Signing-on-the-Fly: Technology Preferences to Reduce Communication Gap between Hearing Parents and Deaf Children

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ABSTRACT

Over 90 percent of Deaf and Hard of Hearing (DHH) children in the United States are born to hearing parents, who have little to no command of American Sign Language (ASL). This leaves the majority of DHH children at risk of language deprivation in early childhood. This study investigates the design space of Augmented Reality (AR) and wearable technologies in supporting hearing parents to offer sign language environments for young DHH children. We conducted an online survey with 65 participants (hearing/DHH parents and teachers of DHH children aged 6 months to 5 years) to gather preferences and interests of technologies that support hearing parents to deliver ASL on-the-fly, and stay attentive to the DHH child's visual attention during joint toy play. We found that Near-Object Projection is most preferred for real-time ASL delivery, and haptic feedback is most preferred for raising the parent's awareness of a child's attention. Results also show a strong interest in using the proposed technologies in interacting with and maintaining joint attention with DHH children on a daily basis. We discuss key design recommendations that inform the design of future technologies that support just-in-time and contextual-aware communication in ASL, with minimal obtrusion to face-to-face interaction.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; **Accessibility**.

KEYWORDS

Computer-Mediated Communication, Augmented Reality, Wearable Technologies, American Sign Language, Joint Attention, Parent-Child Interaction

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1 INTRODUCTION

Imagine a scenario where Jacob, a 9 months old boy and his mom are playing with Jacob's favorite toy bus. The mom naturally starts to sing a familiar nursery rhyme: "the wheels on the bus go round and round", pushes the toy bus along the highchair tray between them, and brings up simple words like "a yellow bus", "look, the wheels are spinning". Everyday interactions between parents and children offer immersive language environments for early language and socio-cognitive development. Jacob, who has been profoundly deaf since birth, may have limited access to such linguistic environment if his family does not know a natural signed language.

Over 90 percent of Deaf and Hard-of-Hearing (DHH) children in the United States are born to hearing parents [24], who often have little to no command of a natural signed language such as American Sign Language (ASL). The resulting lack of immersive language environments poses a chronic and cumulative risk of

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language deprivation to the majority of DHH children in early childhood [10, 11]. This may lead to irreversible delay in development of neuro-linguistic plasticity in the brain [4], and may permanently hamper mastery of any language, signed or spoken [13]. In contrast, DHH children with early sign language exposure from their DHH caregivers tend to achieve appropriate language developmental milestones [5]. Recent pediatrics research emphasizes the importance of parent and family support of sign language to avoid linguistic deprivation for DHH children [12]. Evidence in ASL acquisition suggests that children are able to overcome inconsistencies in non-fluent sign language from late-learner parents [33]. In addition, research shows that young children tend to learn language better from real-life experiences (e.g., joint play with parents) than screen-based learning due to the "video deficit effect" [22].

There are two main challenges that hearing parents and caregivers face. First, the deep learning curve of sign language prevents hearing parents from acquiring ASL in a timely manner to keep up with the critical language development period of DHH children. The already demanding tasks of parenting create further barriers that dissuade hearing parents from learning ASL [18]. Second, even with some competency in ASL, compared to DHH parents, hearing parents tend to pay less attention to where their child is looking, and sign in line with their visual attention to ensure ASL uptake by the child [34]. "Joint attention" pertains to social partners simultaneously attending to the same object or event [37]. The inefficient joint attention strategy is due to a fundamental mismatch in communication modalities between hearing parents (auditory-oriented) with their DHH children (visual-oriented) [6, 26]. As a result, hearing parents have to learn to modify their long-nurtured habits of communication in spoken language to make moment-by-moment alignment of visual attention with DHH children.

Existing technologies often focus on acquiring ASL knowledge (e.g., vocabulary, acute signing) [1, 32, 38], leaving real-time communication in ASL between hearing and DHH individuals largely unexplored. Recent research shows the advancement of Augmented Reality (AR) (e.g., AR head-mounted display, ambient projection), wearable, and mobile technologies (e.g., Smart Glasses, Smart Watch, smartphone/tablet, earphone) in assisting in-situ language access [15, 17, 28], face-to-face communication [16, 29, 36, 39], and social awareness [2, 7, 19–21, 27] for people with diverse needs.

The goal of this study is to explore the design space of AR and wearable technologies to address the communication gap between hearing parents and DHH children during a common daily activity, namely joint toy play. We focus on supporting hearing parents in two scenarios: (1) ***delivering ASL on-the-fly***, and (2) ***staying attentive to a child's visual attention***, while ***maintaining fluent face-to-face interaction***. For each scenario, we proposed four different proof-of-concept prototypes with different form factors (Near-Object Projection, Smart Glasses, Smart Watch, Tablet, Bluetooth earphone) and modalities (visual, haptic, audio). We conducted an online survey study that adopts the design probe method [8]. Participants viewed the video demonstration of the proposed prototypes, and provided feedback of key design aspects (e.g., glanceability, ASL/attention indicator clarity, ease to carry out ASL, unobtrusive toy play, visibility of adult's face, raising awareness of visual attention), interests of usage (daily interaction, ASL learning, joint attention on a daily basis, different types of attention indicator), and strengths and areas for improvement.

Results of an online survey study with 65 participants who are parents (hearing or DHH) or teachers of DHH children aged 6 months to 5 years, show that ***Near-Object Projection*** was most preferred for real-time ASL delivery, and ***haptic feedback*** was most preferred for raising attention awareness. Results also reveal a strong interest in using the proposed prototypes in interacting with and maintaining joint attention with DHH children on a daily basis. We discussed detailed design recommendations for future technologies, which suggest a holistic design approach that integrates visual-haptic feedback in supporting efficient communication in ASL in a just-in-time and contextual-aware manner with minimal obtrusion to face-to-face interaction.

2 RELATED WORK

2.1 Technologies for ASL learning

There is a critical need to support hearing parents to reduce communication gaps with their DHH children during everyday interaction [38]. Much research investigates technologies to support ASL learning (e.g., mobile phone, game and avatar) [1, 3, 31, 32, 38], but the critical role of ***parent involvement*** for language development is largely missing. The advancement of AR and wearable technologies offers unique affordances to facilitate timely access of context-appropriate language. For example, AR head-mounted display (HMD) has been used to support convenient language access by visualizing semantic content directly with physical objects in the environment [15, 17]. This situated visualization may be efficient for language acquisition based on the dual-coding theory of learning [23]. Wearable technologies such as Smart Glasses have been adopted in supporting ASL learning for elementary students, by visualizing ASL videos associated with QR codes [28]. One major limitation of HMD and Smart Glasses is that they may interfere with perception of facial expression and gaze, which are integral components for ASL and social interaction. A recent study proposed the design concept of an AR lamp that projects ASL videos next to physical toys in a tabletop setting during parent-child interaction [36]. This research sheds light on an alternative approach to support communication in ASL with minimal obtrusion to face-to-face interaction.

2.2 Communication strategies to maintain joint attention with DHH children

Joint attention is critical for early language development [30, 37]. The mismatch of communication modalities between hearing (auditory-oriented) and DHH (visual-oriented) individuals often leads to a failure to achieve joint attention between hearing parents and DHH children [35]. Insufficient joint attention may profoundly impede ***language uptake*** for DHH children, who can best perceive ASL signs when it's in line with their visual attention [6]. Compared to hearing parents, DHH parents are often more aware of the DHH children's visual attention, and consistently modify their ASL input such as gesturing with objects and displacing signs in the child's visual field to maximize the uptake of sign language [34]. In this study, we focus on investigating the design space of AR and wearable technologies to raise adult's awareness of DHH children's visual attention. We recruited DHH parents in our survey due to their extended knowledge of joint attention strategies when communicating with DHH individuals.

2.3 Assistive technologies for communication and social awareness

There is a long-standing research effort towards technologies that assist communication and social awareness for people with special needs. For example, interactive tabletop has been demonstrated as an efficient display in supporting medical conversations between a DHH patient and hearing doctor [29]. Audio indicator has been used to provide real-time reminders of communication strategies via a Bluetooth earphone to help parents better interact with children with language delay [16]. Smart Glasses can provide vocabulary support for people with language disorders while avoiding attention diversion from the conversation partner [39], and also transcribe speech and sound to text for DHH individuals during everyday activities [27]. Smart Glasses and wrist-worn devices have been proposed to foster speaker awareness of DHH individuals [19, 21]. Research shows that form factors (e.g., handheld, head-worn, wrist worn) and feedback modalities (e.g., visual, haptic) can influence users' preferences [2, 7, 19–21].

3 RESEARCH METHOD

To obtain feedback of communication technologies that are novel to most participants, this study adopted the design probe approach, which is an established HCI research method that utilizes probes such as visual sketches of prototypes or mockup prototypes on real devices to obtain formative inquiries of technology design around life situations [8, 9]. It has been particularly used for eliciting empathetic engagement with DHH participants [7, 19].

To accommodate COVID-related regulations, and to gather reliable feedback from a diverse population, we conducted an online survey that contains design probes in the form of video demonstrations that depict a hearing individual interacting with a DHH individual in ASL using different mockup prototypes on real devices. This video demonstration approach allows easy deployment in an online survey to gather large scale feedback, and also adopts the advantages of device-based mockups in soliciting in-depth feedback compared to static visual sketches.

3.1 Proof-of-concept prototypes as design probe

The prototypes were designed to fulfill two scenarios: (1) supporting a hearing parent to ***deliver ASL on-the-fly***, and (2) helping the hearing parent to ***stay attentive to their child's visual attention***. Both scenarios aim to offer communicative suggestions (in the form of ASL signs or attention indicators) in a (1) ***just-in-time*** and (2) ***context-appropriate*** manner, with (3) ***minimal obtrusion*** to face-to-face joint play. We chose parent-child joint toy play in an across table setting, which is a well-established daily interactive routine, and is widely investigated in developmental research of young children (e.g., [40]). For each scenario, we proposed four proof-of-concept prototypes, with a combination of form factors (Near-Object Projection, Smart Glasses, Smart Watch, Tablet, Bluetooth earphone) and feedback modalities (visual, haptic, audio). The design decisions are informed by existing research in supporting real-time language access and communicative feedback, as reviewed in the related work section above.

3.1.1 Prototypes to support ASL delivery. The hearing parent and the DHH child sit across a small table from each other, with a toy bus and miniature figure on the table. The prototypes enable the hearing parent to deliver an ASL sign by following three steps: (1) recognize the parent's singing of a nursery rhyme, "Wheels on the bus", while moving the bus toy along the table; (2) display a relevant ASL sign video "bus"; (3) the parent carries out the ASL sign in front of the child. Since ASL is a visual language, only visual modality is considered for all four prototypes as described below.

Near-Object Projection projects the ASL video of "bus" next to the bus toy in real-time using a portable projector (Miroir M45) attached to the edge of the table, making the ASL video closely follow the bus as it moves (Fig.1 (a)). This may lead to three advantages: (1) ***reduce attention diversion***: avoid switching attention between the toy and the ASL video, which helps to maintain fluency of joint toy play; (2) ***avoid occlusion of face***: keep facial expression and eye gaze intact, which is an integral part of ASL and social interaction; (3) ***ASL learning***: coupling physical objects with corresponding semantic contents may enhance language acquisition based on the dual-coding theory of learning [23].

Smart Glasses displays the ASL video near the top right corner of the user's eye using Google Glasses (Fig.1 (b)). This may lead to three advantages: (1) ***reduce attention diversion*** during face-to-face communication [39]; (2) ***high portability***: allows convenient language access in a diverse range of daily activities for people with special needs in communication [7, 27]; (3) ***minimize occlusion of face*** as compared to head-mounted AR displays such as Hololens.

Smart Watch shows the ASL video on an Apple Watch (Fig.1 (c)). This design is inspired by the promising effect of wrist-worn device in fostering sound and conversation awareness [7, 21]. Smart Watch is ***highly portable***, which makes it a convenient device to facilitate ASL access in a wide range of daily activities. Since users need to lift the arm to view the watch display, it may interfere with manual signing, and involves looking away from the joint play.

Tablet shows the ASL video on the screen of a Samsung Galaxy tablet with a fixed location on the table (Fig.1 (d)). It is chosen because tablets are available to many families. Similar to Smart Watch, the individual's attention may be split between the tablet, objects on the table and the DHH child.

3.1.2 Prototypes to support awareness of DHH child's attention. The prototypes raise the hearing parent's awareness of the child's attention switching by following three steps: (1) notice that the child attention switches from the bus toy to the miniature figure, while the parent is still signing "bus"; (2) display an indicator to notify the parent of the child's attention switching; (3) the parent realizes the attention switching, and says "daddy is on the bus" while carrying out the ASL sign of "daddy" correspondingly. To accommodate the high frequency of child gaze shifting [14], the prototype is expected to only remind the parents when the child shifts attention and has his/her gaze fixed on another toy. To complete the survey within a feasible time frame, we focused on a selective combination of form factors and feedback modalities. We designed visual indicators on the Near-Object Projection and Smart Glasses, haptic indicator on

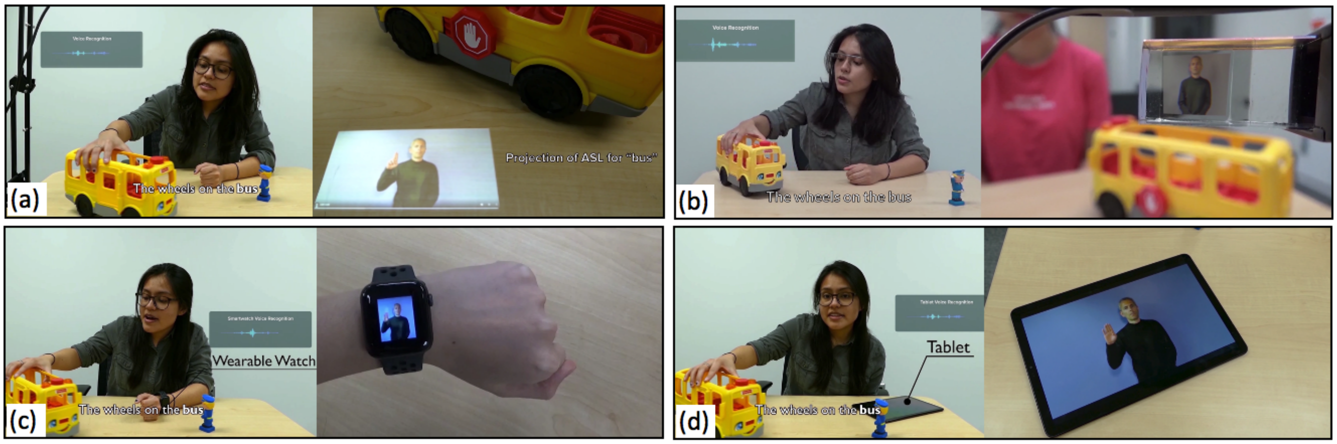

Figure 1: Illustrations of four prototypes for ASL delivery: (a) Near-Object Projection; (b) Smart Glasses; (c) Smart Watch; (d) Tablet. For each prototype, the left image depicts the setting of the display (from the child's view), and the right image depicts the ASL sign on the display (from the parent's view).

the Smart Watch and audio indicator on the Bluetooth earphone. We also adopted three types of indicator with a gradual increase of detail of the attention switching, including the ***moment*** when the child's attention shifts, the ***direction***, and ***specific object or area*** to which the child shifts attention.

Near-Object Projection projects a red semi-circle indicator around the figure toy that the child switched attention to (Fig.2 (a)). In addition to the advantages identified in the ASL delivery scenario, the real-time registration also allows highlighting the specific object/area to which the child shifted attention.

Smart Glasses displays a red arrow icon near the top right corner of the user's eye to indicate the direction to where the child's attention has switched (Fig.2 (b)). The design decision of the arrow icon is recommended as a clear indicator that points to the direction of the source that requires attention [19].

Haptic Indicator makes a quick vibration through the Smart Watch to notify the moment of the child's attention switching (Fig.2 (c)). Previous research shows a strong preference of haptic feedback in DHH population to raise awareness of ambient events (e.g., sound) [7].

Audio Indicator makes a short chime through a Bluetooth earphone to notify of the child's attention switching (Fig.2 (d)). Previous research shows that audio feedback is well received by hearing parents in recommending real-time strategies to interact with children with communication difficulties [16]. Hearing parents suggested the use of a short chime to avoid the feeling of being nagged with repeated spoken reminders.

3.2 Survey design

The survey was hosted through the Qualtrics online survey platform, and is expected to take about 30 minutes. The survey is composed of screening, information sheet, background information and the main survey. First, the participants will answer three screening questions about age, ability to understand the survey protocol, and demographic background (i.e., parent or teacher of DHH children). Participants who meet all the screening criteria will be able to view and download an information sheet that provides a detailed description of the survey study (a waiver of documented consent was approved by the Institutional Review Board). If the participants agree to participate, they will continue to the next sections.

Background information collects participants' demographic information, including age, gender, hearing identity, hearing loss level, ASL fluency, device familiarity, and e-mail address. For parent participants, we also collect demographic information about their DHH children, including age, gender, age of diagnosis, hearing loss level, and early education or school program they attend. For educators, we also collect their teaching background, including the program and activities that they teach, and years of experience.

Main survey contains two sections. The first section gathers feedback about the prototypes for the delivery of ASL on-the-fly scenario, and the second section for the raising awareness of child's attention scenario. Both sections contain the same three-part structure:

(1) **Problem description**: The participant watches a short video (30 seconds) that depicts the problem that a hearing adult may face during joint toy play with the DHH child. In the ASL delivery section, the video depicts the problem that a hearing adult experiences when trying to carry out ASL by searching ASL videos on the mobile phone. In the raising awareness section, the video depicts how a hearing adult's lack of awareness of the DHH child's attention may affect the child's ASL uptake.

(2) **Feedback of individual prototypes**: the participant provides feedback right after watching the video demonstration of each prototype in a random order. The feedback includes three parts: (a) **key design aspects**: the ASL delivery section contains glanceability ("is easy to glance at") [7], ASL clarity ("provide clear ASL signs"), ease to carry out ASL ("enables to carry out the ASL sign easily"), unobtrusive toy play ("allows fluent toy play with the DHH child") [39], and visibility of adult's face ("allows the child to see the adult's face clearly"); the raising awareness section contains indicator clarity ("provides a clear attention shifting indicator"),

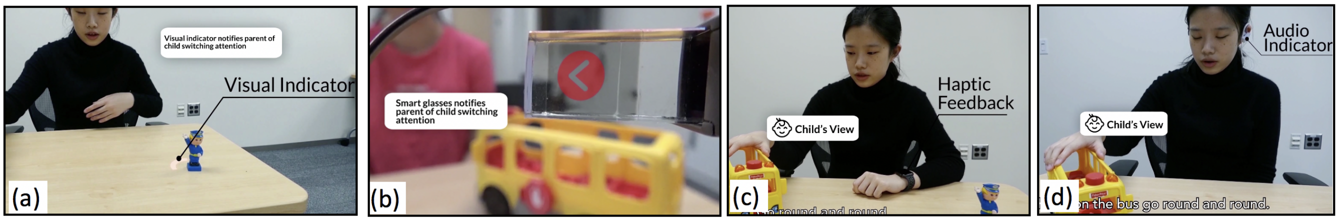

Figure 2: Illustrations of prototypes to raise awareness of DHH child's attention: (a) Near-Object Projection; (b) Smart Glasses; (c) Haptic Indicator (Smart Watch); (d) Audio Indicator (Earphone).

raise awareness of visual attention ("is useful to raise awareness of the child's attention"), and unobtrusive toy play ("allows fluent toy play with the DHH child"); (b) **interest of usage**: the ASL delivery section contains the questions of to what extent a hearing adult will be interested in using the prototype to "interact with DHH child on a daily basis", and "learn ASL"; the raising awareness section contains the question of to what extent a hearing adult will be interested in using the prototype to "maintain joint attention with DHH child on a daily basis"; (c) **suggested improvements** for each prototype.

(3) **Preference of four prototypes**: after providing feedback for each of the four prototypes, the participant is asked to (a) select the prototype they prefer most overall, as well as in each design aspect mentioned in the previous part; (b) explain reasons for the preference, and any concerns or questions; and (c) (raising awareness section only) rate to what extent a hearing adult would be interested in the three types of attention indicator ("the ***moment*** when the child's attention shifting occurs", "the ***direction*** of the child's attention shifting", "the ***specific object/area*** that the child shifts attention to").

3.3 Participants

The study collected feedback from three groups of adult participants: hearing parents, DHH parents, and teachers and educators for DHH children aged 6 months to 5 years old. The participants were 18 years or older, with normal vision to read from a computer screen, and basic understanding of written English. The first 100 participants received a $20 gift card, and the remaining participants entered a $50 raffle. We distributed recruiting flyers through e-mails and social media posts with the assistance of principals, program coordinators, and teachers at schools for the Deaf, community centers and childcare facilities, ASL programs and other DHH and ASL related education organizations, as well as personal connections of the research team.

There were 20 hearing parents, 43 DHH parents and 2 teachers. Their ages ranged from 25 to 45 *M*=31.5, *SD*=4.3), with 65% participants identifying as female (N=42), 32% male (N=21), and 3% other or preferred not to say (N=2). For hearing identity, 31% reported as hearing (N=20), 63% DHH (N=41), and 6% Deaf (N=4). For hearing loss level, 8% reported as none (N=5), 35% mild (N=23), 40% moderate (N=26), 14% moderately severe (N=9), and 3% profound (N=2). For ASL fluency, 2% reported as novice (N=1), 35% survival (N=23), 37% intermediate (N=24), 23% advanced (N=15), and 3% native (N=2). For device familiarity, 95% reported familiarity with smartphones (N=62), 62% Smart Watch (N=40), 17% projector (e.g., conference/portable projector) (N=11), and 25% head-mounted display (e.g., Google Glasses, Oculus Rift) (N=16).

The parent participants reported their DHH children's ages ranging from 25 to 60 months (*M*=44.3, *SD*=10.6). The average diagnosis age for DHH children was 25.6 months (*SD*=12.9). For hearing loss level, 56% reported as moderate (N=35), 35% moderately severe (N=22), 5% severe (N=3), and 5% profound (N=3). 51% of children attended early education programs for DHH children (N=32), 3% mainstream schools (N=2), 8% speech and language training (N=5), and 38% hadn't participated in any early education program (N=24). For teacher participants, one has taught in an early childhood program in a mainstream school for 5 years, and the other has taught a parent infant program in a school for the Deaf for 10 years.

3.4 Data collection and analysis

We conducted a validation process to remove any responses that have duplicated IP addresses, too short completion time (shorter than 15 minutes), reported child beyond the target age range, and inconsistent demographic information (e.g., identified as Deaf but reported spoken language as primary communication with child). The survey collected in total 65 valid responses. We decided to use descriptive statistics (e.g., mean, standard deviation, and percentage) to describe the technology preferences and interest of use collected in the survey due to the unbalanced sample size among the three participant groups. In addition, we investigated the varied feedback between hearing and DHH parents due to their different communication modalities (auditory vs. visual/haptic) and level of knowledge in ASL and communication strategies for joint attention with DHH individuals.

4 RESULTS

4.1 Delivery ASL on-the-fly

4.1.1 Feedback of individual prototype for ASL delivery. Participants provided feedback of each prototype right after watching its video demonstration (Fig.3). All four prototypes received similar positive feedback for key design aspects, with average percentage of positive responses (agree and strongly agree) of ***Near-Object Projection*** at 59.0% (*SD*=8.3), ***Smart Glasses*** at 55.7%, (*SD*=10.1), ***Smart Watch*** at 58.0% (*SD*=8.2), and ***Tablet*** at 59.4% (*SD*=8.9). Glanceability received less positive feedback for all four prototypes (*M*=17.0%, *SD*=1.4 for disagree and strongly disagree), and Smart Watch received a relatively low rating on "Ease to carry out ASL" (26% disagree and strongly disagree).

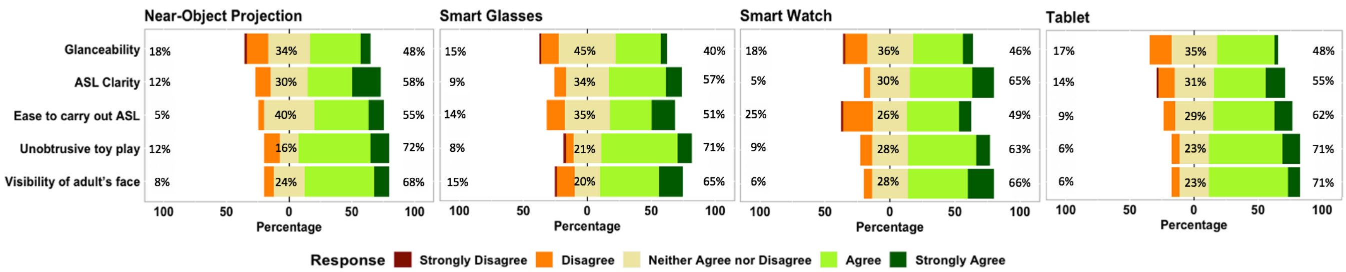

Figure 3: Participants' feedback of each prototype for ASL delivery. The percentage corresponds to disagree and strongly disagree (left), neither agree nor disagree (middle), and agree and strongly agree (right).

4.1.2 Preference of four prototypes for ASL delivery. The participants were asked to select the prototype they prefer most overall and in each design aspect after viewing all video demonstrations. As shown in Fig.4 (left), overall, ***Near-Object Projection*** is the most preferred prototype (N=20), followed by Tablet (N=18), Smart Glasses (N=14) and Smart Watch (N=13). ***Near-Object Projection*** is most preferred for "glanceability" (N=25), "unobtrusive toy play" (N=20) (tied with Smart Glasses) and "visibility of adult's face" (N=24). ***Smart Glasses*** is first for "ease to carry out ASL" (N=25) and "unobtrusive toy play" (N=20) (tied with Near-Object Projection). ***Smart Watch*** is first for "ASL clarity" (N=21). ***Tablet*** is least preferred in all aspects except "ease to carry out ASL" (second least preferred).

Given the low number of teacher participants (N=2), we focus on comparing responses between hearing and DHH parents in this and following sections. Fig.4 (right) shows that hearing parents reported most overall preference for ***Near-Object Projection*** (30%), and least for ***Tablet*** (20%), while DHH parents preferred most ***Near-Object Projection*** (30%) and ***Tablet*** (30%), and least the ***Smart Watch*** (19%). Both hearing and DHH parents preferred ***Smart Glasses*** for "ease to carry out ASL" ((55%) and (33%) respectively). Hearing parents and DHH parents' responses alternated between Smart Glasses and Near-Object Projection as preferred prototype on "glanceability", "unobtrusive toy play", and "visibility of adult's face". Hearing parents considered Tablet as least preferred consistently across design aspects. It also received relatively low ratings by DHH parents, except for "ease to carry out ASL".

4.1.3 Interest of use for ASL delivery solutions. Participants were asked to share their opinion on to what extent a hearing parent will be interested in using the proposed prototypes to interact with DHH children on a daily basis (Fig.5 (left)) and learn ASL (Fig.5 (right)).

Interest of usage for interacting with DHH child: participants held a positive view of all four prototypes. ***Near-Object Projection*** received the strongest interest (63% very interested and extremely interested), compared to Smart Glasses (45%), Smartwatch (45%), and Tablet (40%). When divided between hearing and DHH parent, we found that 80% of hearing parents reported a high interest in using ***Near-Object Projection***. On average, hearing parents reported a slightly higher expectation than DHH parents (*M*=52.5%, *SD*=20.2 vs *M*=46.8%, *SD*=8.1) that hearing parents would be interested in using the proposed prototypes for interacting with DHH children on a daily basis.

Interest of usage for ASL learning: participants held a moderately positive view of all four prototypes that a hearing adult will be interested in using them for ASL learning, with average percentage of very interested and extremely interested at 33.5% (*SD*=3.3). When divided by hearing or DHH parent, results show a higher percentage of DHH parents reported that a hearing parent will be interested in using the proposed prototypes for ASL learning (*M*=37.5%, *SD*=2.9 very interested and extremely interested), compared to hearing parents (*M*=27.5%, *SD*=11.9). There is also a much higher percentage of DHH parents who thought that a hearing adult will be extremely interested (*M*=12.0%, *SD*=4.0) compared to hearing parents (*M*=1.3%, *SD*=2.5).

4.1.4 In-depth feedback. Table 1 shows a summary of comments made by participants explaining what made them prefer a prototype, most, and their suggested improvements for each prototype.

4.2 Raise adult's awareness of DHH child's visual attention

4.2.1 Feedback of individual prototype for raising awareness. Participants provided feedback after watching the video demonstration of each prototype. As Fig.6 shows, all four prototypes received similarly positive feedback for key design aspects, with average percentage of positive responses (agree and strongly agree) of ***Near-Object Projection*** at 51.7% (*SD*=11.6), ***Smart Glasses*** at 54.7% (*SD*=8.7), ***Haptic Indicator*** at 52.7% (*SD*=11.6) and ***Audio Indicator*** at 54.3% (*SD*=7.4).

4.2.2 Preference of four prototypes for raising attention awareness. The participants were asked to select the prototype they prefer most overall and in each design aspect after viewing all video demonstrations. As shown in Fig.7 (left), overall, ***Haptic Indicator*** is most preferred (N=29), followed by Near-Object Projection (N=16), and then Audio Indicator (N=14). Smart Glasses (N=6) is least preferred. ***Haptic Indicator*** is most preferred for "indicator clarity" (N=26) and "unobtrusive toy play" (N=21). ***Near-Object Projection*** is most preferred for "useful to raise awareness of visual attention" (N=22).

When divided by demographic background, the results show that both hearing and DHH parents preferred most the ***Haptic Indicator*** (60% and 40%) and least the ***Smart Glasses*** (0% and 14%)

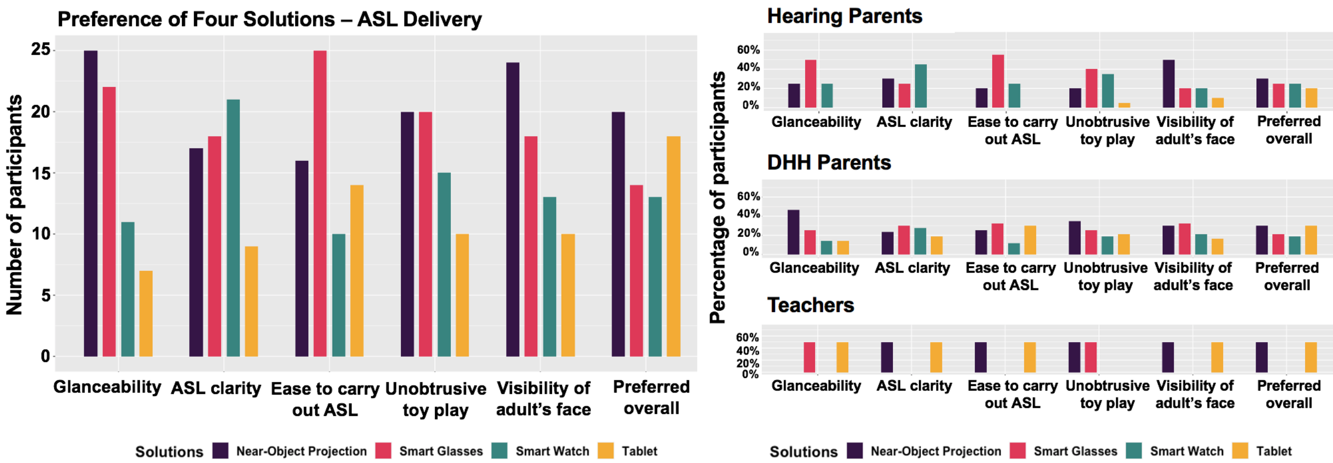

Figure 4: (Left) Number of participants who prefer each prototype for ASL delivery; (Right) Percentage of participants, divided by demographic background (hearing parent, DHH parent, teacher).

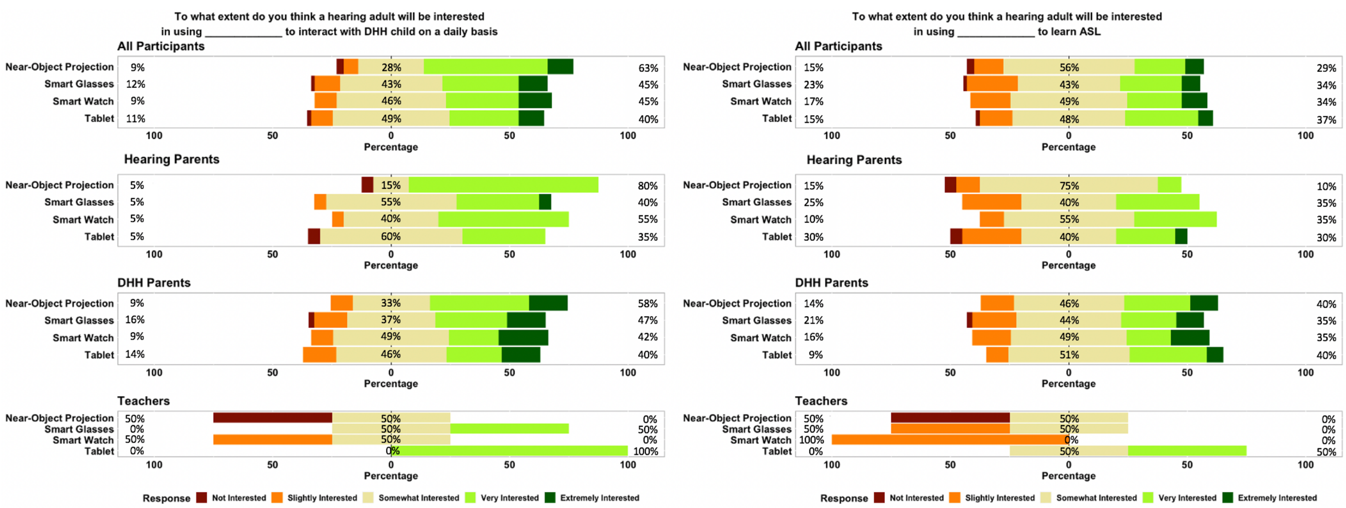

Figure 5: Participants’ feedback of how interested a hearing adult will be in using the prototype to (left) interact with DHH child on a daily basis, and (right) to learn ASL.

Table 1: Advantages and suggested improvements of prototypes for ASL delivery

Prototype	Advantages	Suggested Improvements
Near-Object Projection	Least intrusive for play, supportive, intuitive, attention-grabbing, big picture, convenient, clear	Lighting, limited to one space, arm crossing over the projector view, need to increase clarity
Smart Glasses	Easy to carry, draw attention, convenient	Not practical, not affordable, interfere with visibility of non-manual markers (e.g., facial expression)
Smart Watch	Easy to carry, easy to look at my child, convenient	Small screen to view the sign clearly, may cause errors in signing, distract from playing with child, break eye contact, not very affordable
Tablet	Practical, clear images, affordable, simple to use	May distract the child, monotonous

(Fig.7 (right)). Hearing parents preferred ***Haptic Indicator*** overall, even though they showed a consistent preference to Audio Indicator

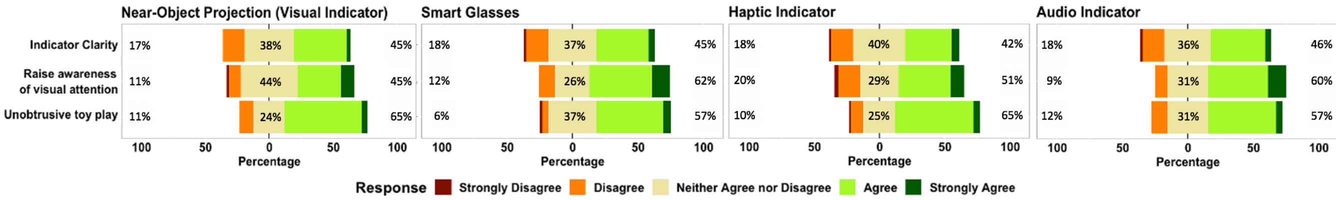

Figure 6: Participants' feedback for key design aspects for raising adult's awareness of DHH child's visual attention.

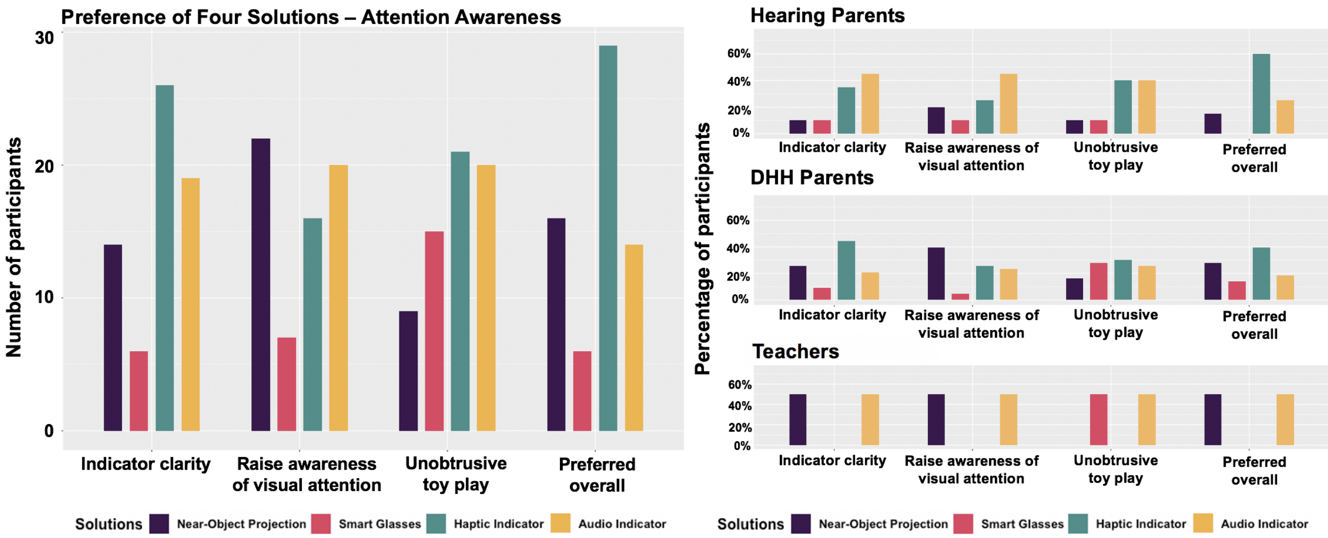

Figure 7: Number of participants who prefer each prototype for visual attention awareness; (Right) Percentage of participants, divided by demographic background (hearing parent, DHH parent, teacher).

on all three design aspects ("indicator clarity" (45%), "useful to raise awareness of visual attention" (45%), "unobtrusive toy play" (40%)). DHH parents showed a mixed preference. They preferred ***Haptic Indicator*** on "indicator clarity" (44%) and "unobtrusive toy play" (30%), and ***Near-Object Projection*** on "raise awareness of visual attention" (40%). Lastly, both hearing and DHH parents preferred ***Smart Glasses*** the least on all aspects except for "unobtrusive toy play" ((10%) and (28%) respectively).

4.2.3 Interests of use for raising attention awareness . Participants were asked to share their opinion on to what extent a hearing parent will be interested in using the proposed prototypes to maintain joint attention with DHH children on a daily basis (Fig.8 (left)), and in receiving different types of attention indicator (moment, direction, and target object/area) (Fig.8 (right)).

Interest of usage for maintaining joint attention with DHH child: Participants held a moderately positive view of all four prototypes (*M*=30.0%, *SD*=3.4, average percentage of very interested and extremely interested). When divided by hearing and DHH parent, a much higher percentage of hearing parent participants (*M*=46.3%, *SD*=4.8) than DHH parents (*M*=23.3%, *SD*=4.8) thought a hearing parent will express a strong interest.

Interest in types of attention indicator: A high percentage of participants thought that a hearing parent would be interested in knowing the ***moment*** of attention shifting (62% very interested and extremely interested), followed by the ***specific object or area*** (52%), and then the ***direction*** of the child's attention shifting (45%). Direction is also most negatively rated (23% disagree). When divided by demographic background, there is a higher percentage of DHH parents who reported strong interest in hearing parents of the three types of attention indicator: moment (77% DHH and 30% hearing parents), object or area (56% DHH and 50% hearing parents), and direction (51% DHH and 30% hearing parents).

4.2.4 In-depth feedback. Table 2 shows the summary of comments made by participants explaining what made them prefer a prototype, and suggested improvements for each prototype for raising adult's awareness of child's attention.

5 DISCUSSION

The positive feedback of the proposed prototypes reveals promising affordances of AR and wearable technologies in bridging the communication gap between hearing parents and their DHH children. This is further confirmed by the strong interest that hearing parents may express in using the proposed prototypes for interacting with and maintaining joint attention with DHH children on a daily basis. Participants preferred ***Near-Object Projection*** most for delivery ASL on-the-fly, and ***haptic feedback*** most for raising

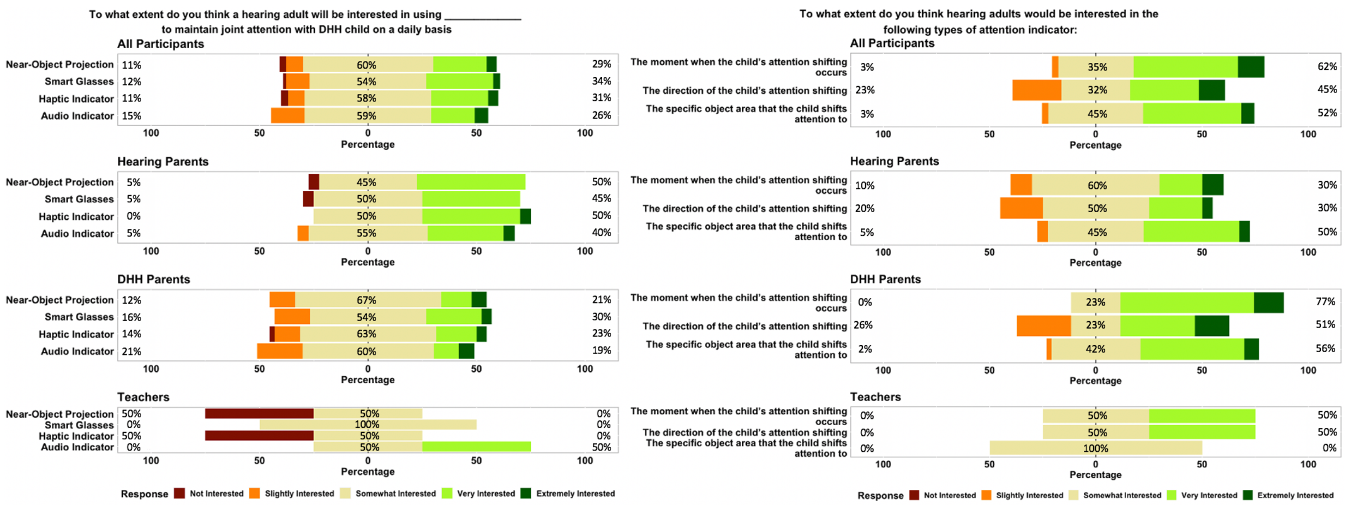

Figure 8: Participants' feedback of (left) how interested a hearing adult is in using the prototype to maintain joint attention with DHH children on a daily basis, and (right) interest in three different types of attention indicator.

Table 2: Advantages and suggested improvements of prototypes for raising awareness of child's attention

Prototype	Advantages	Suggested Improvements
Near-Object Projection	Less disruptive to play, intuitive, simpler, clear, attention-grabbing	The parent may not notice the visual cue
Smart Glasses	Good visual effect, prompt is obvious, easy to wear, simpler, attention-grabbing	Compatibility with ASL video
Haptic Indicator	Takes little time away from child, convenient, more acceptable, cost-effective	A hearing adult is so used to vibration, and may not pay much attention to it
Audio Indicator	Not interrupting play	N/A

awareness of DHH child's attention. These findings inform future investigation on integrated visual-haptic feedback to enable hearing parents to efficiently apply joint attention strategies when signing to DHH children. This corroborates with previous findings on participants' strong preference of both visual and haptic feedback to raise awareness of ambient events [7]. We summarize detailed design recommendations below.

5.1 Design recommendations for delivery of ASL on-the-fly

Near-Object Projection was demonstrated to be a promising display solution to support a hearing individual to sign ASL in a just-in-time and contextual-appropriate manner, with minimal obtrusion to face-to-face joint play. It was the most preferred prototype for ASL delivery, and participants' feedback confirmed the unique affordances of AR projection: ***reduce attention diversion*** (most preferred on "glanceability", and unobtrusive toy play"), and ***avoid occlusion of face*** (most preferred on "visibility of adult's face"). It is further confirmed as the majority of hearing parents (80%) expressed strong interest in using Near-Object Projection in interacting with their DHH children on a daily basis. Constraints of Near-Object Projection reported by the participants include lighting/clarity, fixed location, and possible occlusion with body part, which require future investigation.

Smart Glasses may be a viable display option, but are currently constrained with low accessibility. Participants' feedback confirmed its affordances on ***reducing attention diversion*** (most preferred on "unobtrusive toy play") and ***portability***. It is also most preferred for "ease to carry out ASL", and reported to be attention-grabbing. The low preference is likely due to the high cost as reported by participants. Furthermore, one participant pointed out that Smart Glasses may interfere with perception of non-manual markers of ASL (e.g., facial expression), which highlights the importance of clarity of the signer's face to ensure ASL uptake.

Smart Watch may not be a suitable display option, as it is likely to break the flow of ASL signing and face-to-face joint play. It was least preferred overall, and negatively perceived across design aspects among DHH parents. The participants expressed concerns on interference with manual signing and joint toy play, as the user has to look closer to get a clear view of ASL signs on the small screen. Affordability is another concern.

Tablet was least preferred across all design aspects, especially among hearing parents. This confirmed the advancement of AR and wearable technologies over traditional display to facilitate face-to-face communication in ASL. The relatively high overall preference of Tablet is likely because of its high accessibility, especially among DHH parent participants who value ASL in everyday communication.

5.2 Design recommendations for raising awareness of child's attention

Haptic Indicator was demonstrated the most suitable feedback modality to raise the adult's awareness of the DHH child's attention. It was most preferred by both hearing and DHH parents. Participants' feedback confirmed that haptic feedback offers ***high clarity***, enables ***unobtrusive joint play***, and is ***affordable*** for daily use.

Audio Indicator is a less favored feedback modality. Hearing parents preferred Haptic Indicator to Audio Indicator, even though the latter was most preferred in all key design aspects by hearing parents ("indicator clarity", "useful to raise awareness of visual attention", and "unobtrusive toy play"). One possible explanation is that audio feedback may interfere with the perception of other auditory information, which is the main communication modality of a hearing individual. Further investigation is yet needed.

Smart Glasses may be subject to visual conflict with ASL sign. It is least preferred by both hearing and DHH parents. One possible explanation, as reflected in the participant's comment, was the concern of conflicting access between ASL signs and attention indicators due to the small display size. It may also be impacted by the relatively low interest in the direction of the child's attention shifting, which was displayed on Smart Glasses.

Near-Object Projection may be a viable display solution, likely in combination with haptic feedback. It was the second overall preferred prototype, and was most preferred on "useful to raise awareness of visual attention". This may be due to the special affordance of AR augmentation in locating the specific object or area, which was considered an important type of attention indicator by both DHH and hearing parents. Although the large coverage area of projection may avoid visual conflict as compared with Smart Glasses, one participant expressed concern of the possibility of missing visual indicators due to its lower salience compared to haptic feedback. This suggests a combination of Near-Object Projection and haptic feedback to maximize attention grabbing, and to fulfill hearing parents' interest in both the moment and object or areas of attention switching.

5.3 Interest in technology usage

The high expectation that hearing parents would be interested in using technologies proposed in this study for real-time communication in ASL corroborates with the demanding needs to support hearing parents to reduce communication gaps with their DHH children during everyday interaction [38]. Interestingly, hearing parents showed a lower-level of interests in ASL learning using proposed technologies, which may reflect their reserved attitude of ASL learning due to its deep learning curve and demanding parenting tasks [18]. It will be worthwhile to investigate if signing ASL on-the-fly may shift hearing parents' attitude toward ASL learning over time. Meanwhile, hearing parents exhibited a surprisingly high interest in maintaining joint attention with their DHH children using proposed technologies. Nevertheless, they also exhibited a lower-level of interest than expected by DHH parents in being notified of when and where attention switching happens. This is likely to be due to the gap of knowledge in hearing parents on insufficient joint attention with DHH individuals [6, 35], which calls for future investigation to address this critical but underexplored problem space.

6 LIMITATIONS

Findings of the study are based on a small-scale survey due to the small size of the target population. There were too few teacher participants (N=2) to reveal reliable trends. There was also an imbalanced number of participants between DHH parents (N=43) and hearing parents (N=20), which may be due to the stigma among hearing parents for bilingual (sign and spoken) education for DHH children [25]. This may explain that most hearing parent participants already have existing ASL experience. Thus we suggest interpreting findings of the survey as preliminary implications that guide further investigation. In addition, since the survey method does not allow participants to experience the proposed technologies in person with children, preferences may vary when users interact with working prototypes on real devices [7]. Lastly, we decided to present the prototypes for ASL delivery and raising awareness of attention separately to avoid overwhelming participants due to the novelty and complexity of the prototypes. Future investigations are yet needed to gather participant feedback on more holistic technology solutions.

7 CONCLUSION

Language deprivation in DHH children is an overlooked public health epidemic despite a long history of poor outcomes with hearing loss technologies. Motivated by the recent emphasis of parent and family support of sign language, this study focuses on investigating the design space of novel communicative technologies that empower hearing parents to offer equal and sustained language access for DHH children in early childhood. Informed by the special affordances of AR and wearable technologies in supporting in-situ language access and social awareness, we proposed several prototypes with a combination of form factors of display and feedback modalities that enable hearing parents to efficiently communicate in ASL with DHH children during face-to-face joint play. We conducted an online survey with 65 participants to investigate technology preferences and interests of these proposed prototypes. Results show a strong interest in using the prototypes in interacting with and maintaining joint attention with DHH children on a daily basis. We found that Near-Object Projection was most preferred for supporting hearing adults to sign ASL on-the-fly, and haptic feedback was most preferred for helping hearing adults to stay attentive to DHH child's visual attention. We provided detailed design recommendations of future technologies, which suggest a holistic design approach integrating visual-haptic feedback. In the future, we will gather more in-depth feedback through interviews and in-person evaluation of initial working prototypes informed by design recommendations obtained in this study.

8 SELECTION AND PARTICIPATION OF CHILDREN

No children participated in this work.

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