G. Bekaroo et al. (Eds.)

doi:10.3233/AISE230031

"One for All, All for One"

A first step towards universal access with a social robot

Julie PIVIN-BACHLER [a,1], Randy GOMEZ [b], and Egon L. VAN DEN BROEK [a]
[a] *Department of information and Computing Sciences, Utrecht University Utrecht, The Netherlands*
[b] *Honda Research Institute, 8-1 Honcho, Wako-shi, Saitama 351-0188, Japan*

Abstract. The number of worldwide inhabitants suffering from visual or hearing impairments reaches billions according to the World Health Organization, making the need for universal access and inclusion in Intelligent Environments (IE) essential. An adaptive Rock-Paper-Scissors application using a simulation of the social robot Haru is presented. The accessibility of the application which covers three modes - where the user able to see and hear, only to see, or only to hear - was verified through a user-study. A multivariate analysis of variance with repeated measures determined that the ratings from the 12 participants differed significantly across the three modes with $F(6,6) = 6.823$, $\eta_p^2 = .872$, $p = .017$. Results show that users tend to expect applications to be harder to use when suffering from a disability, especially a visual impairment. All modes in the application were deemed acceptable in terms of usability, proving that the multimodality that comes with IE can help in promoting universal access and reducing social exclusion.

Keywords. Universal Access, Intelligent Environment, Social Robots

1. Introduction

The World Health Organization (WHO) released a study in 2021 predicting a number of 2.5 billion people worldwide with hearing impairment by 2050[2]. Another study from WHO states that 2.2 billion people worldwide suffer from visual impairment[3]. Such high numbers reveal the importance to generalize Intelligent Environments (IE) applications to adapt to the capacities of every user, thus preventing social exclusion [1,2].

According to Augusto et al. [3], IE are physical spaces enriched with sensors, associated with an ambient intelligence that deals with the information gathered from these sensors. The components of an IE are orchestrated in order to interact with the spaces' occupant(s) in a sensible way, and enhance their experience. Universal access is considered as one of the seven grand challenges for living and interacting in such technology-augmented environments [4]. Ntoa et al. [5] demonstrate that when designing applications in IE, it is crucial to incorporate the needs, requirements, and preferences of all individual users. A survey on ambient intelligence states that the interrogations linked to

[1] Corresponding Author: Julie Pivin-Bachler, julie@pivin-bachler.eu
[2] https://www.who.int/news-room/fact-sheets/detail/deafness-and-hearing-loss
[3] https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment

accessibility need to be addressed to avoid social exclusion for certain users [6]. Indeed, the fast development of new technologies lead to a digital divide where vulnerable people, usually the elderly and the disabled, do not have access to new technologies because of their limited capacities [7]. To prevent this gap from getting larger, accessibility and inclusion are paramount when designing new applications in IE [7].

Application designs created to respond to the needs of a specific disability have already been proposed. AmIE [8] is an Ambient Intelligent Environment for the blind and visually impaired for indoor positioning and navigation and Apollo SignSound [9] was designed to integrate sign language in IE for users suffering from hearing loss. Both applications targeted a specific disability in their research. Obrenović et al.[10] and Kartakis et al. [11] are two of the rare examples that addressed several disabilities at once. They proposed respectively a methodological framework and tools to assist designers in developing universally accessible user interfaces. However, they did not present an actual application; they introduced guidelines to create one.

When considering game applications with social robots, the same assessment holds. Most of the existing applications can only be operated by users with no disability or with a specific one. Metatla et al. [12] proposes an educational game that fits the requirements for both sighted and visually impaired children. In his study, the robots are not social robots to directly converse or play with. They are used as a tool to make the game more accessible to visually impaired children.

Robotic agents are expected to be part of IE; they can be used for intelligence in healthcare [13], and they could prove useful to promote accessibility [4,14]. Following this idea, we propose that using a social robot as an agent managing the IE and interacting with the user is helpful for universal access. We present an interactive application with a social robot that can adapt to the user's capacities (cf. [14]). Our aim is to perform a user-study to verify the accessibility of the application when confronted with different disabilities. This paper sheds light on how IE with social robots can be used to promote universal access.

Section 2 presents the adopted design, including the presentation of the chosen social robot and the adaptive game design. Section 3 presents the evaluation of the application through a pilot user study. Finally, Section 4 discusses the results, summarizes the outcomes and illustrates possible future developments.

2. Design

2.1. Rock-Paper-Scissors

Following the goal of designing an application with a social robot accessible to all users, the first choice to make concerns the game to implement. Rock-Paper-Scissors is a relatively simple game. It consists of both the user and the robot simultaneously making a choice between Rock, Paper, and Scissors after a countdown from 3 to 1. Once both choices are stated, the winner of the round is determined. The rules are as follows: Rock smashes Scissors, Scissors cuts Paper, and Paper covers Rock.

The game Rock-Paper-Scissors has already been implemented on robots [15,16]. Ahn et al. [15] used a four-fingered robotic hand to play the game, associated with a camera to recognize the hand motion of the participant. Hasuda et al. [16] used a social

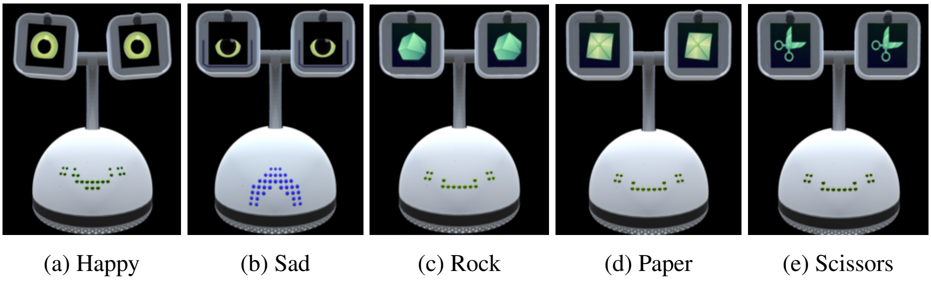

Figure 1. Eyes' display of the social robot Haru to express emotional states (a, b) and to show its choice in the Rock-Paper-Scissors game (c, d, e).

robot, also using a camera to recognize the user's hand motions. The robot responds with facial expressions depending on the outcome of the game. In both examples, vision, and hearing are essential to be part of the game and understand its proceedings. Therefore, the game cannot be played by a user who suffers either from visual or hearing impairments. The aim of the present research is to design a Rock-Paper-Scissors application with a social robot using the IE to adapt to any user, no matter their (dis)abilities.

2.2. The social robot Haru

In this project, the main element of the IE is the social robot Haru [17]. Haru is a table-top robot able to speak, hear, see with the help of cameras, and express different emotional states. Figure 1 demonstrates that Haru's eyes can help strengthen the expression of affective states. Only happy and sad are shown in Figure 1, but the possibilities are numerous: surprised, guilty, bored, angry, ... As presented in Figure 1, its eyes are also used as small screens to display elements such as Rock, Paper, or Scissors for the game. In previous work, Haru was implemented with the Rock-Paper-Scissors game to be evaluated as a telepresence robot to enhance social interaction between two physically separated users [18]. The same designs for Rock, Paper, and Scissors choices were used in the present study, see Figures 1c, 1d, and 1e. All tasks were implemented on Haru with the Robot Operating System (ROS) and Python code.

The physical robot Haru was not available to the researchers at this time; therefore, Haru's virtual environment is used. In an IE, the robot should be enhanced with cameras to see the user and keep eye contact (cf. [19]), multiple screens could be used as well as a physical buttons board. For this prototype, the screens are implemented by different windows that appear around Haru in the virtual environment, and the buttons board is also replaced by a window with which the user can interact through mouse clicks. Instead of the cameras we would use in the IE, the embedded camera from the computer with the virtual environment is used. In this prototype, Haru, acting as manager of the virtual IE, receives information from the camera, the microphone, and the clicks on the computer. To convey information, Haru is able to interact with the user through visuals - in its eyes or on the various windows on the screen -, sounds, and facial expressions.

This application begins by a short introduction from Haru where the proceedings of the game are explained. Then, the game starts and the user can, after each round, either decide to continue or to stop the game. Before closing, Haru states the final score and the winner of the game.

2.3. Three modes of perception

IE implies technological richness which allows for multimodal applications, both in terms of inputs from the user and outputs from the system, to create suitable interactions [4,5]. No single method of interaction can suit every user, which highlights the need for adaptive design [5]. Therefore, three modes of perception are considered in this study: the user is able to see and to hear, to see but not to hear, or to hear but not to see. The proceedings of the game vary accordingly to these distinct modes, see Table 1.

Table 1. Adaptation of the design for user perception (top part) and user expression (bottom part).

User's abilities	See and hear	Only see	Only hear
Score board	✓	✓	✗
Subtitles	✗	✓	✗
Face tracking	✓	✓	✗
Haru says the score	✗	✗	✓
Haru shows its choice	✓	✓	✗
Haru states its choice	✗	✗	✓
Buttons board	✓	✓	✗
Speech recognition	✗	✗	✓

The application stays very similar when the user is able to see and hear, and when the user is only able to see. The only difference is the subtitles added at the bottom of the screen when the user cannot hear, see Figure 2. Throughout the game, Haru speaks to the user - through sound or subtitles -, and expresses different feelings: Haru looks happy - see Figure 1a - when it wins a round or the game, and sad - see Figure 1b - when it loses.

For each round, the user makes their choice by clicking on the buttons board on the left side of the screen. At the same time, the user clicks on the button, Haru displays its own choice through its eyes as shown in Figures 1c, 1d, and 1e. The interface continuously displays the current score on the top right corner of the screen. Additionally, face tracking is implemented with the camera so that Haru can always be looking in the direction of the participant. To decide whether to continue or stop the game, the user is presented with a pop-up window containing a *Yes* or *No* alternative to pursue the game.

When the user is only able to hear, the interactions through clicks are replaced with speech recognition (with the Google speech-to-text API in Python), with the user stating his choices aloud. Haru states the current score aloud at the beginning of each round. To express its feelings, Haru uses small vocalizations sounding either happy or sad.

3. Evaluation

3.1. Study design

A within-subjects user-study with 12 participants was conducted. All participants share the same work profile. All are part of the department of Information and Computing Sciences from Utrecht University, Utrecht, the Netherlands. All interactions in the application are in English in which all participants are fluent.

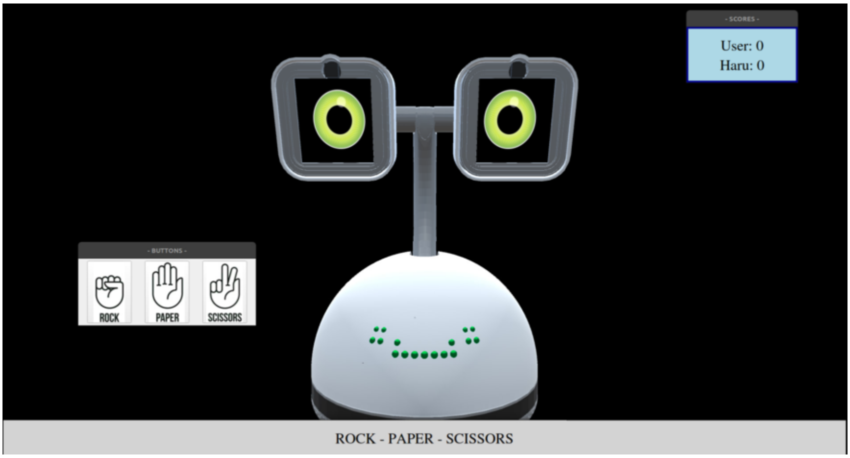

Figure 2. Display of the Rock-Paper-Scissors application with Haru's virtual environment for a user only able to see and not hear. For a user able to see and hear, the interface is similar, without subtitles. For a user only able to hear and not see, a black screen is displayed.

The three modes - see and hear (SH), see but not hear (S), and hear but not see (H) - are tried by each participant with a randomized order of the modes. There is 6 possible combinations for the modes' order, each done by 2 participants. All participants from the study are able to see and to hear. Therefore the sound from the computer was cut for mode S and the application displayed a black screen for mode H.

Two standardized usability questionnaires and two open questions are used to provide insights on the usability of the application for the different modes, see Table 2. The Usability Metric for User Experience (UMUX-LITE) is a 2-item standardized questionnaire, which rates the usability of a particular application with a percentage, the higher the score being the better [20]. Both items are rated on a 7-point Likert scale, from "Strongly disagree" (1) to "Strongly agree" (7). To aid interpretation, the scores of these items need to be transformed in order to fit the range of [0,100] from the System Usability Scale questionnaire [20]. For that purpose, the following linear regression is applied:

$$\text{UMUX-LITE} = 0.65 \cdot \left[[(item_1 - 1) + (item_2 - 1)] \cdot \frac{100}{12} \right] + 22.9, \quad (1)$$

where $item_1$ and $item_2$ are the scores on the 7-point Likert scale for each item of the UMUX-LITE. The operations performed inside the square brackets allow to have a result in the interval [0,100]. The rest of the equation is applied to compensate for the small but statistically significant difference that was found in previous work between the UMUX-LITE and the full UMUX version of the questionnaire [20].

The second questionnaire chosen is the Expectation Ratings (ER) [21]. It consists in collecting the expectation of an application's easiness of use before using it, and then the actual experienced ease of use of that same application. Similarly to the UMUX-LITE, it can be rated on a 7-point Likert scale which results in being able to use the second item of UMUX-LITE as the second item of ER as well, i.e. the one linked to the experienced ease of use. The ER can give two distinct information about accessibility in applications: first, the expectations ratings can show what the participants expect when deprived of their hearing or vision and when they are not. Secondly, the gap between experiences and expectations informs about whether the proposed adaptive design exceeded, matched, or subceeded the participant's expectations considering the mode they were in.

Table 2. Questionnaires and open questions filled in by the participant.

Questionnaire	Item
ER[21]	I expect the application to be easy to use knowing that I am able <*mode*>[a].
UMUX-LITE [20]	This application capabilities meet my requirements.
	This application is easy to use.
Open questions	Which mode suited you the best/the least, and why?
	Can you think of elements that might improve the application's accessibility?

[a] *<mode> ="to see and hear", "to see but not hear", or "to hear but not see".*

The experiment protocol is as follows: the participant is welcomed, invited to sit down in front of the computer, and a brief explanation about the experiment is given. The participant is told about the three modes and can ask about the general rules of the game. No information on how the game is played with the robot is given, as it should be self-explanatory in the application. To enhance the efficiency of face tracking and speech recognition, the participant has a white wall in the background and needs to wait for a "beep" sound before speaking. The participant is warned about this sound. How to rate items on a 7-point Likert scale is explained and the participant is told that they will have three items to rate for each mode. The participant is informed that they have to play from 2 to 4 rounds for each mode to have a complete experience. Before each mode, the participant rates the first ER item. The mode is launched by the researcher, then the two items from UMUX-LITE are rated by the participant. At the end of the experiment, two open questions are asked to the participant. They are then thanked for their participation with chocolates. The whole experiment takes around 15 to 20 minutes per participant.

3.2. Results

A repeated measures Multivariate ANalysis Of VAriance (MANOVA) that compared the three modes on the i) UMUX-LITE percentage obtained from Equation 1, ii) expectation rating, and iii) gap between experience and expectation, unveiled an overall difference between the three modes, $F(6,6) = 6.823, \eta_p^2 = .872, p = .017$. Subsequent Bonferroni corrected univariate tests gave more insights into the significance of each dependent variable taken separately as is shown in Figures 3, 4, and 5.

Figure 3 presents the estimated marginal means of the UMUX-LITE scores for the three modes. According to Bangor et al. [22], a score superior or equal to 70 is considered acceptable. The usability scores of mode S and mode H are close, with a value around 70. Even if mode SH exceeds the other two by 10, S and H still present correct usability scores, meaning the application is usable with visual or hearing impairments. In the open questions, the majority of participants declared preferring mode SH because it corresponds to what they are used to; thus, explaining the higher ratings for mode SH.

As demonstrated by Figure 4, the average expectation ratings for the three modes are substantially different. The expectations for mode H are the lowest with an average rating of 3.83. According to the 7-point Likert scale, it corresponds to the user somewhat disagreeing (3) or having a neutral opinion (4) on the expected application's ease of use

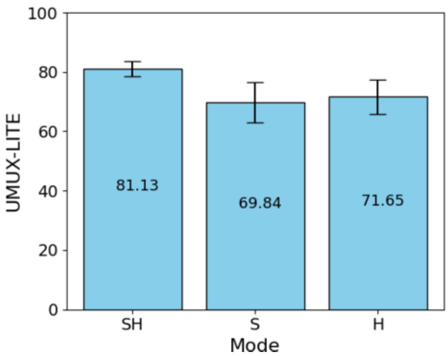

Figure 3: Estimated Marginal Means of the UMUX-LITE score for the three modes SH, S, and H with error bars for 95% confidence intervals. The UMUX-LITE scores differed across the three modes, $F(2,22) = 5.225, \eta_p^2 = .322, p = .014$.

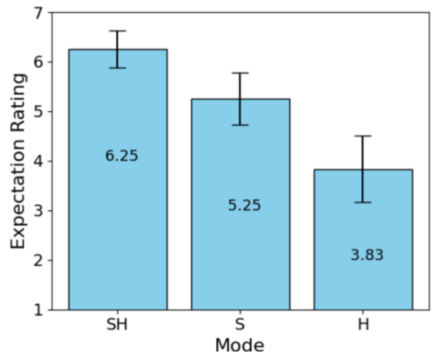

Figure 4: Estimated Marginal Means of the expectation ratings for the three modes SH, S, and H with error bars for 95% confidence intervals. The expectation ratings differed across the three modes, $F(2,22) = 15.400, \eta_p^2 = .583, p < .001$.

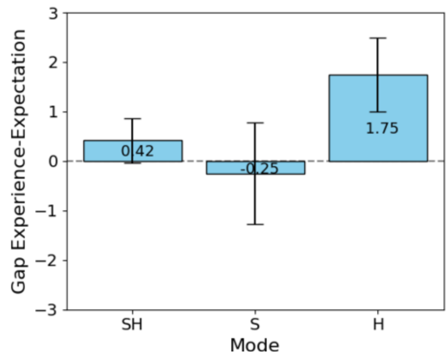

Figure 5: Estimated Marginal Means of the gap between experience and expectation ratings for the three modes SH, S, and H with error bars for 95% confidence intervals. The gap between the experience and expectation ratings differed between the modes, $F(2,22) = 4.738, \eta_p^2 = .301, p = .019$.

before trying it. Mode S also shows lower expectations than mode SH. It can be deduced that while participants expected an application easy to use when able to see and hear, they expected it to be harder when having a disability, especially a visual impairment.

The second element of interest in ER is the gap between the experiences and expectations of the user for the different modes. If the gap is positive or negative, it means the experience respectively exceeded or subceeded the initial expectation. A gap close to 0 indicates that the experience matched the expectations. Figure 5 shows that experiences largely exceeded expectations for mode H, meaning that the application design was substantially easier to use than what the participants expected. The experiences almost matched the expectations for modes SH and S. In average the experience was slightly exceeding expectations in mode SH, and slightly disappointing for mode S.

The answers on the open questions suggest that some participants were overwhelmed by the application in mode S. The visual elements are numerous and possibly hard to keep track of. This would explain the slightly negative gap between experience and expectation in mode S. Most participants preferred mode SH, as it is what they are accustomed to and is more engaging. In contrast, two participants found mode SH to be overwhelming with the use of multimodality - visuals and sound - making it harder to follow than modes S and H. The majority of participants disliked mode H the most, as it really differs from what they are accustomed to, and the pauses in the robot's speech could be confusing, leaving the participant wondering if they needed to say something or not. In mode H, four participants felt the game was unfair because they had to state their choice before Haru, which gave the impression that Haru has an advantage over them.

On the elements to add to make the game more accessible, the choice of interaction with the application was recurrent. Some participants would have appreciated being able to click on physical buttons instead of stating their choice aloud in mode H, and some others would have preferred to always speak instead of clicking in modes S and SH. It was mentioned by several participants that the clicking interaction could be enhanced with a touch screen instead of a mouse or pad. Concerning the display, the only recurring element found concerned mode S, where it was suggested that the visuals should be placed more on the same level to prevent having too many places to look at. Another suggestion was to add more flashy colours or blinking elements to direct the user's gaze.

4. Discussion

Despite the small number of 12 participants, differences between the three modes: i) see and hear, ii) only see, and iii) only hear were unveiled in favor of see and hear. The Rock-Paper-Scissors application's usability was considered good in all modes. Expectations differed among the modes, with see and hear having the highest expectations and only hear the lowest. With both see and hear and only see, the application met the participants' expectations. With only hear, it performed above expectations. Altogether, the results suggest that the social robot Haru can support people with a visual or hearing impairment.

It would be beneficial to perform a study with participants with an impairment. Undoubtedly, this would give additional insights into the game's accessibility. Nevertheless, this study already highlighted several interesting aspects such as a feeling of unfairness with the hear mode, differences in preference of interaction, and a general preference for the multimodal mode, with see suggested to be the most important aspect (cf. [23]).

The social robot Haru can be considered as a first point of contact, a manager, or a butler in an IE. Different windows on the computer replace actual screens and the computer's camera and microphone are used instead of the robot ones. Future work in an actual IE with a design based on this prototype would give more insights into how the use of an IE can promote universal access. Following participants' suggestions, different elements could be added to an IE, which were not in the prototype. These could include connected lights to attract the user's attention on a specific element or to engage them more in the game. Also, physical buttons instead of clicking on a computer was a recurring suggestion from the participants. Wearable sensors could be added to enhance Haru's knowledge of the current physiological and affective state of the user [24].

Two disabilities are included in this study, but universal access should consider many more and cover cases of multiple disabilities. A user could be able to see and hear, but not to click or press buttons, so speech recognition should be available in all modes. A person not able to see and speak would make good use of the physical buttons mentioned earlier. Several factors can be thought of for the manner of perceiving information, such as choosing visuals, sounds, or both. Other elements could be tuned such as paralinguistic aspects of speech [24] and the speed of speech of the robot to avoid an application going too fast for an individual, or too slow with too many long pauses [25].

Physical and cognitive abilities vary throughout life with ageing leading to a decrease in these abilities. IE should adapt to suit the user by meeting their changing requirements [4,14]. Future work could implement a multimodal device where the user can communicate their (dis)abilities. The application should adapt accordingly by providing a suitable method of interaction. In such an IE, Haru can act as manager and relay the information to the different devices to manage inputs and outputs selected methods.

This study proposed a prototype with an adaptive design for an application of Rock-Paper-Scissors with the social robot Haru. To be adaptive to different disabilities, the game had three distinct modes where the user could either see and hear, only see, or only hear. The performed user-study showed significant results on several levels. It suggested that users expected the application to be harder when put into a condition with a disability, especially with a visual impairment. In the end, their expectations were exceeded because the application was on average thought to be accessible in all modes.

Acknowledgements

We thank our partners, members from the HONDA project between the Honda Research Institute in Japan and Utrecht University in the Netherlands, for making the virtual environment of Haru available to us for this research.

References

[1] van den Broek EL. ICT: Health's best friend and worst enemy? In: van den Broek EL, Fred A, Gamboa H, Vaz M, editors. BioSTEC 2017: 10th International Joint Conference on Biomedical Engineering Systems and Technologies, Proceedings Volume 5: HealthInf. Porto, Portugal: SciTePress – Science and Technology Publications, Lda.; 2017. p. 611-6. doi:10.5220/0006345506110616.

[2] Foley A, Ferri BA. Technology for people, not disabilities: ensuring access and inclusion. Journal of Research in Special Educational Needs. 2012;12(4):192-200. doi:10.1111/j.1471-3802.2011.01230.x.

[3] Augusto JC, Callaghan V, Cook D, Kameas A, Satoh I. "Intelligent Environments: A manifesto". Human-centric Computing and Information Sciences. 2013 Jun;3(1):12. doi:10.1186/2192-1962-3-12.

[4] Stephanidis C, Salvendy G, Antona M, Chen JYC, Dong J, Duffy VG, et al. Seven HCI Grand Challenges. International Journal of Human–Computer Interaction. 2019 Aug;35(14):1229-69. doi:10.1080/10447318.2019.1619259.

[5] Ntoa S, Margetis G, Antona M, Stephanidis C. Digital Accessibility in Intelligent Environments. In: Duffy VG, Lehto M, Yih Y, Proctor RW, editors. Human-Automation Interaction. vol. 10. Cham: Springer International Publishing; 2023. p. 453-75. doi:10.1007/978-3-031-10780-1_25.

[6] Dunne R, Morris T, Harper S. A Survey of Ambient Intelligence. ACM Computing Surveys. 2022 May;54(4):1-27. doi:10.1145/3447242.

[7] Pérez-Escolar M, Canet F. Research on vulnerable people and digital inclusion: Toward a consolidated taxonomical framework. Universal Access in the Information Society. 2023;[in press]. doi:10.1007/s10209-022-00867-x.

[8] Kandil M, AlAttar F, Al-Baghdadi R, Damaj I. AmIE: An Ambient Intelligent Environment for Blind and Visually Impaired People. In: Paiva S, editor. Technological Trends in Improved Mobility of the Visually Impaired. Cham: Springer International Publishing; 2020. p. 207-36. doi:10.1007/978-3-030-16450-8_9.

[9] da Rosa Tavares JE, Victória Barbosa JL. Apollo SignSound: an intelligent system applied to ubiquitous healthcare of deaf people. Journal of Reliable Intelligent Environments. 2021 Jun;7(2):157-70. doi:10.1007/s40860-020-00119-w.

[10] Obrenović Z, Abascal J, Starčević D. Universal accessibility as a multimodal design issue. Communications of the ACM. 2007;50(5):83-8. doi:10.1145/1230819.1241668.

[11] Kartakis S, Stephanidis C. A design-and-play approach to accessible user interface development in Ambient Intelligence environments. Computers in Industry. 2010 May;61(4):318-28. doi:10.1016/j.compind.2009.12.002.

[12] Metatla O, Bardot S, Cullen C, Serrano M, Jouffrais C. Robots for Inclusive Play: Co-designing an Educational Game With Visually Impaired and sighted Children. In: Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems. New York, NY, USA: Association for Computing Machinery; 2020. p. 1-13. doi:10.1145/3313831.3376270.

[13] van den Broek EL, van der Sluis F, Dijkstra T. Cross-validation of bi-modal health-related stress assessment. Personal and Ubiquitous Computing. 2013;17(2):215-27. doi:10.1007/s00779-011-0468-z.

[14] van den Broek EL. Robot nannies: Future or fiction? Interaction Studies. 2010;11(2):274-82. doi:10.1075/is.11.2.16van.

[15] Ahn HS, Sa IK, Lee DW, Choi D. A playmate robot system for playing the rock-paper-scissors game with humans. Artificial Life and Robotics. 2011 Sep;16(2):142. doi:10.1007/s10015-011-0895-y.

[16] Hasuda Y, Ishibashi S, Kozuka H, Okano H, Ishikawa J. A robot designed to play the game "Rock, Paper, Scissors". In: 2007 IEEE International Symposium on Industrial Electronics; 2007. p. 2065-70. ISSN: 2163-5145. doi:10.1109/ISIE.2007.4374926.

[17] Gomez R, Szapiro D, Galindo K, Nakamura K. Haru: Hardware Design of an Experimental Tabletop Robot Assistant. In: Proceedings of the 2018 ACM/IEEE International Conference on Human-Robot Interaction. HRI '18. New York, NY, USA: Association for Computing Machinery; 2018. p. 233-40. doi:10.1145/3171221.3171288.

[18] Brock H, Šabanović S, Gomez R. Remote You, Haru and Me: Exploring Social Interaction in Telepresence Gaming With a Robotic Agent. In: Companion of the 2021 ACM/IEEE International Conference on Human-Robot Interaction. HRI '21 Companion. New York, NY, USA: Association for Computing Machinery; 2021. p. 283-7. doi:10.1145/3434074.3447177.

[19] van der Sluis F, van den Broek EL. Feedback beyond accuracy: Using eye-tracking to detect comprehensibility and interest during reading. Journal of the Association for Information Science and Technology. 2023;74(1):3-16. doi:10.1002/asi.24657.

[20] Lewis J, Utesch B, Maher D. UMUX-LITE: When there's no time for the SUS. In: Proceedings of the CHI Conference on Human Factors in Computing Systems. New York, NY, USA: Association for Computing Machinery; 2013. p. 2099-102. doi:10.1145/2470654.2481287.

[21] Albert W, Dixon E. Is this what you expected? The use of expectation measures in usability testing. In: Proceedings of UPA 2003: 12th Annual UPA Conference. Scottsdale, AZ, USA: Usability Professionals Association; 2003. p. Article 10. doi:not available.

[22] Bangor A, Kortum PT, Miller JT. An Empirical Evaluation of the System Usability Scale. International Journal of Human–Computer Interaction. 2008 Jul;24(6):574-94. doi:10.1080/10447310802205776.

[23] van der Sluis F, van den Broek EL, van Drunen A, Beerends JG. Enhancing the quality of service of mobile video technology by increasing multimodal synergy. Behaviour & Information Technology. 2018;37(9):874-83. doi:10.1080/0144929X.2018.1505954.

[24] van den Broek EL, Schut MH, Westerink JHDM, Tuinenbreijer K. Unobtrusive Sensing of Emotions (USE). Journal of Ambient Intelligence and Smart Environments. 2009;1(3):287-99. doi:10.3233/AIS-2009-0034.

[25] Beerends JG, Neumann NMP, van den Broek EL, Llagostera A, Vranic J, Schmidmer C, et al. Subjective and objective assessment of full bandwidth speech quality. IEEE/ACM Transactions on Audio, Speech and Language Processing. 2020;28(1):440-9. doi:10.1109/TASLP.2019.2957871.