Usability of Natural User Interfaces for People with Intellectual Disabilities

Melinda C. Braun[1,2](✉) and Matthias Wölfel[1,2]

[1] Institute for Intelligent Interaction and Immersive Experience, Karlsruhe University of Applied Sciences, 76133 Karlsruhe, Germany
{melinda.braun,matthias.woelfel}@h-ka.de

[2] University of Hohenheim, 70599 Stuttgart, Germany

Abstract. In today's society, information and communication technologies are ubiquitous. They have become an essential part of people's daily lives and have the potential to improve various areas of life and daily tasks of their users. However, these technologies are usually developed for the masses rather than for specific user groups, which makes their use difficult for a large part of the population, especially for people with intellectual disabilities. A possible improvement can be achieved by adapting the user interface to the abilities of the users. This work follows up on a previous study that evaluated current interface types and their adaptability. In this study, we evaluate the usability in the daily use of different technical solutions with a questionnaire using the System Usability Scale. Our questionnaire was completed by 31 participants with varying degrees of disability for 44 solutions. The results suggest that the usability of natural user interfaces is highly dependent on factors such as age, level of customization, or the type of solution used. We found that pointing gesture interfaces are currently the most commonly used type of interfaces. These were mainly used as a standalone input modality, but usability was perceived to be higher with additional system accessibility features. Interfaces with buttons or switches required more adaptation, and interfaces with voice interaction may have potential, but currently there are too many barriers to be usable for this target group.

Keywords: usability · natural user interfaces · accessibility · intellectual disabilities · assistive technology · consumer technology · interface adaptation

1 Introduction

In today's society, information and communication technologies (ICT) are ubiquitous. They have become an important and essential part of people's daily lives [11] and have the potential to improve different areas of life and daily tasks of their users, especially those with intellectual disabilities (ID) [21]. However, these technologies tend to be developed for mainstream users and are not adapted to the needs of each user group, which makes them difficult to use for a large part of

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the population, especially people with ID. This user group often has very individual limitations and abilities, and although design guidelines (e.g. universal design or the EU Directive 2019/882 (on accessibility requirements for products and services) [12]) exist, this range of individual characteristics and abilities can make it difficult to include everyone in the development of digital technologies and interfaces [6]. In a previous study, the current accessibility status of several natural user interfaces ("touch", "voice" and "touchless") was analyzed. This showed that there are problems when these interfaces are used by people with ID, especially in "accessing, selecting or using different types of interfaces" [7], but also a huge potential for improvement. To reduce the so-called "digital divide", which describes a gap between people with ID and mainstream users [21], and to increase the participation of those affected by this gap, different user interfaces need to be customized to the specific abilities and skills of the respective user(s) [6]. This work is an extension of a previous study that evaluated currently available interface types and their adaptability for people with ID [6]. Here we will analyze and evaluate the usability of these interface types and their adaptations when used in the daily lives of people with ID.

1.1 Continuum of Consumer and Assistive Technologies

The boundary between consumer and assistive technologies is not binary. Therefore, in [6], we introduced the *continuum of consumer and assistive technologies* (see Fig. 1). For better understanding and simplicity, it will be described again. Here, these two types of technologies represent the two extremes of the spectrum on the left and right side, respectively. In between there are hybrids with different degrees of adaptation. The categories were designated as follows [6]:

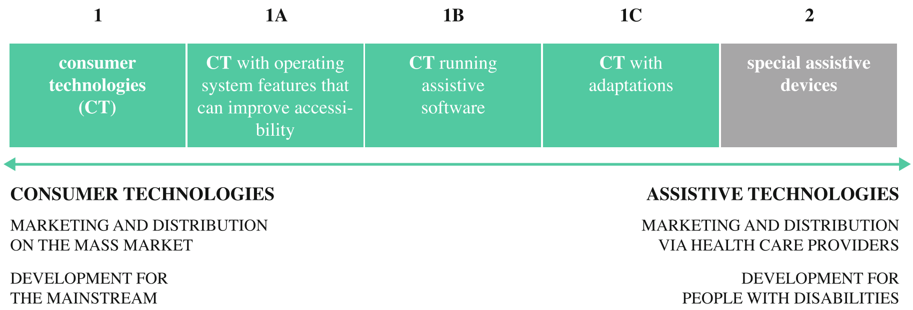

Fig. 1. Continuum of consumer and assistive technologies [6].

– **1. Consumer Technologies:** conventional consumer hardware, without specialized assistive software or hardware adaptations, e.g., an online banking-app used on a tablet or smartphone.

- **1A. Consumer Technologies with Operating System Features that can improve Accessibility:** consumer hardware with accessibility settings, e.g., usability aids, larger fonts used on a tablet or smartphone.
- **1B. Consumer Technologies running Assistive Software:** consumer hardware combined with assistive software, e.g., an app, specifically developed for people with disabilities used on a tablet or smartphone.
- **1C. Consumer Technologies with Adaptations:** adapted or customized consumer hardware, e.g., adding different sensors or buttons on a smartphone or tablet interface.
- **2. Special Assistive Devices:** assistive hardware that was specifically developed for people with disabilities e.g., speech generating devices, special interfaces.

1.2 Natural User Interfaces

The way people interact with ICT and the types of interfaces available have evolved over time and gone through different phases. Starting with the typical command line interfaces, through graphical user interfaces (GUI) to natural user interfaces (NUI). These developments allow users to interact with digital technologies in more and more diverse ways. NUIs have been developed to facilitate a more natural interaction, for example through touch interfaces, gestural interaction or voice interaction. A distinction is made between the input and output modality of an interface [35]. Since a suitable classification of the input and output modalities of current interface types did not yet exist, we introduced one that better reflects the capabilities of a given interface [6]. In this study, we focus on the input modality of each interface.

Interfaces with Buttons or Switch Elements: This describes input modalities with two states, e.g. keyboards, joysticks or buttons [6], which are not classified as NUIs. Since these input modalities are widely used in ICT today, they are also included in this study.

Interfaces with Pointing Gestures: This interface input type is controlled via a two-dimensional pointing device, such as a touchscreen, computer mouse, or pen input [6].

Interfaces with Voice Interaction: These are activated by voice or sound and are most commonly used on devices such as Amazon Echo (Alexa) or Google Home (Google Assistant), but also run on smartphones, tablets, or desktop PCs [6,7].

Interfaces with Object Interaction: Object interaction interfaces (e.g., tangible user interfaces) are operated by using real-world objects to initiate actions [29].

Interfaces with Touchless Interaction: Touchless input is controlled by 3D body or hand gestures, that allow the user to initiate actions without physically touching a device [6].

Interfaces with Multimodal Input: Interfaces with multimodal input are interfaces with more than one input modality. They can consist of two or more of the previously described input types [6]. Multimodal input types can be categorized into competing and combined input. In competing multimodal input, the user chooses one modality or the other, e.g., the user says "turn on the light by the window" or points to the light to turn it on. Here, both can be used separately. In combined multimodal input, different modalities are used together, e.g. the user points to a light by the window and says "turn on the light". In this case, both modalities must be used together.

2 Related Work

This section discusses related work in the field of people with ID and interface use. Currently, there is little research that specifically addresses people with ID and the use of NUIs or possible adaptations. It is suggested that in order to limit the digital divide and realize the full potential of a device, current digital technologies need to be made usable for people with ID through adaptation of their user interfaces or guidance from non-disabled people [4–7,20]. While simple or analogue interfaces can be easily adapted, for example by adjusting a doorknob with plasticine or replacing a button with a larger one, most NUIs rely on pattern recognition and are not easily adapted [6,7].

2.1 Interfaces with Pointing Gestures

This type of input, especially touch input, is widely used and applied in most technologies today (e.g., smartphones, tablets, desktop PCs, laptops) [18,30] and it has great potential for people with ID, e.g. for "communication, access, navigation and independence" [30]. However, there may still be usability and accessibility issues when used by people with ID. This can be caused by the often small screen or pointing area, text or button sizes, difficulties in error handling, inadequate feedback (e.g. the lack of haptic feedback) or the large number of interaction methods [32,36]. Braun et al. analyzed the accessibility of different NUIs for people with ID and found that the majority of participants faced major (29.5%) and minor (51.0%) problems when using touch interfaces, e.g., "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 use only one finger of their hand to touch" [7]. Certain system accessibility features (category 1A, see Fig. 1), [2,17,24], applications (category 1B) [1,25], or customizations (category 1C) [27] and more intensive training can help to make this type of input more accessible to people with ID [6,30].

2.2 Interfaces with Voice Interaction

According to research, this type of input has the potential to be both accessible and inclusive for people with ID [23,26], contributing to greater independence in everyday tasks, such as operating a smart home [10,26] or using commands on mobile devices [4]. But especially users with speech disabilities or non-standard speech have difficulty using it. In most cases, speech recognition requires clear pronunciation [4,26]. Differences in pronunciation, dialects, or vernaculars can have a big impact: Wenzel and Kaufman state that speech interfaces that do not take this into account can lead to not only usability problems, but also psychological problems for minorities [34]. Another difficulty for people with ID in using speech interfaces is the complexity of the commands, which require a certain level of cognitive ability. In order to use a speech interface effectively, users need to remember certain keywords or sequences of words, or to follow a particular sequence of commands [23]. Assistive applications (category 1B), such as [33], can help users with ID interact with voice interfaces [6], but customization options are still scarce. More adjustable input settings (category 1A) [4] or specific adaptation options, such as more prominent feedback, adjustable timing, or commands that include familiar words [23] are needed to make commercial voice interfaces more accessible tools for people with ID. Also, more speech data needs to be collected ethically from underrepresented groups to minimize the high error rate of speech technology [34].

2.3 Interfaces with Object Interaction

By supplementing the digital world with physical objects and materials, this type of input is intended to provide a richer sensory experience and enhance various skills, such as object manipulation or multi-sensory exploration [13,16]. This type of interaction is meant to be natural and intuitive and can be beneficial for people with ID [22]. Gelsomini et al. highlight the potential of this type of interface for interventions with people with ID to improve performance [16]. Although this type of input is rarely used in mainstream technologies, object interaction is often used in semi-public spaces [37]. Popular examples such as [15,31] (category 1C) demonstrate the potential for people with ID by selecting appropriate objects for the individual person. For [15], the interface and physical objects are fully customizable, but certain skills (e.g., programming, woodworking, soldering) are required, which can be a barrier for people with ID and their caregivers or families [6].

2.4 Interfaces with Touchless Interaction

Touchless input is currently mostly used in games, virtual reality, or semi-public spaces such as exhibitions or museums, and therefore few applications exist for users with ID [3,6,7]. This method of interaction could potentially be relevant for people with ID [6], but adaptations need to be developed as the input may be too difficult or complicated for this group of users, especially those with additional motor impairments or problems with fine motor skills [3,7]. Braun et al. tested a touchless interface using a *Leap Motion Controller* with people with ID and found that the interface and its method of interaction (touchless gestures) was often too complex for the participants with ID to understand [7]. Because this type of interface is not yet mainstream, there aren't many options for adaptation. On some devices, such as the *Leap Motion Controller*, it is already possible to train custom gestures [19].

3 Methodology

For a better understanding, this section describes the methodology of past studies, as the current study is part of a larger research project.

3.1 Target Group

People with various degrees of intellectual disabilities (ID) are included to investigate a broad audience, some with additional motor impairments. In [6] we describe three target groups:

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 plain 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 was gained through three institutions in the disability sector in southern Germany, where people with ID live in inpatient or outpatient facilities. Recruitment of this target group can be a time-consuming and difficult process, as some people with disabilities are not able to give consent to participate in studies themselves, and instead parents or legal representatives must give consent. In order to best represent the interests of all participants, an ethical application was approved by the German Society for Educational Science (DGfE) and the data were anonymized.

3.2 Identification of Participation Wishes and Case Selection

In an earlier study, participants with ID were asked about their most important wishes for improving their daily lives through technology. All of the following studies are based on the 150 participant wishes that were identified. The topics were mostly "independence in everyday life in various areas such as entertainment, mobility/navigation, household tasks (e.g. shopping), learning, or (digital) communication" [6]. These wishes were analyzed by the researchers according to the expected improvement of participation and technical feasibility in order to find suitable solutions for the users. In this process, inappropriate wishes were excluded.

3.3 Technology Testing and Selection

In our previous study [6], possible solutions for the previously evaluated participation wishes were tested with the participants. The goal was to find the most suitable interface and technology, so between one and three possible solutions were tested with each participant. This study was based on the user-centered approach of *Scenario-Based Design* [9] and varied in execution depending on the type of solution and the individual skills of the participants, e.g. with multiple or written solution scenarios, testing of prototypes, wizard-of-oz testing or testing of currently existing solutions. This process resulted in 116 possible solutions for 41 participants with varying degrees of adaptation [6].

3.4 Integration of the Solutions into Everyday Life

Once the technology was selected, each participant received a proposal with the necessary hardware and software to purchase. A questionnaire was then sent to each participant asking whether the proposed technology was purchased and used, how the solutions were integrated into everyday life, and how the participants rated the solutions. At this point, the researchers had no control over how often or when each solution was used. Participants were not assigned specific tasks during use. The use of the solutions was left to the participants and their caregivers to ensure a natural interaction. Information about the frequency and context of use, as well as the situations in which the solutions were used in daily life, was collected later through the questionnaire.

Type and Cost of Solutions: Solutions were limited to low-cost consumer technologies and it was always considered whether the solution could be implemented using hardware already available to the participants. Suggested hardware for the solutions included Android or iOS smartphones and tablets, PCs, laptops, single board computers such as Raspberry Pis, smartwatches, smart speakers such as Amazon Echo, joysticks, controllers, keyboards, or smart pens. The software used depended on the type of solution and the level of adaptation required (see Sect. 1.1), e.g. regular applications or software (1), system accessibility features (1A), assistive software (1B) or adapted software (1C). Special attention was given to minimizing the cost to participants; in each case, the most affordable options were proposed. In some cases, certain hardware was already available, eliminating the need for new purchases. The study staff also offered to cover the cost of some solutions with project funds and to provide them to the individuals concerned if no other funding option was available. Ultimately, the decision to purchase and use a solution was made by caregivers or family members and the participants themselves.

System Usability Scale (SUS): In addition to general questions and questions about the solution, as well as duration and frequency of use, the *System Usability Scale* (SUS) [8] with a 5-point Likert scale (strongly agree to strongly disagree) was used to inquire about the usability of each solution. There is currently no usability evaluation questionnaire for people with intellectual disabilities, so the SUS was chosen in a slightly adapted form. It can distinguish between unusable and usable systems, and asks about issues such as complexity, need for support, training, effectiveness, and satisfaction while using a technology [8]. The 10 individual items of the SUS and the rest of the questionnaire have been translated into plain language to make it accessible to participants with ID. For scoring, the items were coded in a specific way, summed, and multiplied by 2.5. The *SUS score* goes from 0 to 100, where 100 is the best possible score, but should not be interpreted as a percentile ranking [8]. The items translated into the plain language of the SUS are as follows:

1. *Q1: I think I will continue to use the technology.*
2. *Q2: I find the technology complicated to use.*
3. *Q3: I find the technology easy to use.*
4. *Q4: I need help from another person to use the technology.*
5. *Q5: I think the functions of the technology are good.*
6. *Q6: I find the technology difficult to understand.*
7. *Q7: I think most people learn to use technology very quickly.*
8. *Q8: I find the technology very cumbersome to use.*
9. *Q9: I feel very confident using the technology.*
10. *Q10: I had to learn a lot before I could use the technology.*

Questionnaire for Observing Communicative Skills - Revision (OCS-R): In a previous study [7], we assessed certain skills that participants needed to use different types of interfaces (touch, voice, and touchless interfaces). Data on the cognitive and motor skills of participants with ID were collected using parts of the *Questionnaire for Observing Communicative Skills-Revision (OCS-R)* [28]. Then, an expert interview was conducted to analyze which important and unimportant skills are required to use each type of interface. These results should show how usable and accessible the different types of natural user interfaces are for this target group [7]. In the current study, we want to find out if there are associations between the scores on the OCS-R and the scores that participants achieve on the SUS.

4 Study

The current phase of our research began in the summer of 2022 and is still ongoing. Initially, 41 people participated in our previous study [6], where 116 solutions were proposed to them. At the moment, 40 solutions have been implemented as we proposed, 6 differ from our proposal, possibly changing the type of input. One person chose a new solution that we did not propose, which will also be evaluated. These now 47 solutions are currently in use by the participants[1]. The remaining 70 proposed solutions were not acquired or are no longer

[1] Supplementary material on this study can be found at: https://www.researchgate.net/profile/Melinda-Braun/research.

in use for various reasons (not accepted by the user, no further participation, no response to follow-up questions, etc.).

4.1 Participants and Questionnaire

Currently, 31 participants have completed our questionnaire for 44 of the 47 solutions. Participants range in age from 25 to 76, with an average age of 49. Of the participants, 22 identify as male and 9 as female. 14 participants belong to target group 1 (as described in Sect. 3.1), one of them with additional motor impairments and one with sensory impairments. 15 belong to target group 2, 6 of them with additional motor impairments. Two participants belong to target group 3, all of them with additional motor impairments.

The way in which the questionnaire was completed—independently, with the help of a caregiver or family member, or without the participant's involvement—depended on the individual's limitations and the caregiver's judgment. Of the 31 participants, only 1 from target group 1 completed the questionnaire independently, 15 completed it with assistance (11 from target group 1 and 4 from target group 2), and 12 had a caregiver complete it on their behalf (1 from target group 1, 9 from target group 2, and 2 from target group 3). This information is missing for 3 participants.

4.2 Solutions and Input Types

Table 1. Occurrences of the Input Modalities.

Input Modality (N)	Overall	N = 1	N = 2	N = 3
Pointing gestures	29	18	9	2
Buttons or switch elements	21	3	16	2
Object interaction	12	0	11	1
Voice interaction	7	0	6	1

Table 1 gives an overview of how often the individual input modalities occur in the different solutions. The most frequent interface type is *pointing gestures* (n = 29), 18 times as a single input modality, 9 times together with one other input modality, and two times together with two other input modalities. The second most common input type (n = 21) is interfaces with *buttons or switches*, which occur 3 times as a standalone input, 16 times alongside one other input modality, and twice alongside two other input types. Interfaces with *object interaction* occur 12 times, never as a standalone input modality, 11 times alongside another input modality, and once alongside two other input modalities, and interfaces with *voice interaction* occur a total of 7 times, 6 times alongside another input modality, and once alongside two other input modalities—also never as a standalone input modality.

Table 2. Multimodal Input (⊘ SUS Scores).

Input Modalities	Sum	Competing Input	Combined Input
Object interaction + Buttons or switch elements	10	0	10 (55.5)
Pointing gestures + Buttons or switch elements	4	0	4 (30.0)
Pointing gestures + Voice interaction	3	3 (72.5)	0
Buttons or switch elements + Voice interaction	3	3 (25.0)	0
Pointing gestures + Object interaction	1	1 (80.0)	0
Pointing gestures + Buttons or switch elements + Voice interaction	1	0	1 (50.0)
Pointing gestures + Buttons or switch elements + Object interaction	1	0	1 (50.0)
Sum	23 (49.9)	7 (53.2)	16 (48.4)

Table 3. Level of Adaptation (⊘ SUS Scores).

Input Modalities	1	1A	1B	1C	Sum
Pointing gestures	9 (68.2)	4 (83.8)	4 (52.2)	1 (70.0)	18 (68.3)
Buttons or switch elements	1 (42.5)*	0	2 (75.0)	0	3 (64.2)
Object interaction + Buttons or switch elements	1 (77.5)†	0	0	9 (53.1)	10 (55.5)
Pointing gestures + Buttons or switch elements	1 (37.5)*	0	3 (27.5)*	0	4 (30.0)
Pointing gestures + Voice interaction	0	3 (72.5)	0	0	3 (72.5)
Buttons or switch elements + Voice interaction	0	1 (25.0)	2 (25.0)	0	3 (25.0)
Pointing gestures + Object interaction	1 (80.0)	0	0	0	1 (80.0)
Pointing gestures + Buttons or switch elements + Voice interaction	0	0	1 (50.0)	0	1 (50.0)
Pointing gestures + Buttons or switch elements + Object interaction	1 (50.0)	0	0	0	1 (50.0)
Sum	14 (63.8)	8 (72.2)	12 (45.2)	10 (54.8)	44 (57.9)

Multimodal Solutions: As shown in Table 2, 23 solutions used multimodal input in different combinations. The most common combination was *object interaction and buttons or switches*—used in 10 solutions, followed by *pointing gestures and buttons or switches* (n = 4). *Voice interaction* was used with either *pointing gestures* (n = 3), *buttons or switches* (n = 3), or both (n = 1). Of the 23 multimodal solutions, 16 had to be used with all input modalities (combined multimodal input) and 7 could be used with either modality (competing multimodal input).

Level of Adaptation: Table 3 shows the level of adaptation and refers to the categorization in the *continuum of consumer and assistive technologies* as seen in Fig. 1. [6]. Most solutions belonged to category 1 (n = 14), with no adaptation, followed by category 1B (n = 12), with adaptations using assistive software, category 1C (n = 10), with hardware adaptations, and category 1A (n = 8), with operating system features that can improve accessibility.

Non-acquired Solutions: Of the 70 non-acquired solutions, 39 belonged to *pointing gestures*, 15 to *pointing gestures* combined with *voice interaction*, 5 belonged to interfaces with no input modality and 4 belonged to *pointing gestures* combined with *object interaction*. 3 belonged to interfaces with *buttons or switches* and the remaining 4 belonged to *touchless interaction*, *object interaction*, *pointing gestures* combined with *buttons or switches* and *object interaction* combined with *buttons or switches*.

5 Findings

This section will describe the findings of our work, mostly regarding usability.

5.1 Usability

SUS [8] was used to measure the usability of the different solutions and interfaces. Therefore, the *SUS scores* were evaluated. The average of all *SUS scores* is 57.9 (out of 100), with the highest individual score being 90.0 and the lowest being 25.0. Table 3 shows the average *SUS scores* for each interface input type. The input type with the highest score is *pointing gestures and object interaction* (80.0, but only used in one solution), followed by *pointing gestures and voice interaction* (72.5), and *pointing gestures* as a standalone input modality (68.3). The lowest scores were for *buttons or switches and voice interaction* (25.0) and *pointing gestures and buttons or switches*" (30.0).

Duration of Use: The questionnaire asked how long the technology had been in use (not long: 0–3 months or somewhat longer: over 3 months). 25 solutions have been in use for more than 3 months, 17 for 0–3 months. Information is missing for 2 of the solutions. The average of the *SUS scores* of the interfaces that have been in use for 0–3 months is 54.9, the average of the solutions that have been in use for over 3 months is 60.0. No significant relationship was found between *duration of use* and *SUS score*. Long-term use and comparison of individual users between initial use and longer use need further observation.

Age: SUS Score and **Age** show a negative relationship (Spearman's Rho = -0.392, p = 0.010), this could indicate that age has an effect on the *SUS score* and the older a participant, the lower their score.

Suggested vs. Own Solution: As mentioned above, 6 solutions were not purchased or executed with the technologies or interfaces we proposed (marked with a * in Table 3. For one of these solutions, the questionnaire has not been answered yet. This was the case, when caregivers decided against a solution (mostly because of budget) and used existing hardware, e.g., an old, existing laptop instead of a new tablet or smartphone. Another solution was realized for one participant without being known to us beforehand as a participation request (marked with a †). When looking at the scores, it is noticeable that only this solution (†) has a higher score (77.5). The other solutions (*) show noticeably low scores (all between 27.5 and 42.5, with an average of 32.5), suggesting a general dissatisfaction with the execution. For solutions acquired and executed as we proposed, the average score was 60.9. *Suggested (1) vs. own solution (2)* and *SUS Score* showed a negative relationship (Spearman's Rho = −0.435, p = 0.004). Even though the sample size is small, there is an indication that more appropriate solutions can be suggested by experts. This is also supported by the statement that people with intellectual disabilities and their relatives or caregivers often do not know which technologies are available or which interfaces are usable for them [7,14].

Level of Adaptation: The level of adaptation (categories 1-1C) for each solution was determined based on the *continuum for consumer and assistive technologies* (see Fig. 1). *Level of adaptation* and *SUS score* show a negative relationship (Spearmans Rho = −0.376; p = 0.017). This shows that—in this study—the higher the level of adaptation, the lower the *SUS score*.

Competing and Combined Multimodal Input: *Competing (1) vs. combined (2)* multimodal input and *SUS score* showed a negative relationship (Spearman's Rho = −0.653, p = 0.002). This may suggest that type of multimodal input can influence usability for people with ID.

SUS and OCS-R: The *OCS-R scores* from a previous study [7] and the *SUS scores* from the present study were compared to see if there was a correlation between participants' physical, mental, and communicative abilities and their ratings of the interface they were currently using. However, since we do not have these data for all current participants, only some were evaluated (n = 18). A strong positive relationship was found between *SUS* and *OCS-R scores* of interfaces with pointing gestures (Spearman's Rho = 0.913, p =<0.001). Due to the small sample size, we could not calculate correlations for the remaining cases (n = 8). These results may indicate that *OCS-R scores* on participants' abilities and skills to use the specific interface type may predict in advance how they will later evaluate its use and whether a specific interface will be accepted. However, this comparison would need to be repeated with more data to make a clearer statement.

Table 4. Individual SUS Items.

Input	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Pointing gestures	4.4	2.4	4.1	2.6	4.1	2.9	3.7	2.4	3.6	3.8
Buttons or switch elements	4.3	1.7	4.3	3.7	4.0	3.0	3.7	3.0	3.0	2.3
Object interaction + Buttons or switch elements	3.5	2.7	3.2	3.6	3.9	2.5	3.4	2.4	2.9	3.3
Pointing gestures + Buttons or switch elements	3.3	5.0	1.0	3.0	3.0	4.5	3.0	3.0	2.0	4.8
Pointing gestures + Voice interaction	5.0	1.7	3.7	3.0	5.0	2.0	3.7	1.7	2.3	2.3
Buttons or switch elements + Voice interaction	3.0	5.0	1.0	5.0	3.0	1.0	3.0	5.0	1.0	5.0
Pointing gestures + Object interaction	5.0	1.0	5.0	3.0	5.0	2.0	4.0	1.0	5.0	5.0
Pointing gestures + Buttons or switch elements + Voice interaction	1.0	4.0	2.0	5.0	4.0	2.0	4.0	2.0	3.0	1.0
Pointing gestures + Object interaction + Buttons or switch elements	3.0	3.0	3.0	3.0	3.0	4.0	2.0	2.0	3.0	2.0
Mean value	4.0	2.8	3.3	3.2	3.9	2.8	3.5	2.6	3.0	3.6

Individual Scores: It is not standard procedure, nor is it generally recommended, to report the scores for the individual items that make up the SUS. We do this to gain additional insight into how the different input modalities perform on individual items (1 = strongly disagree and 5 = strongly agree). Table 4 provides an overview of the individual results for the different input modalities.

It seems that participants tend to continue using most interfaces (Q1, mean 4.0). Regarding Q2 and Q3, which ask about the simplicity and complexity of the system, it is noticeable that there exist differences in the evaluation of simplicity and complexity between the interface types. This may be due to the input, but also to the degree of restriction of the persons. It is interesting to note that *voice interaction with pointing gestures* is generally considered low complexity and easy to use, while *voice interaction with buttons or switches* is considered rather complex and not easy to use. This may be due to the abilities of the participants: although all belong to target group 1, the participants using *voice with buttons or switches* had additional motor and communication limitations, whereas the participants using *pointing gestures and voice* did not.

Regarding Q5, in general, the functions of the solutions are sufficient (mean value = 3.9). Most of the time, the solutions are easy to understand (Q6) (mean value 2.6), but there are exceptions: *pointing gestures with buttons or switches* and *pointing gestures with object interaction, and buttons or switches* are considered difficult to understand.

Most participants did not find the solutions cumbersome to use (Q8, mean value 2.5), except with *buttons or switches and voice interaction.* Again, this probably has something to do with the abilities of the participants (with both motor and language difficulties), as it is more difficult for these cases to find a perfectly fitting solution from already existing consumer technologies.

The last question asked whether participants had to learn a lot before they could use the technology (Q10), which is more likely to be the case (mean 3.6). For some interface types, the results indicate that they had to learn a lot before using the technology. On the other hand, for other input types, participants didn't have to learn much before using the technology. It is interesting that *pointing gesture-only* interfaces are considered more complex to learn than *pointing gestures with voice interaction*, but again, the small group size must be considered.

5.2 Other Correlations

In addition to the *SUS scores*, referring to usability, the following relationships were found among the individual categories:

- **Level of Adaptation and Target Group (1–3)** show a positive relationship (Spearman's Rho = 0.519, p =< 0.001).
- **Level of Adaptation and Competing (1) or Combined (2) Input** show a positive relationship (Spearman's Rho = 0.494, p = 0.027).
- **Competing (1) or Combined (2) Input and Target Group (1–3)** show a positive relationship (Spearman's Rho = 0.527, p = 0.017).

This implies that people with more severe disabilities were more likely to use adapted technologies and more likely to use combined multimodal input. That is, the lower the person's limitation, the more often interfaces with multiple input modalities were used. Conversely, the higher the limitation, the more often interfaces were used where all input modalities were required to use the interface. These results may indicate that interfaces for people with more severe limitations need to follow a more defined pattern, with specified input modalities. Too many choices of input modalities could be too complex and lead to confusion. However, further studies would have to be conducted to investigate this in more detail.

5.3 Non-acquired Solutions

As mentioned before, 70 of the proposed solutions were not acquired or are no longer in use. This was due to various reasons (more than one reason may apply), such as:

1. *Prioritization (n = 28):* Participants had more than one participation wish and decided to implement other solutions.
2. *Not yet acquired (n = 16):* Some solutions had not yet been acquired at the time of publication of this study.
3. *No feedback (n = 12):* It is unclear why these solutions were not acquired. Since communication with people with intellectual disabilities requires multiple parties (for example, legal guardians, caregivers, parents), communication is often difficult. Often there was also no response to several queries.
4. *No acceptance (n = 7):* Solutions were acquired, but already at the beginning of usage the participant showed a rejection towards the technology.
5. *Budget (n = 6):* People with ID often have too little or no budget to purchase technology or cannot buy anything without the prior consent of a caregiver or legal representative. There were cases where the person was interested in the technology, but the caregiver or legal representative intervened, so there was no acquisition.
6. *Withdrawal from the study (n = 6):* Some participants decided themselves not to participate any longer or were obliged to do so by other circumstances (e.g., illness, death).

6 Conclusion and Outlook

In this study, different technical solutions, especially their interface types, were tested and evaluated for people with ID in everyday life. Usability was evaluated using the *System Usability Scale (SUS)* [8].

We found that the most used input type by participants with ID was *pointing gestures*, which was also the input type that could be used as a standalone interaction method a lot of the time. This makes sense, since at the moment, most consumer digital technologies use this type of input (e.g., smartphones, tablets), and some participants already owned a mobile device prior to this study. This input type was also the one that needed lesser adaptation in general and usability was perceived as acceptable (68.3), but usability was perceived higher when being used with additional system accessibility features (83.8). When used alongside other input modalities, it was mostly used with *buttons or switches*—where usability was perceived as rather low on average (30.0)—or *voice interaction*, where usability was perceived as higher (72.5).

Buttons or switch elements were the second most used type, interestingly mostly in combination with *object interaction*. Although this is an established interface type, it often required more adaptation, such as button adjustments (size, function, etc.) or finger guide grids. When used with *object interaction*, solutions had to be custom-built for participants, which can also be seen as a barrier. This type of input was often used by participants with more severe disabilities. Despite its potential, problems were encountered when interacting with the buttons or placing the tangible objects in the right spot.

Voice interaction was never used as a standalone input modality, only alongside *pointing gestures, buttons or switches* or both. Although *voice interaction* is often seen as having great potential for this target group [23,26], there are still major problems with its use. When this type of input was used, usability was considered relatively high, but many of the participants were not even able to try this type of interaction, so it was only used 7 times. At present, there are still too many barriers and difficulties in using voice input for people with ID, mainly due to pronunciation difficulties caused by language limitations or the complexity of the commands, and not many adaptations exist for this target group. Future developments will show whether this potential can be realized.

Interfaces with *touchless interaction* were generally too difficult for the participants to use, so the 4 initially planned solutions were not acquired. This type of input also doesn't have a lot of customization options, and in most cases other input modalities were easier to use for the participants.

Regarding the perceived usability of the solutions, the average scores were rather low (57.9), which shows that there is still a lot of room for improvement for people with ID using digital technologies. However, overcoming this is complex: we found that usability depended on many different factors, such as the age of the participants, whether the solution was suggested by experts or not, the level of adaptation used, or the type of multimodal input used—and these factors also depended on the level of disability the participants had. Solutions with no adaptation had higher scores, but were also more likely to be used by people with less severe disabilities. People with more complex and severe disabilities were more likely to use more adapted technologies and results suggest that too much choice between input modalities could possibly lead to confusion.

In the process of acquiring the individual solutions, it became clear that some solutions—even when the least expensive option was proposed by the researchers—were often quite expensive for the participants due to their limited financial resources. Successful acquisition and use of the solutions also had a lot to do with the time resources of the institution and its staff. It was noticeable that participants with a motivated carer or family member were offered more opportunities.

In conclusion, the usability of current NUIs is highly dependent on the person using them. To address this, it is important to incorporate the needs of users with ID into technology development processes, especially with regard to inclusivity and adaptability. This approach can help reduce the digital divide and increase participation in daily life. By prioritizing user-centered design and adaptability, NUIs can be developed that benefit and empower a wider range of people with ID, paving the way for a more inclusive digital future.

This study had several limitations. Not all input modalities were used equally often, so there are large differences between the group sizes. The use of an interface depended on the type of solution and the disability of the user. There are also limitations regarding the questionnaire: although we used a standardized questionnaire, it was not adapted for and tested with people with ID. The use of plain language has improved this, but it cannot be guaranteed that the questionnaire will be understood in the same way by everyone. It can never be assumed with certainty that people with ID have correctly understood or answered the questions in the questionnaire. Even though the participants with more severe disabilities always had a carer present when they completed the questionnaire, errors cannot be completely ruled out.

In the future, the long-term use of these solutions and interfaces will be further investigated. A second questionnaire will be sent out to participants who have recently started using the solution to determine possible changes in long-term use. This will allow us to determine any differences after they have become accustomed to the technology.

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