would be higher in the HWD condition than the mobile phone. On average, in the HWD condition participants passed and received 0.3 (*SD*=0.2, range: 0-0.5) of the available matches, and in the phone condition, *M*=0.2 (*SD*=0.1, range: 0.1-0.3). The higher proportion of matches in the HWD condition compared to the phone condition suggests that a larger study may find support for *H4*.

4.2.2.2 Number of Vocabulary Words Used from the Device

We hypothesized that the HWD would better support use of the device's vocabulary during conversation. On average a participant in the HWD condition used 8.2 words to support their request during the task (*SD*=2.9, range: 4-13) and in the phone condition, *M*=4.7, (*SD*=2.7, range: 2-9). The higher average number of words used from the HWD compared to the phone condition suggest support for *H5*.

4.2.2.3 Mean Time Per Turn

We hypothesized that it would take less time to use the HWD during a turn at play that it would to use the phone. On average, a participant in the HWD condition took 28.3s per turn (*SD*=9.5s, range: 16.3-40.1s), and for the phone condition *M*=34.1s (*SD*=8.9s, range: 19.6-45.2s). The lower average time per turn suggests support for *H6*.

Participant Data for Device Use During the Go Fish Game														
ID	Device	Background				Items Correctly Named in Baseline (Total #)	Mean Time Per Turn (s)	Go Fish Performance		Target Vocabulary		Subjective Ratings		
		Age (Yrs.)	Gender	Hand	Smartphone Owner			Passes	Passes/Total	Insertions	Total Turns	Focus on Conver-sation	Focus on Partner	Overall Experience
C4	HWD	72	M	L	N	6	39.7	0	0	6	8	6	6	7
C6	HWD	50	M	L	Y	13	22.9	3	0.15	9	14	6	5	5
C12	HWD	42	M	L	Y	26	19	10	0.5	13	22	6	5	6
C13	HWD	31	M	L	Y	28	16.3	10	0.5	10	14	7	7	6
C14	HWD	38	F	R	Y	26	31.9	4	0.2	7	13	4	3	7
C15	HWD	55	M	L	Y	12	40.1	8	0.4	4	11	5	6	5
M		48				18.5	28.3	5.8	0.5	8.2	13.7	5.7	5.3	6.0
SD		13.3				8.5	9.5	3.8	0.2	2.9	4.3	0.9	1.2	0.8
Max		72				28	40.1	10	0.8	13	22	7	7	7
Min		31				6	16.3	0	0	4	8	4	3	5
C3	Phone	64	M	L	N	23	39.5	4	0.2	7	12	7	7	6
C7	Phone	57	F	L	N	21	45.1	2	0.1	2	9	4	4	4
C8	Phone	54	M	R	N	17	22	6	0.3	9	18	6	7	6
C11	Phone	61	M	L	N	16	37.9	2	0.1	2	11	1	4	1
C16	Phone	74	M	L	N	8	34	3	0.2	7	12	6	6	3
C17	Phone	55	F	L	N	23	40.7	4	0.2	4	10	4	4	4
C18	Phone	61	M	L	Y	20	19.6	6	0.3	2	13	7	7	7
M		60.9				18.3	34.1	3.9	0.2	4.7	12.1	5.0	5.6	4.4
SD		6.3				4.9	9.0	1.6	0.1	2.7	2.7	2.0	1.4	1.9
Max		74				23	45.1	6	0.3	9	18	7	7	7
Min		54				8	19.6	2	0.1	2	9	1	4	1

Table 4 – Provides detailed data from study 3's tasks for each participant

In summary, we compared the ability of a HWD and a smartphone to support individuals with aphasia in requesting cards during Go Fish. Subjective ratings of the HWD and the phone suggested that the overall experience of using the HWD in conversation was better than using the phone. However, ratings on support for focus on the conversation or on the conversation partner suggested that there was no difference between the two devices. Though, it is notable that the ratings for the HWD never appeared below the middle range for support of focus and so indicate that participants did not think it strongly detracted from their focus. Overall, the HWD better supported participants in the study task than the phone according to performance measures: participants had a higher proportion of matched cards, a higher number of vocabulary used from the device, and a faster mean time per turn. These preliminary findings suggest that the HWD may better support conversation for individuals with aphasia, though its support for focus may not be higher than the phone from the perspective of the wearer.

4.3 Discussion

4.3.1 Study Results and Related Research

Constructing the study task as a game supported comparison of speaking turns and time frames of device interaction while still enabling participants to proceed through the trials advancing the larger objective of winning the game. This allowed the study to model how assistive devices may be employed during the dynamic shifts of naturally occurring conversations and to evaluate device use when a participant was challenged by the required vocabulary. This shifted focus from the device as a support tool for speaking, to its fit within other aspects of conversation such as listening, clarifying, and comprehending. Surprisingly, the video-taped sessions revealed that participants used the device as a reflexive tool to ensure they were naming a picture correctly, to coach their own pronunciation, and to resolve ambiguity on whether they understood what the researcher was requesting. Findings from video-analysis are beyond the scope of this study, but the higher proportion of cards passed, greater number of vocabulary used from the device, and the quicker time per turn provide some evidence for the HWD having a greater role than the phone within this conversational ecology.

4.3.2 Problems and Limitations

As discussed in the Analysis section, switching to a between-subjects analysis reduced statistical power compared to the original within-subjects design and caused the study to lose a substantial amount of data. Another limitation this study did not address is that the speech of some participants was characterized by switches from the target syllable (phonemic paraphasia): some participants stumbled on the first phoneme of a target word, but were able to correctly say the rest of the word correctly. In these cases, where further information was needed to resolve ambiguity (*e.g.* did the person say “present”—one of the target words—or “pheasant”, a semantic error for the target word “bird”?), the researcher encouraged participants to use the text-to-speech feature of the device to help with pronunciation. For a fraction of these participants the audio feature supported them in saying the target syllable. For those who it did not, the audio prompt clarified what the participant's target vocabulary word was in the phone condition because the text-to-speech was available to the conversation partner to hear. For participants using the audio prompt in the HWD condition, the text-to-speech was not publicly audible. Thus, there were some cases where the log data indicated that the participant was viewing the target vocabulary word, but they were unable to express the word to the conversation partner. So there may have been cases in the HWD condition when a matching card should have been exchanged, but was not because of phonemic paraphasia. The proportion of matches was higher in the HWD condition nevertheless. This raises the question of whether the HWD is an appropriate design for individuals whose speech is characterized by phonemic paraphasia. The audio prompt and display may serve to isolate these persons' communication from their conversation partners more that support them.

4.4 Conclusion

Findings from the controlled study should be treated as preliminary verification of the themes raised by the formative studies of the second chapter. Overall participants found the experience of using a HWD in conversation supportive, and rated it higher than a smartphone. Although participants in the two formative studies found the input mechanism distracting and the near-eye display supportive, the HWD was not greatly rated lower or higher than the smartphone for supporting focus on the conversation task or partner in the controlled study. Participants were however, able to advance farther through the conversation task, use more of the device’s vocabulary in their requests, and execute their turn more quickly using the HWD than they were using the phone. As findings from this study suggest preliminary support for the HWD, a larger follow-up study with greater statistical power would be needed to determine whether the HWD is more supportive of conversation than a mobile phone.

Chapter 5: Discussion and Future Work

Persons with aphasia often experience the need for communication support mid-conversation. External assistive devices divert attention away from the conversation and partner to access support. This thesis examined how a HWD could support maintenance of conversational dynamics when individuals with aphasia employ assistive technology mid-conversation. A set of formative studies was conducted to gauge the feasibility of persons with aphasia using a head-worn display (HWD) to support communication. Following up on the positive findings, we conducted a controlled comparison of a HWD approach to a smartphone-based approach to determine whether the HWD better facilitated focus on the conversation and partner, joint progress through the conversation, use of assistive vocabulary, and quicker execution of the conversation turn. These studies together showed that a HWD provides a reasonable design alternative for the physical form of AAC devices for individuals with aphasia. Preliminary findings suggest that a HWD may provide benefits over an external device like a smartphone.

5.1 Summary of Findings and Contributions

The formative studies elicited ideas and feedback from 14 individuals with aphasia on using a HWD to support communication as well as examined how a HWD vocabulary prompting application would be used by those participants in a field and lab setting. Participant responses suggested that the ability to retrieve vocabulary from a glanceable display contributed to keeping their attention on their conversation partner and helped them stay engaged in the conversation task while seeking out support. Nine participants described problems with the right-sided touchpad of the HWD and being distracted by wrist-mounted, gesture navigation. Overall, participants responded positively to using head-worn vocabulary in busy environments, and thought the HWD would help them respond quickly. Combined, the formative studies contributed 1) a proof-of-concept prototype for presenting vocabulary prompts on a HWD, 2) a qualitative evaluation of the prototype in lab and field settings, and 3) identification of potential contexts when HWD vocabulary prompts may be most beneficial.

We then conducted a controlled study with 17 persons with aphasia comparing use of a HWD in conversation to use of a mobile phone in terms of overall experience, support for focus, and the ability to progress through conversation accurately and quickly. As a result of the formative study findings, we created a button-based remote control for the HWD to address criticisms of the input mechanism, and we used a card game to simulate the busy environment participants thought the HWD would support. Unfortunately, due to necessary post-hoc changes to the statistical analysis (using a between-subjects instead of within-subjects design), the statistical power of the experiment was lower than had been expected. Findings from this study should thus be considered to be preliminary, but can be used to guide future work. While there was no evidence that the HWD improves the user's ability to focus on the conversation compared to the smartphone, participant feedback suggests that the overall experience of using the HWD in conversation may be better. In terms of performance measures, the HWD may support quicker execution of conversation turn, support greater progress through the conversation, and better enable use of specific vocabulary in conversation. These trends can guide hypotheses to be tested in future studies.

5.2 Reflections

One of this thesis's central goals was to describe the perceived attentional demands of using a vocabulary prompting application on a HWD and to determine whether the HWD required less attention to use mid-conversation than a smartphone. The formative studies' findings suggested that the HWD's near-eye display contributed to paying attention to the conversation partner and staying engaged in the topic. The controlled study's findings suggested that participants were more easily able to use assistive vocabulary (indicative of engagement in the topic), yet there was not a perceivable difference between the HWD and the phone's support of focus. The lab setting and the card task of the controlled study may not have provided a busy enough context to elicit any perceived differences between the phone and HWD in supporting focus, or the "livelier role" identified by participants who used the HWD in the market (See S3's comments and the difference in log data between the lab and market reported in Chapter 3). This suggests that there may be a trade-off in the suitability of the device's form factor depending on the conversation task. A wearable form such as a HWD may be more appropriate for asking a grocery clerk which aisle an item is on (see S2's comments about misplacing his phone in Chapter 3) or asking a librarian for a book (see S6 in Chapter 3), yet a phone or tablet may be more appropriate for monologue as envisioned for storytelling over photo albums (see [14,67]).

Additionally, this thesis sought to address concerns on how to effectively augment a person with aphasia's conversation, and whether HWDs are better designed for this task than smartphones. Combined, the studies presented here identified conversational contexts where a wearable device with private perceptual access to assistive content may be more supportive than an external device. Participants from the formative studies highlighted contexts where they desired greater influence over groups and the need to quickly engage group dynamics. These contexts included asking questions during a board meeting, yelling at a soccer team, and clarifying requirements to board a bus. The participants thought the private display and speaker of the HWD would better support them in speaking for themselves and contributing to these contexts. To address the concerns identified by participants, the controlled study simulated dynamic exchange by structuring the study task so that the participant needed to balance requests and using the device vocabulary with playing the game of Go Fish. Preliminary findings showed that participants in the HWD condition were able to execute their turn quicker and use assistive vocabulary on a greater number of occasions. Thus, the HWD may better support balancing use of the assistive device with the conversation: enabling a person with aphasia to quickly insert specific vocabulary in their speech during rapidly changing contexts.

As a third goal, this thesis examined the availability of communication support mid-conversation and whether or not the HWD was more readily available than a smartphone. Participants from the first set of formative studies highlighted availability problems in their current support strategies: they often misplace support tools such as phones and pens, or they use elaborate social networks that depended on particular conversation partners (see the 4 participants' comments in the interview study in Chapter 3). Participants thought a wearable design would be less likely to be misplaced. Preliminary findings from the controlled study showed that participants took less time per turn and were able to proceed further through the conversation in the HWD condition. A HWD may support persons with aphasia in quickly retrieving assistive vocabulary independently.

5.3 Limitations

A primary methodological issue encountered in this thesis was the need to adapt the analysis approach posthoc for the comparative study, discarding half of the data and using a between-subjects analysis instead of a within-subjects analysis. The decreased statistical power limits the ability to accept or reject the hypotheses outlined in Chapter 4 comparing HWD and smartphone vocabulary support. Instead, the findings from this study should be used to refine hypotheses for a future study with greater statistical power.

Another limitation of this thesis is that some participants took part in more than one of the studies. During the formative studies, all 8 participants in the interview study also participated in the *in situ* study. Of those 8, 3 participated in the third, controlled study with 2 assigned to the HWD condition and one assigned to the phone condition. Of the other 6/14 who took part in the second, *in situ* study, 3 participated in the controlled study. Two were assigned to the phone condition and the other, C5, was excluded from the analysis. This consistency enabled us to iterate on a well-defined set of user needs. However, there is the danger that participants felt more invested in the design than they would have otherwise, and their prior experience with the HWD may have unduly impacted the results.

Finally, the preliminary findings from the controlled study may not directly address themes raised by the formative studies. The controlled study was conducted in a quiet lab setting, but as noted above, this setting differs in important ways from the busy environment highlighted by participants in the *in situ* study. A mobile environment could place demands on the input mechanism that were likely un-elicited by the controlled study. For example, often individuals with aphasia walk with a cane to help with right-sided hemipareisis and they may find the remote control encumbering by occupying their only free hand. This fact may also point to weaknesses in use of a mobile phone for augmented communication in a mobile environment. Further, the semi-transparent display of Google Glass may prove more difficult to see against busy backgrounds as found in prior work with individuals without aphasia [28], or the ability to hear the text to speech as found in the formative studies and documented elsewhere [20]. Further work may be needed to validate whether the preliminary findings extend to a mobile setting like a market.

5.4 Future Work

The findings from the controlled study are preliminary, and future work will need to verify them. A follow-up study should use the within-subjects design as originally envisioned to control for the high variability in participants' communicative ability. Such a study could also include some disruption during the task to reflect a more realistic use scenario in the confines of a controlled environment. This may include evaluating the devices in a dual task situation that simulates conversational engagement, but has also been verified with individuals who do not have aphasia such as that found in Murray, et al.'s work [39].

Preliminary findings from the controlled study may indicate that the HWD did not pose any significant challenges to balancing conversation with use of the device. Future work would need to examine whether the negligible difference between the HWD and the phone for supporting focus provides evidence that the HWD has introduced new distractions comparable to those reported for external device use in conversation [20] or whether the device has effectively become invisible (a mark of successful design [12]). The negligible difference in the ratings of the smartphone could indicate that the

HWD would be capable of the ubiquitous use the smartphone enjoys today. The findings here are inconclusive. Being focused may not be perceptible the way being disrupted is, and the quiet lab setting may have supported focus regardless of the device used. Future work would need to closely examine perceivable differences between the HWD and the smartphone that the conversation task could elicit such as the degree to which participants feel in control of the conversation or their ability to shape its direction.

5.5 Conclusion

In order to employ assistive technology in conversation, individuals with aphasia must balance retrieval of the desired vocabulary with engaging in the conversation. This thesis presented three studies investigating the potential of HWD to support this task. The first two formative studies showed that individuals with aphasia were positive about the idea of using HWD to support conversation and could successfully use the device in conversation with unfamiliar partners. Further, the near-eye display and private perception of the audio prompt were seen by participants to support staying engaged in the conversation and assuming a stronger communication role in busy environments. The controlled study provided preliminary evidence that the HWD may support individuals in conversation better than a phone. Further work is needed to verify these findings, but they point to the potential of HWDs to provide AAC support for persons with aphasia.

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