VOICE Actuated Control Systems (VACS) for Accessible and Assistive Smart Homes. A Preliminary Investigation on Accessibility and User Experience with Disabled Users

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Abstract Recently, mobile and in-home Voice Actuated Control Systems (VACs) have become affordable and reliable, allowing the control of several IoT devices from a distance. Individuals with motor impairments could benefit from VACS installed in smart domestic environments to operate home appliances and other devices. The

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present paper explores the potentials of using such systems in terms of accessibility and user experience by involving a group of individuals with motor disabilities and mild speech impairments. Participants were invited to directly try out the voice-controlled assistant by operating different smart devices (e.g., lights, fan) in a friendly living-room like environment. Results show that all participants were able to perform the proposed tasks after a brief practice section and few failures, and that the interaction experience was well received by participants.

Keyword Voice actuated control systems · Voice user interfaces · Voice-controlled assistants · Motor disability · Smart devices · Disabled users · Accessibility · Smart home

1 Introduction

Voice Actuated Control Systems (VACs) and their Voice User Interfaces (VUIs) are becoming increasingly accessible in our everyday lives. Thanks to technological advancements, voice recognition units can reliably identify speech entities in near-real time [1]. Moreover, the drop of their cost [2] has made VACs and VUIs a common way to interact with a wide range of technologies, e.g., in-vehicle assistants, smartphone, and smart home technologies. Several major companies have developed voice-controlled home-based assistants which exploit VUIs (e.g., Google Home or Amazon Echo). These systems offer users hands-free voice control and allow to perform a variety of different activities, such as asking for information, playing video and music, and operating smart home appliances.

While in many studies voice-controlled home-based assistants have been evaluated with able-bodied users, the experience of disabled users has been overlooked so far. Nevertheless, people with motor disabilities could benefit from the interaction with voice-controlled home-based assistants, because no motor interaction is involved. For example, users with limited mobility could control door locks, thermostats, and home's lighting by issuing voice commands [3–5]. Thus, these systems may improve the autonomy of people with motor disabilities and, in general, positively affect their quality of life.

The aim of the present study is to assess the feasibility of using a voice-controlled home assistants (i.e., Google Home) with a group of participants with motor disabilities and in some cases slightly impaired speech production.

1.1 VACSs and Individuals with Disabilities

People suffering from motor disabilities can present a wide range of secondary deficits, including speech impairments. The degree of speech impairment is variable

and the clinical picture is different for each patient. In general, the language production can show abnormalities in terms of phonatory, articulatory, or prosodic aspects [6]. Although people with motor disabilities may benefit from the use of VACs, the coexistence of motor and language deficits raises some issues about accessibility of these patients to these systems. Indeed, speech impairment can hamper accessibility to VACs [7].

Since VACs are relatively new, especially voice-controlled home-based assistants, few studies investigated how speech impairment can affect accessibility to these systems. Rudzicz and colleagues [8] explored speech interactions with personal assistive robots in a group of older adults with Alzheimer Disease. The authors showed how the linguistic difficulties of patients, namely the non-continuous speech, represented a barrier of accessibility to the use of speech-based assistants. Similarly, Pradhan and colleagues [9] observed that one of the main accessibility problems in people with physical disabilities concerned the speech interaction. In this work, authors observed that some users with speech problems reviewed speech-based assistants as inaccurate in speech recognition. In particular, users could not pronounce clearly or loudly enough the command, and the device timed out before the user could complete the command.

Taken together, these studies highlight how speech problems can negatively impact accessibility of voice-controlled home-based assistants in users with disabilities. Of interest, previous studies developed voice-controlled systems designed on the needs of individuals with speech impairments. Hawley and colleagues [10] described a prototype, installed on a laptop, of a speech-based environmental system (to control TV, radio, and a lamp) for individuals with severe dysarthria. The authors showed promising results, even if the designed system required very long training (namely a 6-week period) to increase its response accuracy. In a more recent research [11], another prototype was developed but still the time needed for the training phase was very long (2–4 weeks).

In this paper, we present an experiment that involved individuals with motor and mild speech deficits.

2 The Study

The present study reports on a preliminary evaluation that aimed to evaluate the feasibility of an affordable voice-controlled home-based assistant (i.e., Google Home) for individuals with motor disabilities and deficit in speech production. More specifically, two sessions have been run so far, each one week apart. The session lasted about 2 h and a half and was conducted by an expert moderator and one assistant. Four participants with motor disabilities accompanied by two professional assistants were involved in each session.

2.1 Participants

A total of 8 participants (M age = 40.5, SD = 7.56; F = 4) were involved in the study. They were all individuals with motor disabilities (N = 7, needed a wheelchair) and had mild issues in speech production. The medical history of participants showed ascertained motor and language impairments.

2.2 Setting and Equipment

The experimental sessions took place in a living laboratory. The room was furnished with a large table, two smart lamps, a fan connected to a smart plug, and a large TV screen connected to Google Chromecast. All the devices were connected to Google Home (Inc.), which allowed to control several functions.

2.3 Tasks

Several realistic tasks were arranged, which involved the following devices: smart lamps, a fan connected to a smart plug, and a smart TV. Participants were asked to activate a series of functions using the Google Home system (e.g., changing the color lamp, turning on/off the fan, selecting a song from Spotify). Furthermore, other tasks concerned different activities which involved only Google Home (e.g., asking the weather forecast). A detailed list of considered devices and commands is showed in Table 1.

2.4 Procedure

On the day of the test, participants were welcomed at the premises of the Human Inspired Technology Research Center (University of Padova) and were debriefed on the purpose and unfolding of the activity. We conducted the study in two different sessions that lasted about 2 h and a half each. An expert moderator and one assistant conducted the sessions. In each session, four participants and two professional assistants were involved. During the experimental sessions the atmosphere was kept friendly and informal, not to stress participants. Before starting the session, participants gave their informed consent. Afterwards, an experimenter introduced the Google Home device and explained how to operate it by providing several practical examples. Participants were instructed how to properly convey the commands. In particular, they were told that, after activating Google Home using the “Hey Google” command, they had to wait for the light feedback to show before pronouncing the

Table 1 List of devices and commands participants were asked to perform during the session

Device	Command
Smart lamps	Turning on/off
	Changing colours
	Changing light intensity
Fan	Turning on/off
TV (Netflix)	Selecting movies,
	Pausing
	Playing
TV (YouTube)	Selecting videos
	Increasing/decreasing volume
TV (Spotify)	Selecting songs
	Increasing/decreasing volume
Google Home	Asking the latest news
	Asking the weather forecast
	Setting an alarm

actual command. Participants were invited to try out some sample commands, in order to ensure that they had understood the instructions. After this preliminary phase, every user was invited to carry out a set of tasks. To keep the sessions friendly and prevent participants the feel- ing of being in a 'testing situation', the sequence of tasks was alternated across participants. In case difficulties in speech recognition arose, in order to avoid frustration, participants were gently encouraged and supported by the moderator to try again. At the end of each session, a set of questions was asked to collect participants' opinions regarding their experience. A brief interview was run, including questions regarding: an overall evaluation of the interaction with the device; preferences regarding the different controls and the location in their homes for Google Home; and which other smart devices they would like to control by means of this device. Meanwhile, the other trained observer was responsible for taking notes while monitoring participants' interactions and spontaneous comments.

2.5 Results

The Google Home system was well received by all participants. Indeed, the responses showed a generally positive opinion of the interaction with such a device. Overall, participants were able to accomplish the proposed tasks. In some cases, they had to attempt several times in order to be able to properly give the specific commands to Google Home. Indeed, sometimes users did not wait the light feedback on the Google Home device before starting speaking, so the device did not process the commands. In other instances, users waited too long and the system was not capable of elaborate

the message. In both cases, Google Home was providing an error message "I'm sorry, I do not know how to help you".

Considering the general evaluation of the systems, users assigned at least 8/10 or more than the maximum possible score of the scale to the device (e.g., P04: "I mark Google Home 20 out of 10"). In regard of the preferred functions, some of the respondents reported the music control (N = 4/8) and the majority were interested in being able to turn on/off the lights (N = 7/8). Participants would like to have the opportunity of utilizing this speech-based interface mainly in the living room (N = 6/8) and in their bedrooms (N = 8/8). The majority of the respondents expressed the desire to have Google Home also at their home (N = 6/8). Finally, participants mentioned several other devices that they would like to control using Google Home (e.g., P06: "to control the computer"; P03: "changing the environmental temperature", "opening/closing the blinds").

3 Discussion

The aim of this study was to assess the feasibility of using one voice-controlled home-based assistant (i.e., Google Home) in a group of participants with motor disabilities and co-existing speech production impediments. People with motor disabilities could benefit from these devices, as long as their speech abilities are partially preserved. Unfortunately, speech production abnormalities frequently coexist with motor impairments and those few studies that investigated this topic show that speech production impediments hamper accessibility to voice-speech assistants [8, 9]. Contrary to this premise, one of the most important results of this study concerns the fact that, although our participants were characterized by a peculiar clinical picture with motor and speech problems, everyone was able to operate the voice-controlled home-based assistant. This encouraging outcome suggests that within a certain degree of speech impairment, these devices may be accessible to people with motor disabilities. Our results are in line with a previous study by Ballati and colleagues [12] that verified to which extent patients with dysarthria could be understood by three virtual assistants, namely Siri, Google Assistant, and Amazon Alexa. The study reported a percentage of speech recognition accuracy around 50–60%, without differences between the systems. However, they did not involve human patients.

In the present study, we overcome this limitation by recruiting human participants. Our results show that almost all the participants were able to carry out the commands correctly. This success could be given by the fact that the interaction between the participant and the device was guided by the experimenter [13]. Indeed, the solely feedback provided by Google Home "I'm sorry, I do not know how to help you" it is not sufficient to make the users understand if the device has not understood the message or that it is intrinsically not able to accomplish that specific task. Therefore, at least in a first phase in which the disabled user is instructed, the presence

of a caregiver could be crucial to close the gap between disabled users and voice-controlled home-based assistant. The second result regards the quality of experience reported by participants. In general, participants reviewed the system enthusiastically. The Google Home system was well received by all participants. Indeed, the responses showed a generally positive opinion of the interaction with the device. This result reveals that in an assisting living context, voice-controlled home-based assistants could be well accepted by users with physical disabilities. To conclude, results of this study encourage to further develop voice-controlled home-based assistants, especially keeping in mind the needs of people with physical disabilities [14]. To improve accessibility of people with disabilities, future voice-controlled systems could exploit supplementary modalities, for example, the combination of speech and gesture modalities [15]. In addition, future studies should also consider the integration between VACs and voice control wearable devices, after a proper user acceptance evaluation [16]. The integration of these systems may allow disabled people to control remote devices everywhere and break down physical barriers that these people face every day. Furthermore, the installation of these systems in ambient-assisted living scenarios (e.g., co-housing solution and nursing home) could improve quality of life and safety in disabled people [17]. Definitely, these devices could represent an important opportunity that can be leveraged by many disabled people to support them achieve daily routines and overcome everyday challenges.

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References

1. Andolina S, Orso V, Schneider H, Klouche K, Ruotsalo T, Gamberini L, Jacucci G (2018) Investigating proactive search support in conversations. In: Proceedings of the 2018 designing interactive systems conference. ACM, pp 1295–1307
2. Noda K (2018) Google Home: smart speaker as environmental control unit. Disabil Rehabil Assist Technol 13(7):674–675
3. Rudzionis V, Maskeliunas R, Driaunys K (2012) Voice controlled environment for the assistive tools and living space control. In: 2012 federated conference on computer science and information systems (FedCSIS). IEEE, pp 1075–1080
4. Busatlic B, Dogru N, Lera I, Sukic E (2017) Smart homes with voice activated systems for disabled people. TEM J 6(1):103
5. Domingo MC (2012) An overview of the Internet of Things for people with disabilities. J Netw Comput Appl 35(2):584–596
6. Duffy JR (2013) Motor speech disorders-E-book: substrates, differential diagnosis, and management. Elsevier Health Sciences
7. Brewer RN, Findlater L, Kaye JJ, Lasecki W, Munteanu C, Weber A (2018) Accessible voice interfaces. In: Companion of the 2018 ACM conference on computer supported cooperative work and social computing. ACM, pp 441–446
8. Rudzicz F, Wang R, Begum M, Mihailidis A (2015) Speech interaction with personal assistive robots supporting aging at home for individuals with Alzheimer's disease. ACM Trans Access Comput (TACCESS) 7(2):6

9. Pradhan A, Mehta K, Findlater L (2018) Accessibility came by accident: use of voice-controlled intelligent personal assistants by people with disabilities. In: Proceedings of the 2018 CHI conference on human factors in computing systems. ACM, p 459
10. Hawley MS, Enderby P, Green P, Cunningham S, Brownsell S, Carmichael J, Palmer R (2007) A speech-controlled environmental control system for people with severe dysarthria. Med Eng Phys 29(5):586–593
11. Hawley MS, Cunningham SP, Green PD, Enderby P, Palmer R, Sehgal S, O'Neill P (2013) A voice-input voice-output communication aid for people with severe speech impairment. IEEE Trans Neural Syst Rehabil Eng 21(1):23–31
12. Ballati F, Corno F, De Russis L (2018) Hey Siri, do you understand me?: virtual assistants and dysarthria. In: Workshop proceedings of the 14th international conference on intelligent environments (IE 2018)
13. Derboven J, Huyghe J, De Grooff D (2014) Designing voice interaction for people with physical and speech impairments. In*:* Proceedings of the 8th Nordic conference on human-computer interaction: fun, fast, foundational. ACM, pp 217–226
14. Reyes-Cruz G, Fischer J, Reeves S (2019) An ethnographic study of visual impairments for voice user interface design. arXiv:1904.06123
15. Anastasiou D, Jian C, Zhekova D (2012) Speech and gesture interaction in an ambient assisted living lab. In: Proceedings of the 1st workshop on speech and multimodal interaction in assistive environments. Association for Computational Linguistics, pp 18–27
16. Spagnolli A, Guardigli E, Orso V, Varotto A, Gamberini L (2015). Measuring user acceptance of wearable symbiotic devices: validation study across application scenarios. In: International workshop on symbiotic interaction. Springer, Cham, pp 87–98
17. Gamberini L, Fabbri L, Orso V, Pluchino P, Ruggiero R, Barattini R, Sozza A (2018) A cyber secured IoT: fostering smart living and safety of fragile individuals in intelligent environments. In: Italian Forum of Ambient Assisted Living. Springer, Cham, pp 335–342