Demands on User Interfaces for People with Intellectual Disabilities, Their Requirements, and Adjustments

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Abstract. Information and communication technologies are ubiquitous in today's society. They have the potential to enhance the life of its users in various areas, especially the life of people with intellectual disabilities (ID). Unfortunately, natural user interfaces are often too complicated to use and not adapted to the varying needs of every user group. A possible improvement can be achieved by adapting the respective user interface to the abilities and skills of the respective user(s). Therefore, this study evaluates currently available interface types and their adaptation possibilities and requirements for people with ID. 116 individual solutions and prototypes were tested with 41 participants. We found that interfaces with pointing gestures are currently the preferred interface type for most people with ID, as this input type is used in most technologies today and provides the most accessibility features and possible adaptations. Other input types, such as voice or object interaction, offer great potential for people with disabilities and ID, but are currently more difficult to adapt to the individual needs of users with ID.

Keywords: natural user interfaces · consumer technologies · interface adaption · accessibility · intellectual disabilities

1 Introduction

Information and communication technologies (ICT) are ubiquitous in today's society and have become an essential part of people's daily lives [1]. They have the potential to enhance the life of its users in various areas, especially the lives of people with intellectual disabilities (ID) [2]. Unfortunately, natural user interfaces are often too complicated to use and not adapted to the varying needs of every user group. While design guidelines like "universal design" or the EU Directive 2019/882 (on accessibility requirements for products and services) [3] already exist, which is likely to continue to improve the accessibility of ICT, people with ID have very individual limitations and abilities. This makes it

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difficult for developers or manufacturers of digital technologies to include every unique physical and intellectual difference.

An analysis of the current accessibility status of the natural user interface types "touch, voice, and touchless" showed a lot of existing problems when used by people with ID, but also a great potential for improvement. People with ID currently have difficulties in "accessing, selecting, or using different types of interfaces" [4]. This is the reason for the so-called digital divide that has formed between people with ID and the "regular" user [2]. Because of the underlying potential of ICTs, it is needed to reduce the digital divide and increase participation for users with special needs. A possible solution or improvement of this problem can be achieved by adapting the respective user interface to the abilities and skills of the respective user(s). Adaptations and customizations of technologies and interfaces can have different levels of complexity to implement, for this reason we created a continuum that shows the level of possible adaptation to modern mainstream technologies and assistive technologies.

The focus of this research is primarily on cost-effective and easy-to-use information and communication technologies, e.g., smartphones, tablets or smart home devices, which we refer to as consumer technologies in the following. The definition by [5] describes assistive technology devices as "any item, piece of equipment or product system whether acquired commercially off the shelf, modified, or customized that is used to increase, maintain or improve functional capabilities of individuals with disabilities", there is no clear distinction between assistive or consumer devices. For this reason, we distinguish consumer technology devices from assistive technology devices by the fact that they are not primarily and exclusively developed for people with disabilities, but for the general public. Consumer and assistive technologies can therefore be divided into different categories, depending on the degree of focus on people with disabilities. We created a continuum in which consumer technologies and assistive technologies represent the two sides (left and right) of the spectrum (see Fig. 1). In the middle, there are mixed forms between the two types of technologies, for instance with different degrees of adaptation. The categories were then coded and named as follows:

- **1. Consumer technologies:** regular consumer hardware, without special assistive software or hardware adaptations, e.g., an online banking-app used on a regular tablet or smartphone.
- **1A. Consumer technologies with operating system features that can improve accessibility:** regular consumer hardware that is more accessible through operating system settings, e.g., usability aids, larger fonts.
- **1B. Consumer technologies running assistive software:** consumer hardware combined with additional assistive software, e.g., an app that was developed for people with disabilities used on a tablet or smartphone.
- **1C. Consumer technologies with adaptations:** consumer hardware combined with hardware adaptions, e.g., adapting and customizing a smartphone interface with different sensors or additional buttons.
- **2. Special assistive devices:** special assistive hardware, developed for people with disabilities e.g., speech generating devices, special interfaces.

Consumer hardware is primarily marketed and distributed via the mass market while assistive hardware is marketed and distributed via health care providers.

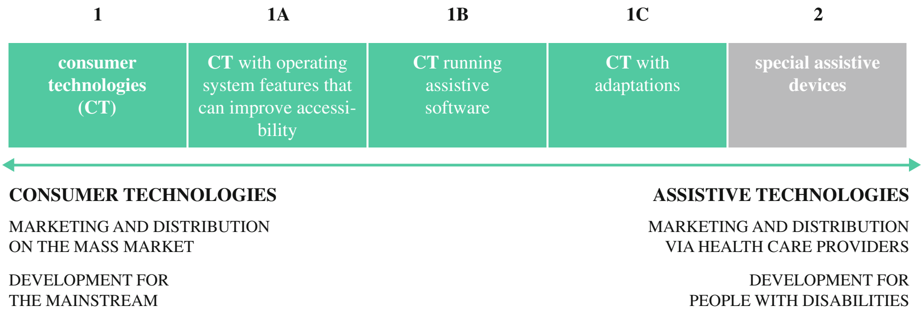

Fig. 1. Continuum of consumer and assistive technologies.

2 Related Work

There is currently not much research that specifically addresses people with ID and the use of user interfaces; studies available are predominantly related to specific applications or features, or specific types of disabilities. Research suggests that, to limit the digital divide and to "exploit the full potential of the respective device" [4], current digital technologies have to be made usable for people with ID through adaptation of their user interfaces or through guidance by non-disabled persons [4,6–8]. While simple or analog interfaces can be modified easily, e.g., adapting a door knob with clay or replacing a button with a bigger one, most natural user interfaces rely on pattern recognition, so they aren't as easy to be adapted [4].

2.1 Adaptation Possibilities for Interface Input Modalities

We differentiate between the input and output modality of the respective interface type. Since a suitable classification of input and output modalities of current interface types does not yet exist, we created our own. In the following sections, the different input and output modalities of the user interfaces included in the study are examined for their accessibility and adaptability at the current state of the art. For the sake of clarity and length of this study, it should be noted that this overview includes examples of adaptability and does not cover all possible solutions. Also, we focus on the input modality of the respective interface type. Other forms of input as the types stated below are *interfaces with multimodal input* - with more than one input modality, they can consist of two or more of the interface types described - and *interfaces with no input modality*. This is the case if the interface is triggered by someone or something else than the user or if there is only output.

Interfaces with Pointing Gestures: These are interfaces operated with two-dimensional pointing devices, like touch, computer mouse, or pencil input. Pointing gestures are among the most commonly used input modalities, especially touch interfaces have replaced other interface types in recent years and are nowadays used on smartphones, tablets or smartwatches as well as on desktop PCs or laptops [9]. Although Interfaces with pointing gestures, especially touch-sensitive interfaces are ubiquitous in society, people with ID still face problems in using them, caused by small screens, text or button sizes, difficult error handling, inadequate feedback, and a wide range of interaction methods [10,11]. Braun et al. analyzed different natural user interfaces and their accessibility for people with ID and found several (physical and cognitive) skills needed for using these types of interfaces. By comparing the needed skills with the actual skills of 44 people with ID, they found that 29.5% of the participants would face major problems in usage, 51.0% would still face minor problems and only 19.6% would be able to use the interface type without problems. Difficulties that the participants faced while using the interface were for example "small play button size, letting go of the button (pressing too long and using it as a physical button), keeping their whole hand on the screen and not being able to only use one finger of their hand to touch" [4].

Regarding system accessibility features (*category 1A* of the continuum, see Fig. 1) Apple developed several accessibility features for its touch interfaces, like "assistive touch" where the user can choose between different touch gestures (e.g., tap, double tap, hold) or create their own for certain actions; or "touch accommodations", where the user can change the hold duration (time until touch is recognized), tell the system to ignore accidental repeated taps and only recognizing one of them, or settings and assistance for swipe gestures. Also "predictive text" give suggestions for following words of a sentence [12]. Android also has certain accessibility features available, like "touch & hold delay" or "action blocks", especially addressing people with ID. It is possible to create different actions that can be triggered with only one touch gesture, making difficult processes with multiple steps easier to handle [13]. On Windows users can adjust and customize the color and size of the mouse cursor [14].

There are some applications available that can make interfaces with pointing gestures more accessible for people with ID. The "Shortcuts" app for iOS is comparable to Androids "Action Blocks" and users can create shortcuts of one or more actions [12]. Also, there are launcher apps (e.g., "BIG Launcher", "easierphone") available for the different operating systems that replace the home screen of the device (*category 1B*). Only the most important functions or apps (such as taking pictures or writing a message) can be stored there, which can lead to easier usage and less overwhelm caused by too much information [15,16]. Possible adaptations for touch interfaces can be finger guide grids, created with the help of a 3D printer, which can be adapted to the respective touch surface and application (*category 1C*). They provide security when selecting a field and simplify the selection [17]. For people that are not able to use this input modality correctly, it is also possible to adapt smartphones, tablets or PCs with alternate input methods, e.g., like additional buttons, pencils, controllers or external keyboards (*category 1C*) or using voice commands or head tracking instead of pointing gestures [18].

Interfaces with Buttons or Switch Elements: This input modality describes elements that provide two states, such as keyboards, joysticks, or buttons. Problems while using keyboards for people with ID or additional physical impairments can be the lack of writing skills [19] and therefore not understanding the different keys. Also, the complexity of the interface input can be a problem for people with ID. A study of 353 participants, ranging from mild to severe disability, found that 38.8% of the participants could not use a keyboard at all, and most of them performed poorly when using the keyboard [20]. More training, larger buttons or keyboard elements, or a simpler layout focusing on the most important elements could help improve usage. There are alternative keyboards and joysticks available for people with disabilities (*category 2*) with different sizes, layouts, or colors or the possibility to rearrange buttons [21]. Specifically for gaming, Microsoft has launched the Xbox Adaptive Controller, which connects to a range of devices and to which a variety of different buttons, switches, mounts, or joysticks can be connected to enable customized use [22]. For people with ID that can use keyboards but no other input modalities like touch, it is possible, for example, to use and navigate mobile devices like tablets with external keyboards. It is also possible to train keyboard shortcuts that perform certain tasks or use text replacements or suggested words (*category 1A*). Possible adaptations for keyboards can also be finger guide grids that help the selection and prevent the unintentional pressing of multiple keys (*category 1C*) [17]. People who are unable to use keyboards or lack literacy skills can alternatively use voice commands or dictate text [18].

Interfaces with Voice Interaction: Voice-controlled interfaces are triggered by voice or sound. They are most commonly used on specially developed devices such as Amazon Echo (Alexa) or Google Home (Google Assistant), but can also run on smartphones, tablets, or desktop PCs (e.g., Siri) [4]. They have the potential to be accessible and inclusive for people with ID and especially with limited mobility or blind users [23] and computerized speech interaction is even being used in therapy for people with speech impairments [24]. They can be useful for people with disabilities and help them to be more independent in their daily lives, for example by enabling them to operate a smart home [23,25], e.g., to regulate lights or temperature or play music and use the TV, or by using them for operating mobile devices and thus avoid spelling and typing problems [7]. However, accessibility challenges that people with ID face are primarily related to speech impairments or not using standard speech. Most speech recognition software requires clear pronunciation to recognize a command [7,23]. Balasuriya et al. propose adjustable input settings for voice assistants to be more accessible for people with pronunciations that vary from the norm [7].

There are some operating system features (*category 1A*) for voice input devices that improve accessibility, however, most of them refer to the speech output of the device, not to the user's speech input. For Amazon Alexa it is possible to change the input modality and use the device with touch instead of voice [26]. Google Nest allows the user to set a start and end sound when the Assistant has recognized the wake word ("Hey Google", "Ok, Google") and has processed the voice command [27]. While these settings do not address the issues of people with ID and speech recognition, there are solutions that do address them: "Voiceitt" (*category 1B*) is an app specially developed for people with non-standard speech to use voice assistants. By training different commands or statements, the app learns the user's individual speech pattern. Any kind of repeatable audio pattern can be trained, no matter the speech impairment. When the user gives a trained command, it is translated into the desired expression and by linking it to Alexa, e.g., smart home devices can be controlled. There is also a communication mode in which unclear speech is translated into words and sentences that can be understood by others. Through machine learning and statistical modeling, "Voiceitt" improves with each use. The developers of "Voiceitt" are also working on an expansion that recognizes spontaneous speech and doesn't require training [28].

Interfaces with Object Interaction: These are interfaces that connect the digital and physical world by manipulating real objects to trigger an action. They are controlled via a 3D interaction element and rely on the sense of touch [29]. Although this input modality is rarely used in consumer technologies at the moment, it could have great potential for people with ID. One example of a consumer technology that uses object interaction is the "Toniebox" (category 1) - an audio system that is controlled by putting little figures on top of a box to choose songs or stories to be played [30]. While the official "Toniebox" cannot easily be adapted, the modified "Phoniebox" - a project of the maker community - can (*category 1C*). There is a large community of makers who are constantly developing and improving the "Phoniebox". The interface is fully customizable, but since it is a "DIY" project, it must be built by the users themselves, which requires programming and various making skills [31]. The objects needed for interaction can be individually selected and customized, they just need to be linked to an RFID tag, which can possibly have a positive effect on the accessibility of this input modality. People with ID or their caregivers and relatives can thus choose objects that are usable and tangible for the individual person.

Interfaces with Touchless Interaction: Interfaces with touchless input are controlled via 3D body or hand gestures and are tracked via depth sensors. They allow the user to trigger actions without physically touching an interaction device like a keyboard or screen. They have not fully entered the mainstream as an input modality of consumer technologies yet and are mostly used in gaming applications (e.g., with the Microsoft Kinect), virtual reality (e.g., with a

Leap Motion Controller) or semi-public places (e.g., in exhibitions or museums) and therefore few applications with touchless input have been made available to people with ID [4,32]. Touchless approaches in the field of assistive technologies exist that enable the control of wheelchairs or other aids (*category 2*). They are particularly interesting for people with restrictions in their motor control who cannot use buttons, joysticks, or touch switches [33]. The capabilities of touchless consumer devices are constantly improving, e.g., the Leap Motion Controller can detect hands and corresponding fingers including small movements. This interaction method could also be relevant for people with disabilities (and people with ID), however, these users often do not have the necessary skills, such as interaction precision or speed, to use this type of interface, which makes it mandatory to adapt and personalize the interaction [32]. An application with the Leap Motion Controller and people with ID was tested by Braun et al. [4]. The authors found that this interface was difficult to use for people with ID who had an additional motor disability or had problems with fine motor skills. Also, the concept of touchless interaction was difficult to understand for many of the users, as evidenced by them touching the device instead of performing touchless gestures. Although the Leap Motion Software currently only supports a small number of gestures, it is possible to train custom gestures [34], which could be beneficial for people with ID.

2.2 Adaptation Possibilities for Interface Output Modalities

Since interfaces always have an input and output modality, possible output modalities are briefly described here for completeness but are not the main focus of this study. If interface feedback consists of more than one output modality it is classified as multimodal output.

Interfaces with Visual Feedback: This covers all forms of visual feedback, like text, motion graphics, pictures, LEDs or colors. A study in 2013 with over 1600 students with ID found that “29.3% do not read at all, 6.8% read at a logographic stage, 31.9% at an alphabetic and 32% at an orthographic level” [19]. Problems that can arise for people with ID can be small text or button sizes [4,10,11], and also lack of literacy skills. Additional disabilities like impaired vision or blindness can also affect the usage of this output modality [4]. Apple has several built-in accessibility features regarding visual feedback (*category 1A*) that can help people with ID use interfaces with visual feedback better. It is possible to adapt font size and strength or use display zoom, which enlarges everything. Also, light or dark modes can be used, and it is possible to increase the contrast or invert colors or adjust screen brightness. For lesser distractions and sensory overload, it is possible to cancel out ads or navigation bars when using safari (with Safari Reader). The size of app icons on the home screen can be changed or used to only display important apps, and the movement of onscreen elements can be decreased, also leading to less sensory overload. People with a lack of literacy skills or vision problems can use “VoiceOver”, which is a screen reader that describes elements on the screen or “Spoken Content”, which also reads out the content of the screen [18].

Interfaces with Auditive Feedback: These interfaces use sound or voice notifications as output. Problems that could arise for people with ID are not understanding the auditive output - e.g., because of hearing loss, the output speed or possibly distracting sounds or sound effects [23]. System accessibility features that are currently available for Amazon Alexa are settings to change the preferred speech rate and adjustable volume for timers, alarms or media (*category 1A*). Amazon Echo devices can be paired with certain Bluetooth speakers for better sound and some can display captions (visually) [26].

Interfaces with Haptic Feedback: This covers all sorts of haptic feedback which is mostly vibrations or tactile feedback. For people with ID, an interface with haptic feedback can “potentially contribute to an enhancement in perception of objects and overall ability to perform manipulation tasks” [35]. For mobile devices like smartphones, tablets or smart watches haptic feedback has already been established, like for notifications, phone calls, or alarms. These vibrations can be turned off and on and the intensity can be adjusted [12] (*category 1A*). Tactile feedback is also used often in navigation systems to deliver navigation information, increase situation awareness, and to support eyes-free usage (*category 1B*) [36]. There are several wearables available for navigation, e.g., vibration belts (*category 2*) [37], which could also possibly help people with ID make navigating easier.

3 Methodology

To find out which consumer technologies, interface input modalities and their adaptations are currently usable and suitable for people with ID, a study was performed in which people with ID were asked about their most important participation wishes to improve their everyday life through consumer technology. These wishes were analyzed by the researchers according to feasibility and cost-effectiveness to find suitable consumer solutions.

The individual abilities of people with ID were considered when selecting the technology and the respective interface type. The prototypical solutions, often several solutions with different input and output modalities and different degrees of adaptation, were tried out with the participants in a technology testing scenario. Together with participants and their caregivers and relatives we were then able to decide in a participatory manner which solution was the most appropriate for the participant. These solutions have been evaluated and analyzed for their input modality and adaptation level in the presented study.

3.1 Target Group

This study includes people with various degrees of ID, some with additional motor impairments. Based on this, 3 target groups were identified:

1. *Individuals with mild ID*, who can speak and, if applicable, read and write (with motor limitations, if applicable).
2. *Persons with moderate ID*, who can understand simple language and can express themselves with limited speech (if applicable, with motor limitations).
3. *Persons with multiple disabilities* in the sense of ID with severely impaired intentionality and understanding of symbols combined with significant motor impairments.

Access to the field has been secured through three different institutions from the disability sector in southern Germany, where people with ID live in residential or outpatient facilities. Recruiting this target group can be a time-consuming and difficult process since some people with ID cannot give their consent to participate in studies themselves and parents or legal advisors must give their consent instead. To best represent the interests of all participants, an ethical application was approved by the German Society for Educational Science (DGfE) and data was anonymized.

3.2 Case Selection and Planning

The following method was chosen for case selection and planning of the possible technical solutions, matching the identification of participation wishes:

1. *Case selection by researchers according to the following criteria:*
   - expected improvement in participation
   - technical feasibility
2. *Technology identification:* Workshops were held with the researchers and 4 experts in aided communication, participation, assistive technology, human-machine interaction, and interface/interaction design. The goal was to find out which participation wishes were feasible and to collect 1–3 solution ideas per case, matching the cognitive and physical abilities of the participants, in order to use them for further development of prototypes. Consideration was given to how the solution could be implemented technically and how much effort would be required. The workshops consisted of a presentation of existing solutions (based on previous research), followed by an initial phase in which each participant considered solutions individually. Subsequently, solution ideas were developed through discussions with all workshop participants and the further procedure for the development of the prototypes was determined.

3.3 Participatory Technology Testing and Selection

In order to find the most suitable solution, 1–3 ideas were presented to the participants and then evaluated and discussed in a participatory manner. This process was based on the user-centered approach of *Scenario-Based Design* [38]. It varied depending on the type of solution and individual abilities, e.g., visual or written solution scenarios, prototype testing, wizard-of-oz testing, or actual technical solutions if they were already implementable (e.g., installing a certain app, for example for using smart home devices with non-standard speech like "Voiceitt" or setting up accessibility features like bigger fonts or screen readers for easier interaction with a device). Here, the participants were given simple tasks to solve (e.g.: "Turn on the music using the Voiceitt app" or "Open the Deutsche Bahn app and enter your destination in the search bar"). Afterwards, the pros and cons of the different solutions and possible adaptations were discussed with the participants and/or their caregivers. This resulted in one or more (depending on the number of realizable wishes) suitable solutions for each of the participants.

4 Study

Here we describe our user study, which took place from June 2021 to July 2022. 43 people with ID who had also previously attended the identification of participation wishes participated. This resulted in 150 wishes. The number ranged from 1 to 7 wishes per person, with a mean of 3.5 wishes. The participation wishes surveyed primarily concerned more independence in everyday life in various areas such as entertainment, mobility/navigation, household tasks (e.g. shopping), learning, or (digital) communication. The IDs ranged from mild intellectual disabilities to more serious disabilities and were often combined with motor impairments. Of the 43 participants, 18 were categorized in target group 1, 22 in target group 2, and 3 in target group 3. Of the 18 participants in target group 1, 4 had an additional motor impairment and one had an additional sensory impairment. In target group 2, 7 had an additional motor impairment. All the people in target group 3 had severe additional motor impairments. The age of the participants ranged from 24 to 76 years, with an average of 48.8 years. Of the 43 participants, 29 identified as male and 14 as female.

4.1 Study Setup

In addition to the participant, one or two staff members from the research team participated in the technology selection. In many cases, a close relative or caregiver was also present. The appointments took place in inpatient residential facilities within these, in familiar surroundings. For evaluation, video recordings with two cameras from two angles, an additional sound recording, and observation protocols were made.

4.2 Case Selection and Planning and Participatory Technology Testing and Selection

The case selection and planning resulted in various proposed solutions, possibly suitable for the cognitive and physical abilities of the participants. The participatory technology testing resulted in the selection of different types and technologies and interfaces. In this process, 34 participation wishes were eliminated. The reasons for this were, for example, lack of feasibility, no added value provided by a technical solution, or no further participation of the person in the study due to personal reasons. The 116 possible solutions - belonging to the remaining 41 participants - will be examined in this study. For the analysis, each solution is classified into the interface input and output modalities introduced in Sect. 2, as well as into the adaptation level category based on the proposed continuum.

5 Findings

In this section, the collected data is analyzed, and our findings are presented. As stated before, 116 technical solutions for 41 people with ID were examined.

5.1 Interface Input Modality and Level of Adaptation

Looking at Table 1 and 2, we can analyze the suitable interface input types for the participants. 67 consumer solutions had one input modality, 41 used multimodal input with two input modalities, and 3 solutions used three input modalities. 5 solutions had no input modality. The level of adaptation (Table 3) refers to our classification in the *continuum of consumer and assistive technologies* introduced before. The percentage in brackets refers to the total occurrence of the respective input modality. Since we focused on consumer technologies for possible solutions, *category 2 (special assistive devices)* is not applicable and therefore not evaluated.

Table 1. Interface Input Modalities.

Input Modality (N)	Overall	N=1	N=2	N=3
Pointing gestures	95	60 (89.6%)	32 (68.1%)	3 (100.0%)
Voice interaction	25	0	23 (48.9%)	2 (66.7%)
Buttons or switch elements	22	5 (7.5%)	12 (25.5%)	3 (100.0%)
Object interaction	17	1 (1.5%)	15 (31.9%)	1 (33.3%)
No input modality	5	0	0	0
Touchless interaction	1	1 (1.5%)	0	0
Total	116	67	41	3

Interfaces with pointing gestures are, unsurprisingly, the most used interface type, appearing 95 times in the 116 solutions. This makes sense since this type of input modality is used in most devices nowadays [9]. It is used 60 times as a single input modality, 32 time alongside one other input modality (23 times with “voice interaction”, 6 times with “object interaction” and 3 times with “buttons or switch elements”) and 4 times alongside 2 other input modalities (two times

Table 2. Multimodal Input Modalities.

Input Modalities	N
Pointing gestures + Voice interaction	23 (19.8%)
Object interaction + Buttons or switch elements	9 (7.8%)
Object interaction + Pointing gestures	6 (5.2%)
Pointing gestures + Buttons or switch elements	3 (2.6%)
Pointing gestures + Buttons or switch elements + Voice interaction	2 (2.6%)
Object interaction + Pointing gestures + Buttons or switch elements	1 (0.9%)

Table 3. Level of Adaptation.

Input Modality	*Category 1*	*Category 1A*	*Category 1B*	*Category 1C*
Pointing gestures	26 (43.3%)	4 (6.7%)	30 (50.0%)	0
Voice interaction	0	0	0	0
Buttons or switch elements	1 (20.0%)	0	4 (80.0%)	0
Object interaction	0	0	0	1 (100%)
Touchless interaction	1 (100.0%)	0	0	0
Pointing gestures + Voice interaction	7 (30.4%)	4 (17.4%)	12 (52.2%)	0
Object interaction + Buttons or switch elements	0	0	0	9 (100.0%)
Object interaction + Pointing gestures	4 (66.7%)	1 (16.7%)	0	1 (16.7%)
Pointing gestures + Buttons or switch elements	2 (66.7%)	0	1 (33.3%)	0
Pointing gestures + Buttons or switch elements + Voice interaction	0	0	0	2 (100.0%)
Object interaction + Pointing gestures + Buttons or switch elements	1 (100.0%)	0	0	0

with "buttons or switch elements" and "voice interaction" and one time with "object interaction" and "buttons or switch elements"). Because these types of input modalities are already widely used in current consumer technologies and have more accessibility features than other interface types, they can already be used as they are by a lot of participants with ID (43.3% in *category 1*, where no adaptation has occurred and 6.7% has been adapted with accessibility features (*category 1B*). However, in 50.0% of the cases where this input modality was used, it had to be adapted with assistive applications to be usable for the participants, which highlights the demand for assistive apps for this interface input type for people with ID.

Interfaces with voice interaction are the second most used input modality with 25 occurrences in total. Interestingly, they are never used as a single input modality, only alongside other types of input. They are used 23 times with "pointing gestures" and 2 times in combination with two other input modalities (with "pointing gestures" and "buttons or switch elements"). This interface type could not be used as a standalone input modality in our study, which shows that voice-only solutions bear difficulties for this target group. Most of the time, they are used in combination with interfaces with pointing gestures, where 30.4% belong to *category 1*, 17.4% belong to *category 1A* and 52.2% belong to *category 1B*. When trying out the different solutions with people with ID in the study, it also often became apparent how little speech input currently works for people with different speech impairments and how poorly they are often understood by the technology. This usually led to frustration and is the reason that in the end other input modalities were selected for the participant or a multimodal input was chosen. Voice interfaces need more adaptation options for people with disabilities so that people with all types of speech can use this input modality. Solutions like *Voiceitt* [28] have already taken a big step in this direction.

Interfaces with physical buttons or switch elements are the third most used interface input type in the study, with 22 uses in total, 5 times as a single input modality, 14 times alongside one other input modality (9 times with "object interaction" and 3 times with "pointing gestures"), and 3 times alongside two other input modalities (2 times with "pointing gestures" and "voice interaction" and 1 time with "object interaction" and "pointing gestures"). As a standalone input type, 80.0% belonged to *category 1B*, and 20.0% to *category 1*. Used with object interaction, all solutions belonged to *category 1C*, in combination with pointing gestures, 66.7% categorized in *category 1* and 33.3% in *category 1B*.

Interfaces with object interaction are used 17 times in total. This shows the potential for certain people with ID, even though this input modality is not often used in consumer technologies. It is only once used as a standalone input modality and 15 times alongside one other input type (9 times with "buttons or switch elements" and 6 times with "pointing gestures"). It is used one time with two other input modalities ("pointing gestures" and "buttons and switch elements"). This input type was only used once as a single input modality in *category 1C* (where hardware or sensory adaptions had been made) and was most of the time (n = 9) used in combination with "buttons or switch elements", where also all solutions belonged to *category 1C*. In combination with "pointing gestures" (n = 6) adaptation wasn't needed as often (66.7% of the times belonging to *category 1*, 16.7% *category 1A* and 16.7% *category 1C*. The numbers imply that interfaces with object interaction must be adapted more when they are used alone or in combination with "buttons or switch elements" and less when they are combined with "pointing gestures", as there are already more adaptation possibilities available for this interface type.

Interfaces with touchless interaction were only used once, as a standalone input modality without adaptation. This supports the statement that this type of interface has not yet finally arrived in consumer technologies [4,32] and that it is therefore more difficult to use the available solutions with people with ID. Before this type of input can be used in consumer technologies by people with ID it has to become standard for the regular user and possible adaptation possibilities must be developed. However, the use of this input type in various assistive technologies shows the potential for certain types of disabilities [33].

5.2 Interface Output Modality

In total, 105 interfaces used visual feedback (44 as a standalone output modality), 72 used audio feedback (11 as a standalone output modality) and 6 used haptic feedback (none as a standalone output modality). 67 solutions used multimodal feedback, the most used multimodal feedback was audio and visual (n=56). Haptic feedback was always used in combination with visual feedback.

5.3 Correlation Between Adaptation Level, Target Group and Age

We investigated the correlation between the *Target Group* (Group 1, 2 or 3) and *Level of Adaptation* (*categories 1-1C*) and *Age* using Pearson's correlation. This showed a positive relationship of $r=0.282$ (p-value=0.002) and means that *Target Group* has a weak effect on *Level of Adaptation* of possible consumer technologies and people with more serious IDs or multiple disabilities possibly need more adaptation. Also, *Age* had a weak positive relationship with *Level of Adaptation* with $r=0.316$ (p-value=<0.001) showing that age could play a factor in the needed adaptation level of consumer technologies.

5.4 Target Group and Input Modality

The most used interface input type in target group 1 was pointing gestures (47.3%) and pointing gestures + voice interaction (30.9%). In group 2 it was also pointing gestures (58.6%), pointing gestures + voice interaction (10.3%), and object interaction + buttons and switch elements (10.3%). In group 3 the only interface input types used were object interaction + buttons or switch elements (66.7%) and interfaces with no input modality (33.3%). This shows that especially for people with more severe disabilities, interfaces with physical object interaction + buttons and switch elements may have a big potential for participation and that voice interaction now can mostly be used by people with less severe disabilities.

6 Discussion and Conclusion

This study focused on current user interfaces, especially their input modalities. They were analyzed on suitability and adaptation options for people with ID. The requirements that this target group has for user interfaces and the adaptations that need to be made to make them usable were evaluated. Our user study resulted in 116 possible solutions and prototypes with different input modalities and varying degrees of adaptation, tested by 41 participants with ID, with the aim of being integrated into the participants' everyday lives. We found, that interfaces with pointing gestures (e.g., touch or mouse input) are currently the preferred interface type for most people with ID, as this input type is used in most technologies today and provides the most accessibility features. Also, voice input has a high potential for a lot of people with ID but must currently be used as a multimodal input type, alongside one or more input modalities, as many necessary accessibility features are missing. As voice input continues to improve and adapt to the needs of people with ID, this input modality could be used by many more. Especially people with more severe and multiple disabilities (target group 3) are unable to use most interface types. The level of disability (target group) had a significant positive correlation to the level of adaptation needed, which shows that people with more severe disabilities need more adaptation possibilities for current consumer technologies and interfaces. Also, age of the participants plays a factor in the level of adaptation needed.

The analysis of related work and state of the art has also shown that currently, most accessibility features and possible adaptations are developed for interface input with pointing gestures (like touch or mouse input). Other input types, like voice interaction or object interaction, may have a big potential for people ID, but are currently more difficult to adapt to the individual needs of different users. There are approaches to make more interface types accessible to this target group, but in the future, the needs and abilities of people with disabilities, especially people with ID, need to be much more involved in the design and development process of new technologies.

There are some limitations to our research. Since there are no well-researched methods for conducting usability studies or evaluating different interfaces with people with ID, an exploratory approach was chosen. Also, not every interface input type could be tested with every participant, as the consumer solutions depended heavily on each person's participation wishes and abilities. This causes, for example, that not all input modalities occur equally often, which makes the comparison more difficult (e.g., touchless interfaces only occurred one time). Our study also did not yet include how training and longer-term use can affect the usability of an interface type. In future work, we will investigate the usability and suitability of the different solutions and interfaces in the everyday life of the participants. It will be shown how useful the individual solutions are and whether they can be integrated into their daily lives and are accepted in the long term. This study highlights the current potential of interface used by people with ID and emphasizes the need for more adaptability of consumer technologies.

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