Using Mobile Devices to Support Communication between Emergency Medical Responders and Deaf People

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ABSTRACT

Fast and effective communication is crucial during medical emergencies, but patients' disabilities can make it a challenging task for emergency medical responders. This paper proposes a mobile system to deal with the communication barrier between medical responders and deaf patients. The system allows medical responders to quickly browse a collection of emergency-related sentences, and show videos of the corresponding translations in sign language to the deaf patients. The design process involved experts in emergency medicine as well as experts from the deaf community. The evaluation carried out on ten emergency medical responders and ten deaf subjects showed that the system is useful to support communication with deaf people during medical emergencies.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—*Graphical user interfaces (GUI), User-centered design*; J.3 [**Life and Medical Sciences**]: *Health*; K.4.2 [**Computers and Society**]: Social Issues—*Assistive technologies for persons with disabilities*

General Terms

Design, Experimentation, Human Factors

Keywords

Computer-mediated communication, sign languages, medical emergencies, mobile devices, deaf people, first responders

1. INTRODUCTION

Fast and effective communication is crucial during medical emergencies. For example, emergency medical responders (hereinafter, EM responders) have to quickly and accurately elicit information about symptoms and medical history of patients to provide them with the most appropriate treatment. However, communication can be a challenging task for EM responders, and becomes even more difficult when communication barriers (e.g., people with sensory or cognitive disabilities, foreign language speakers) are present.

In this paper, we focus on the linguistic barrier between EM responders and deaf people who communicate using a sign language. Sign languages, which vary from country to country, are visual languages that rely on finger, hand, arm and body movements. More precisely, given a specific sign language such as the American Sign Language (ASL) or the Italian Sign Language (LIS), a sign with a particular meaning is uniquely identified by four parameters (i) *handshape*, i.e., the position of fingers or their movement, (ii) *palm orientation*, i.e., the direction towards which the palm is facing, (iii) *location*, i.e., the part of the body or a place close to it where the sign starts to be performed, and (iv) *movement*, i.e., the sequence of positions of the hands in space during performance of the sign. Recently, some sign languages have also introduced *facial expression* to distinguish among signs.

Signs are combined in sign language sentences following a specific grammar, which can be very different from that of spoken language in the same country. Therefore, deaf people whose first language is a sign language can have difficulties in reading and writing in languages used by hearing people [4, 6]. This is particularly critical in emergency situations, since written questions, instructions, and descriptions of the activities that EM responders are going to perform can be misunderstood by deaf people. Moreover, while deaf people can usually rely on interpreters or relatives to have speech translated into their sign language during planned events (e.g., a physical examination or a meeting), they may be alone during a medical emergency.

Despite the communication barrier, EM responders should ask deaf patients some fundamental questions (e.g., about pain location and intensity) to distinguish between different pathologies and administer the right treatments, some activities have to be described by EM responders to deaf patients before being performed (this is mandatory in some countries, since patients have the right to decline treatments), and deaf patients should properly understand some life-critical instructions (e.g., about medicines to take). To help EM responders communicate with deaf people using sign language, this paper proposes a mobile system. The system allows

MobileHCI'10, September 7–10, 2010, Lisbon, Portugal.
ACM 978-1-60558-835-3/10/09.

EM responders to quickly browse a collection of emergency-related sentences, and show videos of the corresponding sign language translations to deaf patients.

The paper is organized as follows. Section 2 describes related work, focusing, in particular, on existing systems that support communication between deaf and hearing people, and were applied to realistic settings. Section 3 introduces the proposed mobile system, its design, and its flexible implementation to support different emergency medical services and sign languages. The application of the system to the Italian Emergency Medical Service is described in Section 4. Section 5 describes the experimental evaluation with ten EM responders and ten deaf subjects, while its results are discussed in Section 6. Section 7 concludes the paper by summarizing lessons learned and outlining future research.

2. RELATED WORK

To support communication between deaf and hearing people, some researchers (e.g., [2, 3, 4, 13, 14]) are working on real-time translation from speech to sign and vice versa. Speech-to-sign translation involves (i) *speech recognition*, i.e., the recognition of a spoken sentence and its transcription into written text, (ii) *semantic interpretation*, i.e., the interpretation of the meaning of the written text for translating it into an equivalent sign language sentence, and (iii) *sign language synthesis*, i.e., the synthesis of the signs in the sign language sentence by means of videos or animations of virtual humans. Sign-to-speech translation involves (i) *sign language recognition*, i.e., the analysis of data from input devices such as cameras and data gloves to recognize gestures that correspond to particular signs in a sign language sentence, (ii) *semantic interpretation*, i.e., the interpretation of the meaning of the sign language sentence for translating it into the corresponding written text of a spoken language, and (iii) *text-to-speech*, i.e., the synthesis of the spoken sentence corresponding to the written text.

Some systems have been proposed to perform speech-to-sign (e.g., [2, 4]) or sign-to-speech (e.g., [13, 14]) translation. However, while speech-to-text and text-to-speech technologies are mature enough for some real-world applications and a recent approach [3] to sign language recognition has achieved a recognition rate of 91.9% using a vocabulary of 5113 signs, semantic interpretation remains challenging, so we cannot expect translation to be fully automated in a near future [6] and recent system such as [13, 14] do not currently deal with it. Therefore, all current systems applied in realistic settings have to introduce simplifications such as:

- *Limiting the sentences that the system accepts to a set of pre-defined ones.* For example, Tessa [1] is a system to translate English sentences spoken by UK Post Office clerks into British Sign Language (BSL) signs, performed by a 3D virtual human. The system was evaluated with six deaf subjects and three clerks, using a set of 133 sentences with 444 signs. Transactions handled using the system lasted longer and were perceived by clerks and deaf users as worst than transactions handled without the system, but limiting the set of sentences was not among the main factors that caused these negative results.

- *Using a hybrid between a sign and a spoken language instead of a real sign language.* For example, the commercial system iCommunicator [12] recognizes spoken English words and shows the corresponding written words. Then, it shows the sign for each recognized word without any semantic interpretation, so signs are shown in the same order of the words in the spoken sentence instead of following ASL grammar. The resulting language, called Signed English, is a hybrid between English and ASL, and might be useful to deaf people who have learned English, while it is confusing for deaf people who always use ASL.

- *Using forms of communication without signs.* For example, the system described in [11] supports medical conversation between a hearing physician and a deaf patient by showing the written transcription of physician's spoken sentences together with medical images (e.g., diet plans) on a tabletop display. The system does not integrate sign language support, but the authors are considering such feature as future work.

While none of the previously mentioned systems addresses emergency issues, two proposals [9, 15] deal with communication between emergency responders and deaf people. CAP-ONES [9] is a web-based system for emergency responders to send alert notifications (e.g., about earthquakes or homeland security). By exploiting an ontology on accessibility, devices, disabilities, emergencies, and media, alert notifications are tailored to recipients' disabilities and the devices they can use. TTY Phone [15] is a mobile system that allows deaf people to contact an emergency service dispatcher. By using an instant messaging style interface, deaf people can send and receive text messages that are converted into signals for teletypewriters, i.e., text-based telecommunications devices, which are mandatory installed in all US emergency call centers. Both the described proposals support communication between deaf people and emergency responders who provide them with preliminary help from a distance, while no proposal supports communication between deaf people and emergency responders who help them on the field.

3. THE PROPOSED SYSTEM

3.1 Requirements analysis

To design our system to support communication between deaf people and EM responders on the field, we firstly identified needed features and possible simplifications of the translation process in an emergency setting. To this purpose, we involved the local emergency medical service and deaf community to elicit information that guided the design and the development of the system. More precisely, (i) an emergency physician and a deaf sign language expert were part of our team during the whole design, development, and evaluation cycle, (ii) we observed, interviewed, and carried out process tracing sessions with three ambulance nurses, and (iii) we engaged members of the deaf community in a focus group.

We interviewed the EM responders (the physician as well as the ambulance nurses) about the set of the sentences they may need to tell patients, and about the logical sequence and the structure of these sentences. Fundamental communication usually consists in 10 to 15 sentences which can be questions, instructions, or descriptions of the activities the EM responders are going to perform. Some of the sentences are the same in most emergencies, while other sentences vary with the different kinds of emergencies. Despite this variety, a comprehensive set of sentences can be identified from medical literature (e.g., [8]) and EM responders experience, and then hierarchically organized in groups (e.g., primary questions, questions about symptoms, questions about cardiovascular issues, ...). While some questions expect a yes/no answer (e.g., do you have a headache?), answers to other questions (e.g., what kind of pain do you feel?) are more complex. As a result, a deaf patient's answer in a sign language is not likely to be understood by an EM responder who does not know that language. To solve this issue, questions can be reformulated as a set of questions whose possible answers are yes/no or a number. For example, a general question about the kind of pain can be organized as a set of questions about specific kinds of pain (e.g., is the pain stabbing?). We also aimed at identifying possible constraints due to the activities to perform, their timing, the available equipment, and the environment where first aid is provided. The EM responders pointed out that, despite during emergencies their attention is mostly dedicated to monitor life parameters and timely administer adequate treatments, communication is fundamental and they have to schedule it among the activities to perform. With respect to using a mobile device for computer-mediated communication, the EM responders said they would use it if easily portable. They also said they could use both hands to interact with the system, but one-handed and thumb-based interaction would be preferred, so they could have the other hand free to perform other activities at the same time (e.g., checking the radial pulse). Finally, they said that the activities and the environment do not limit the use of visual and audio channels to provide feedback.

Deaf people from the local community were instead invited to describe their experiences (if any) as patients during an emergency, as well as to inform us about preferred means of communication and ability to read and write sentences in spoken language grammar. Some deaf people reported about distressing experiences due to treatments about which they were not told in advance. Indeed, since deaf people cannot hear EM responders, they would like, at least, to try to read their lips. Most of the deaf people we interviewed is able to read lips, but lip reading requires them considerable effort, since they have to recognize spoken words by closely watching speaker lips, and interpret the spoken language sentence by identifying the structure of the sentence and associating words with their meaning. Even deaf people who are more familiar with spoken language grammar may often misunderstand lip read sentences, and thus the speaker could be asked to repeat them slowly one or more times. During an emergency, such misunderstandings could become more frequent (e.g., because the patient is stressed or confused) and more critical (e.g., EM responders may administer wrong treatments to the patients, if they answer wrongly to some questions). Due to the translation effort, written communication may be difficult as well for a lot of deaf people, so it should be limited to a few isolated words (e.g., names of medicines), rather than complex sentences. Fingerspelling, which consists in performing a sign for each letter in a word, is not commonly employed, is inefficient, and may be misunderstood. Instead, sign language communication is the preferred way to communicate and can significantly improve the medical experience. In particular, it could reduce the sense of frustration deaf people usually feel when physicians or nurses take decisions concerning their health without communicating directly with them.

3.2 Design

Requirements analysis motivated the design of a system based on an easily portable device and able to show the sign language translation of the hierarchically organized set of sentences. We chose PDAs and smartphones with a touch screen as target devices, since they can easily fit the pocket of the suit worn by EM responders and can support VGA video playback of sign language sentences as well as thumb-based interaction. It must also be noted that EM responders use cellular phones to communicate among them and so the same device could serve multiple purposes.

Since EM responders primary task is monitoring life parameters and administering treatments, system design was inspired by minimal attention user interfaces (MAUIs), i.e., interfaces that provide mechanisms to minimize the amount of user attention required to perform a particular task [10]. A MAUI should take care of the limited attention capacity of the user, and facilitate high-speed interaction. To allow for one-handed, thumb-based, and eyes-free interaction, Pascoe et al. [10] suggest using hardware buttons or large software buttons on the touch screen, and organizing a form-filling interface as a sequence of screens, each requesting users a single data element (e.g., the choice of an item from a set). The use of a PDA as a secondary task is studied also in [7], which recommends the use of audio feedback to reduce required visual attention, and presents a system that can be operated using only four buttons.

The set of sentences has been organized in a tree whose leaves correspond to the sentences, while the other nodes are menus that group sentences or sub-menus. In the application of the system to the Italian Emergency Medical Service (see Section 4), the tree has seven levels of depth and up to nine items per menu. As a result, a traditional menu would not allow one-handed and thumb-based interaction, since the items would be too small on the mobile device screen. Following [10], we organized interaction in a sequence of screens. Each screen shows the title of the current menu (Figure 1a), up to six software buttons to select a sentence (pale green, Figure 1b) or enter a sub-menu (pale blue, Figure 1c), and a software button to go one level up in the tree (pale red, Figure 1d). Although color-blind persons cannot be EM responders in the Italian Emergency Medical Service, we nevertheless included an option that allows color-blind persons to use the system in other possible contexts: when the option is enabled, text in software buttons is written in italics or underlined to differentiate software buttons for sub-menus from those for sentences. To facilitate one-handed and thumb-based interaction, we constrained the number of menu items to a maximum of six per screen, so that the corresponding software buttons are 240x140 pixels or larger in size on a VGA screen. If a menu has more than six items, items are organized in pages that can be navigated by pressing previous and next software buttons (pale blue, Figure 1e).

Since fast interaction is crucial during emergencies, software buttons are selected with a single thumb tap. For error recovery, any choice can be undone in a single thumb tap by (i) going a level up, or (ii) selecting a previous page, or (iii) canceling a sentence selection in a confirm screen before sign language video playback, or (iv) interrupting sign language video playback at any time. To provide audio feedback on selection, every processed thumb tap is acknowledged by means of a beeping sound.

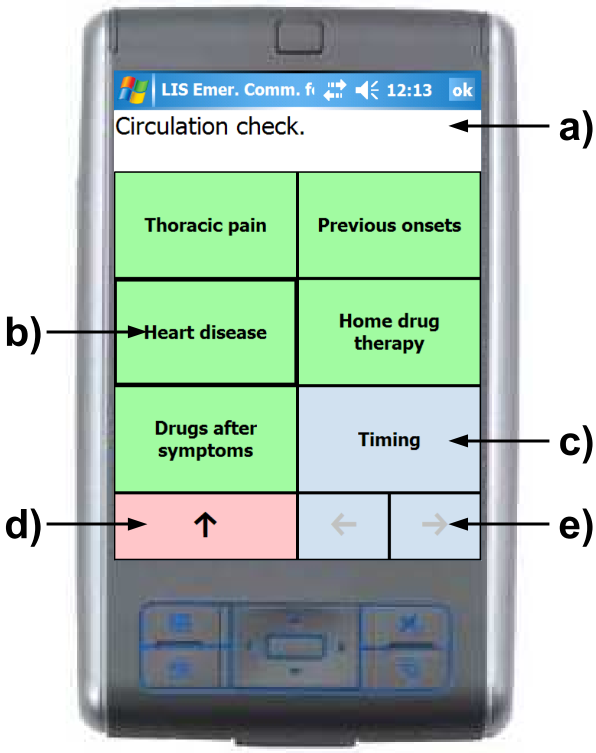

Figure 1: Browsing the tree of sentences: a) description of current menu (e.g., "circulation check"), b) pale green software buttons to select sentences, c) pale blue software button to enter a sub-menu, d) pale red software button to go one level up in the tree, e) pale blue software buttons to navigate menu pages (disabled in menus with a single page). While the tested application is in Italian, this screenshot shows English items for readers' convenience.

When EM responders confirm a sentence selection, sign language translation of the sentence is visualized by means of a full-screen video (Figure 2a). Some researchers [1, 2, 6] advocate using 3D animations instead of videos to visualize sign language sentences because (i) 3D animations can be rotated to see the signs from different points of view, (ii) 3D animations of isolated words can be concatenated to dynamically build sentences, (iii) 3D animations require less memory space than videos, and (iv) creating a set of 3D animations does not require to have the same actor and setting as in the making of a set of videos. However, most of these advantages do not apply to the medical emergency domain. For example, deaf patients are not expected to interact with the mobile device: they are in a situation which requires medical attention (e.g., they can be injured or in pain), so they would not be able to play with the point of view. Moreover, there is no need to dynamically build sentences, since a pre-defined set of alternatives is sufficient, and there are no space issues, since videos can be stored in a common memory card. Getting proper facial expression for sign language is also much easier when filming human actors rather than programming virtual humans. Finally, from interviews with tens of members of the local deaf community, it turned out that all interviewed members were familiar with watching sign language videos, while only one of them was familiar with 3D animations.

Carefully choosing the setting where sign languages videos are shot is very important. For example, the deaf sign language expert suggested a light blue or light green background to prevent eye strain. Moreover, the actor who performs sign language should wear a black shirt to contrast with the background and ease the recognition of arm movements. Signs are performed in a rectangular region of space whose height is from hips to slightly above the head and its width is the same as the extension of the arms, so the width of sign language videos should be greater than their height, and landscape orientation of the device is recommended during video playback.

To give EM responders audio feedback about displayed video, the corresponding spoken sentence is played as well. In this way, if the sentence is not the intended one, the EM responders can immediately correct the wrong choice. Moreover, since the sign language sentence is usually longer than the spoken sentence, and the mobile device should be turned towards the deaf patient during video playback, a specific sound is played at the beginning and at the end of each video playback to notify EM responders that they can turn the mobile device.

3.3 Implementation notes

The system was implemented to be flexible in supporting different sign languages and emergency medical services. More precisely, menus and videos are dynamically loaded from an XML configuration file and a folder tree with sign language videos. The XML configuration file stores the tree of menus and sentences: each item has (i) its type (i.e., menu or sentence), (ii) the short piece of text to be displayed on its software button, and (iii) menu description or sentence text. Therefore, to apply the system to any given emergency medical service, only the specific XML configuration file and folder tree need to be changed. Moreover, the size of software buttons for menus and sentences is dynamically rearranged by the system according to the number of items in the selected menu. This is meant to exploit all the available screen space, maximizing target size for thumb-based interaction. The system was developed in C# and .Net Compact Framework 3.5 for Windows Mobile devices.

4. APPLICATION TO THE ITALIAN EMERGENCY MEDICAL SERVICE

To test our system in a real setting, we applied it to the Italian Emergency Medical Service. We proceeded by (i) acquiring the whole set of questions, instructions, and descriptions of activities Italian EM responders need to communicate, (ii) hierarchically organizing sentences in menus, (iii) translating all the sentences in LIS, and (iv) shooting the videos of the LIS sentences.

For the first two tasks we involved three EM responders. We invited them to think about all the steps in their activities and the sentences they need to communicate at each step. We extended the set of sentences identified by the EM responders with the Italian translation of those questions in [8] that were relevant for pre-hospital care, and we checked the whole set back with the EM responders, also asking them to hierarchically organize the sentences in menus. The set

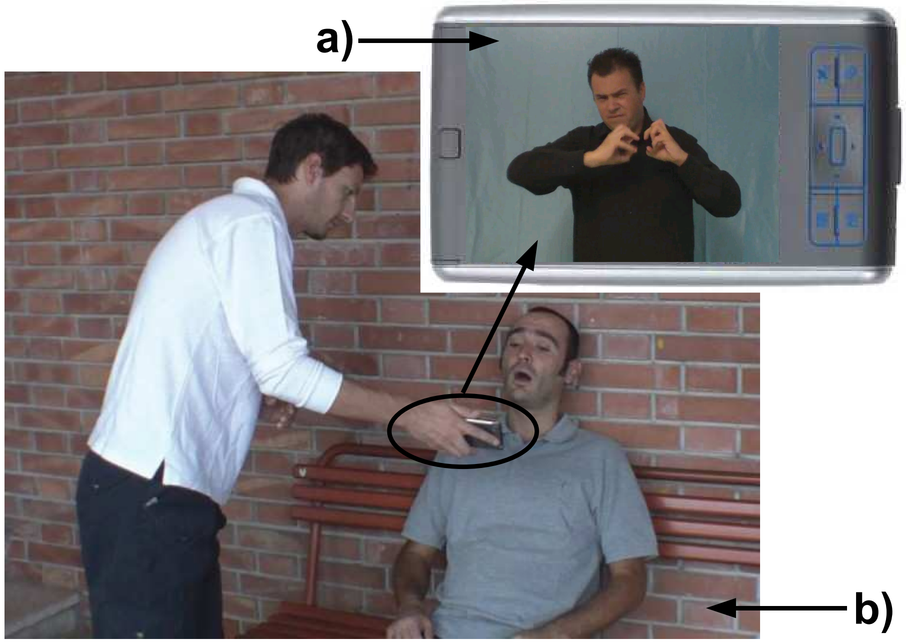

Figure 2: System usage: a) a frame of a sign language video on a mobile device, b) an EM responder communicating with a deaf patient in the setting chosen for the experimental evaluation.

of sentences was checked again after LIS translation, since some Italian words have no LIS translation and so we had to reformulate a few sentences. A further reorganization of the sentences in menus was performed after the pilot test that preceded the evaluation described in the next section, since problems in finding some sentences as they were organized were found. The final set consisted of 96 sentences, organized in seven menu levels.

For LIS translation and video shooting, we involved two deaf sign language teachers and a deaf actor. The deaf sign language teachers translated the sentences into LIS, while the deaf actor was filmed performing the sentences. Video was acquired by means of a HD camera (1280x720px, 16:9, 50fps, H.264 / MPEG-4) and then encoded at a lower quality (640x480px, 4:3, 12fps, WMV) to allow for a smooth playback on mobile devices. LIS translation and video acquisition were challenging tasks: sign language teachers carefully analyzed shot videos and asked us to film again the videos of sentences that could be articulated better or performed in a more accurate way. Eventually, the 96 videos for the required sentences were chosen out of a set of 175 videos.

5. EXPERIMENTAL EVALUATION

To compare communication with and without the proposed system in a realistic setting (Figure 2b), we carried out an experimental evaluation that required EM responders to communicate with deaf people, who acted as patients, in two emergency scenarios. The goal of the evaluation was to test if the system could improve communication between EM responders and their deaf patients. More precisely, we were interested in communication difficulty and mutual understanding, as perceived by both EM responders and deaf people. Since, as mentioned in Section 3.1, deaf people may experience distress in interacting with EM responders, we aimed also at investigating perceived comfort and satisfaction of deaf people, as well as perceived comfort and required effort of EM responders. Finally, we wanted to test learnability, usability, and effectiveness of the developed system, as well as the understandability of sign language videos on the mobile device.

5.1 Participants

The evaluation involved ten deaf subjects and ten EM responders. The deaf subjects (7 M, 3 F) were recruited from the members of the local deaf association. Their age ranged from 43 to 64, averaging at 55.5. Nine deaf subjects regularly watched sign language videos, while one watched them sometimes. No deaf subject ever used a mobile device to watch videos. The EM responders (5 M, 5 F) were recruited from the local emergency medical service. Their age ranged from 34 to 54, averaging at 38.9, and they were all ambulance nurses. Two of them regularly used a touch screen device, two tried it sometimes, while the other six had never used a touch screen device before. No EM responder knew the Italian Sign Language. We formed ten pairs by associating each deaf subject with a different EM responder. We decided to follow a random association strategy, since in emergencies no particular relation exists between deaf patients and the EM responders who give them first aid. The resulting pairs were very varied: there was at least a pair for each possible gender association (i.e., female deaf with male EM responder, male deaf with female EM responder, both male, and both female), and the difference in age between paired users ranged from 2 to 27 years.

5.2 Task

The task for the EM responders consisted in helping the deaf subject they were paired with in a realistic scenario. The EM responders were asked to carry out all the steps of a real first aid operation from the arrival on site to the trip to the hospital. Since the emphasis of the evaluation was on communication, the EM responders were invited to tell deaf subjects all the sentences they thought to be useful at each step, while activities such as attaching electrodes or giving pills should be simulated. Correct handling of the defined emergency scenarios required asking the deaf subject eight questions, giving him/her one instruction, and describing five activities to him/her before performing them. If the EM responders needed to perform a medical test to identify the pathology, the experimenter communicated them the outcome after they had simulated the corresponding activities (e.g., if the EM responders acted as if they were attaching some electrodes on patient's chest, the experimenter told them the outcome of the electrocardiogram). The EM responders were provided with a Pocket PC featuring a 624MHz CPU and a 3.5" VGA (480x640) display.

The deaf subjects were asked to act as patients and to answer the questions of the EM responders according to a specific scenario. Before the task, deaf subjects were provided with all the details about the health condition they had to simulate (e.g., their symptoms and medical history), but no other detail about the scenario (e.g., the expected questions and instructions). To avoid misunderstandings, as suggested in [5], a fluent interpreter instructed deaf subjects about the task in their sign language, checked if they correctly understood the health condition to simulate, and explained them that medical activities of the EM responders would have been simulated and thus would not cause any pain or harm.

We prepared two different scenarios of the same complexity, i.e. the same number of questions, instructions, and activities to successfully complete the first aid operation. The two scenarios started from the same background. A deaf person feels sick while walking alone in a park. This is a realistic situation where deaf people cannot count on the translation of an interpreter or the help of a relative. The deaf person sits on a bench and is helped by a hearing passerby who calls the emergency medical service. The emergency service dispatcher asks the passerby about deaf person's symptoms and sends an EM responder to the site. As mentioned before, the actual task starts when the EM responder arrives on site, and it ends when he/she is going to the hospital after giving first aid to the deaf patient. In one scenario, the deaf person, who is in treatment for cardiovascular problems, is having a heart attack. The emergency service dispatcher informs the EM responder that the deaf person is in pain, and keeping a hand on his/her chest. The EM responder and the deaf person should communicate effectively to identify the pathology (e.g., a discriminant between a heart attack and other problems is how much chest pain the patient is suffering), so that the EM responder can give first aid to the deaf person, and then bring him/her to the hospital. In the other scenario, the deaf person, who has never experienced breathing problems before, is having a pulmonary edema. The emergency service dispatcher informs the EM responders that the deaf person breathes heavily. As in the previous scenario, effective communication is fundamental to exclude other pathologies (e.g., allergies).

5.3 Procedure

The experimental design was within-subjects, so each pair of users carried out the task twice: once using the system and once without using it. To prevent learning and order effects, each condition was tried in a different scenario and the order of presentation of the two conditions, as well as their association with the two scenarios, were counterbalanced. The evaluation took place outside the main building of the emergency medical service. Participants were initially briefed about the nature of the experiment. An experimenter spoke with the EM responders, while an interpreter provided deaf subjects with information in LIS in a separate place. Participants could ask any question to clarify possible doubts concerning the experiment or the task to be carried out. EM responders had also up to five minutes to familiarize with the system.

Subsequently, the experimental task was carried out under the two conditions. At the end of each, the experimenter separately administered a questionnaire to the EM responder and a different questionnaire to the deaf subject. Questionnaires asked about the agreement with statements on a standard 5-point scale (1 meaning strongly disagree and 5 meaning strongly agree). EM responders were asked about communication issues, effectiveness, and user experience (the English translation of the statements is provided in Figure 3 along with the results). For the condition with the system, EM responders were also asked about system learnability, usability, and effectiveness (Figure 4). The questionnaire for the deaf subjects consisted of five statements about communication issues, effectiveness, and user experience from the point of view of the patient (Figure 5). For the condition with the system, deaf subjects were also asked to rate four statements concerning comfort in communicating through the system, understandability of LIS videos on the mobile device, and effectiveness of the system to support communication (Figure 6).

To avoid misunderstandings due to language issues, an interpreter showed the deaf subjects the LIS translation of each sentence in the questionnaire. After filling in the questionnaire, the EM responders and the deaf subjects were also briefly interviewed, in Italian and LIS respectively, to collect their comments, opinions, and suggestions. In particular, we asked them to comment on their ratings about the system and provide us with suggestions on how to improve it. An evaluation session lasted about 30 minutes.

6. RESULTS AND DISCUSSION

Figures 3 and 5 show level of agreement from, respectively, EM responders and deaf subjects about statements concerning communication. For each statement, the figures provide its English translation as well as mean (μ), standard deviation (σ), p-value (p), and distribution of ratings with the system (hereinafter, W condition) and without it (hereinafter, W/O condition). The p-value for each statement in each condition was calculated using chi-square goodness-of-fit test. 13 of 20 results were statistically significant. For all statements, the difference between the mean values in the two conditions was ≤ 0.5, and no statistically significant difference was found using Wilcoxon signed-rank two-tailed test ($p>0.05$ for all statements).

This may seem in contrast with the ratings given by the users to the statements concerning the system (Figures 4 and 6), since the mean values for all these statements were positive, and 5 of 8 results were statistically significant using chi-square goodness-of-fit test. In the following paragraphs, we provide more details about the results and discuss them by describing what we learned from the interviews.

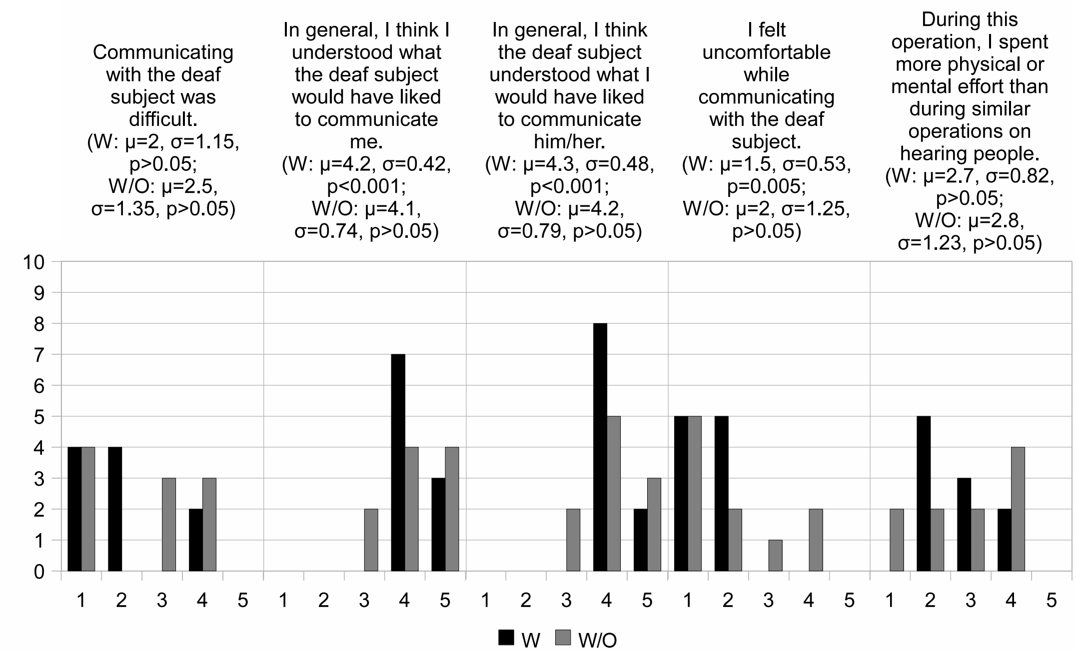

Figure 3: Levels of agreement from EM responders about statements concerning communication with (W) and without (W/O) the system (1=strongly disagree, 2=disagree, 3=neither agree nor disagree, 4=agree, and 5=strongly agree).

6.1 EM responders

The distribution of ratings for the statement concerning communication difficulty for EM responders was not statistically significant in both conditions ($p>0.05$). However, it is worth noting that, while a greater number of EM responders found the communication not difficult in W condition, the number of EM responders who found it difficult was low in both conditions. When we discussed the ratings with EM responders, some of them said they were often involved in first aid operations where the patients spoke a foreign language, and so they developed some skills in communicating by means of spontaneous gestures such as pointing the ambulance to communicate they were going to carry the patient into it, or showing a device to communicate they were going to use it on the patient. Therefore, some EM responders tried spontaneous gestures also to communicate with the deaf subjects, while others spoke much more slowly than usual to ease lip reading. All EM responders agreed that they understood deaf subjects and were understood by them in W condition, and the results were positive and statistically significant (μ=4.2, σ=0.42, $p<0.001$ for understanding, μ=4.3, σ=0.48, $p<0.001$ for being understood). On the contrary, two EM responders were neutral about these two statements in W/O condition, and the positive results were not statistically significant ($p>0.05$ for both understanding and being understood). No EM responders felt uncomfortable in W condition and the result was statistically significant (μ=1.5, σ=0.53, p=0.005), while two EM responders felt uncomfortable and one was neutral under W/O condition, and the result was not statistically significant ($p>0.05$). Under both conditions, the results for the statement concerning physical and mental effort were not statistically significant ($p>0.05$), and the distribution of ratings was very varied: an EM responder agreed under both conditions, another one disagreed under both conditions, while the other EM responders agreed only in one of the two conditions. During the interviews, two EM responders who spent more effort in W condition said that they spent effort using the system, since they were not familiar with the device, while two EM responders who spent more effort in W/O condition said that communication with the deaf subject took much more effort than communication with hearing patients, and that the system helped to reduce it.

Results from EM responders for all the statements concerning the system were positive and statistically significant. EM responders agreed that they quickly learned how to use system (μ=3.9, σ=0.32, $p<0.001$). The only EM responder who was neutral commented on her rating saying that a little more practice would have been sufficient to use the system more effectively. Also other EM responders said they would have needed more practice to learn where to find all the available sentences, while they said that the interface of the system was intuitive and well-organized. All the EM responders agreed that the system was easy to use (μ=4, σ=0, $p<0.001$). While the usefulness of the system did not emerge from statements concerning communication, EM responders agreed that the system helped them to communicate with the deaf subjects (μ=4, σ=0.47, $p<0.001$). Most EM responders said that the system can be particularly useful when they are in the ambulance and they need to refine diagnosis by asking complex questions. In general, they would like to use the system for the questions they cannot easily communicate or that can be misunderstood by using improvised gestures or speech. Moreover, most of EM responders found the system particularly useful also to describe the activities they are going to perform on their

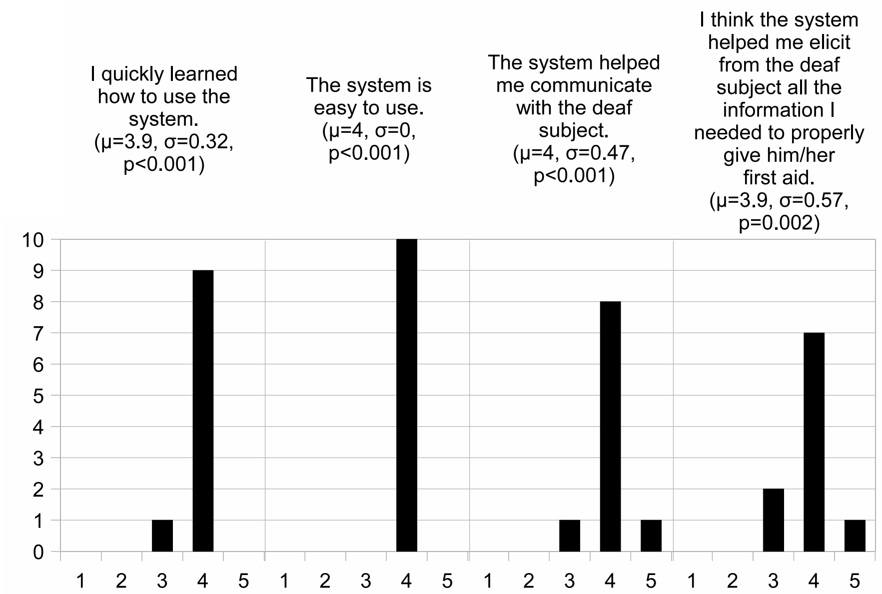

Figure 4: Ratings given to the system by EM responders (1=strongly disagree, 2=disagree, 3=neither agree nor disagree, 4=agree, and 5=strongly agree).

patients, since in Italy patients have the right to decline treatments and must be accurately told in advance about them. For similar reasons, EM responders also positively rated the statement about completeness of the information elicited by means of the system (μ=3.9, σ=0.57, p=0.002). Discussing this statement, most of the EM responders said that there was a single relevant sentence missing (i.e., the description of a monitoring device whose sensors should be clipped or attached to the patient), while in future versions of the system they would like to see also less relevant, but still useful sentences about patients' relatives (e.g., "do you live alone?", "would you like me to call your relatives?") and some sentences to calm down the patients while waiting to reach the hospital (e.g., "we are arriving at the hospital", "the pain will cease quickly").

6.2 Deaf subjects

The results of all statements about communication experience from the point of view of the deaf subjects are statistically significant in both conditions. Communication with the EM responders was difficult in both W and W/O condition (W: μ=3.7, σ=0.67, p<0.001; W/O: μ=3.3, σ=0.67, p=0.027). The shift towards agreement under W condition may possibly be due to the adoption of a technology which no deaf subject was already familiar with, since no deaf subject ever watched videos on mobile devices. Since the deaf subjects were instead familiar with sign language videos on other devices (e.g., television or PC), we will investigate the use of mobile devices with a larger screen (e.g., tablet PCs or netbooks), as also suggested by one of the deaf subjects. Discussing this aspect with the EM responders, some of them said that they could not use a device bigger than a PDA when they are on the field, while they thought a tablet PC can be used on the ambulance. Despite the difficulty, in general deaf subjects thought they understood the EM responders or were neutral about this statement in both conditions, and the mean values were similar (W: μ=3.3, σ=0.67, p=0.027; W/O: μ=3.5, σ=0.53, p=0.005). Only a subject disagreed about this statement in W condition, and, in the same condition, the same subject also did not think to be understood by the EM responder. However, of the other deaf subjects, eight agreed about the statement and one was neutral in W condition, while six agreed and four were neutral in W/O condition (W: μ=3.7, σ=0.67, p<0.001; W/O: μ=3.6, σ=0.52, p=0.003). Considering the statement about feeling uncomfortable during communication, all the deaf subjects except one (who agreed in W condition and was neutral in W/O condition) specified the same level of agreement in both conditions (W: μ=3.6, σ=0.7, p=0.002; W/O: μ=3.5,σ=0.71, p=0.011). The mean value for the overall satisfaction about the first aid operation was instead positive, and was the same under the two conditions (W: μ=3.9, σ=0.57, p=0.002; W/O: μ=3.9, σ=0.88, p=0.027). However, in W/O condition, one deaf subject was not satisfied, while all subjects were satisfied in W condition.

While, on average, the deaf subjects agreed they felt uncomfortable during communication, half of them agreed about feeling comfortable communicating by means of the system, and the other half were neutral about the statement (μ=3.5, σ=0.53), so the system did not introduce discomfort. This result was statistically significant (p=0.005), while the results for the other three statements concerning the system were not (p>0.05). The mean values for these statements are positive (μ $\geq$3.4), but the standard deviation is > 1, since a single deaf subject strongly disagreed with all the three statements. The subject commented about his ratings saying that he did not understand LIS videos on the mobile device because its screen was too small, and he consequently did not benefit from the system. However, in general, considering deaf subjects' lack of familiarity with videos on mobile devices, the result about the understandability of sign language videos played by the system was encouraging: of the remaining nine subjects, five agreed about video understandability and four were neutral. As mentioned be-

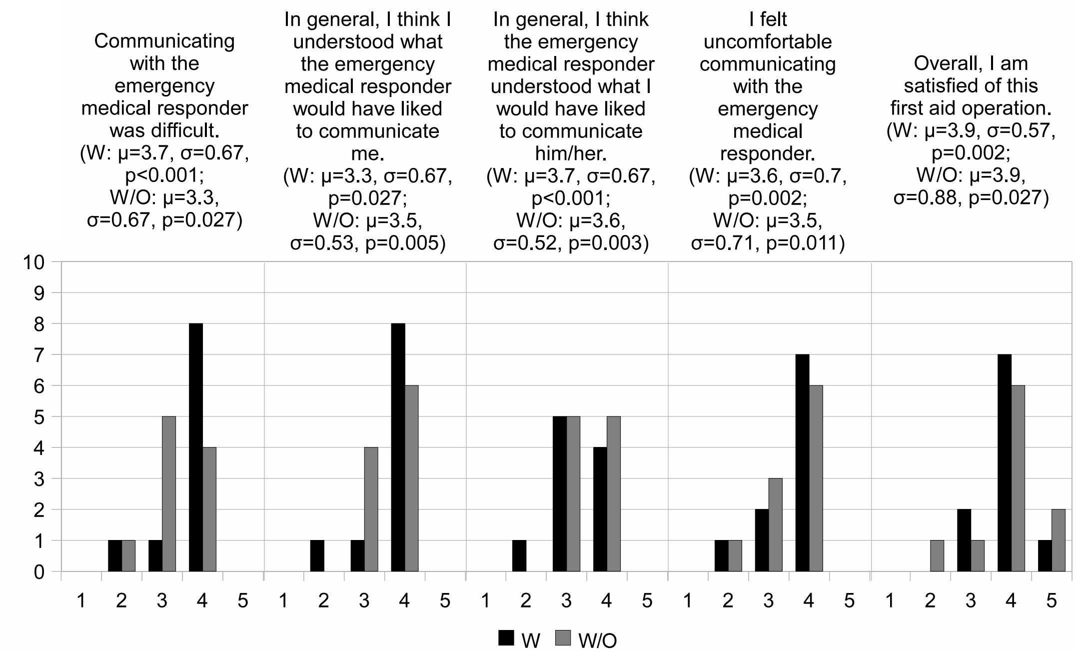

Figure 5: Levels of agreement from deaf subjects about statements concerning communication under the conditions with (W) and without (W/O) the system (1=strongly disagree, 2=disagree, 3=neither agree nor disagree, 4=agree, and 5=strongly agree).

fore, a comment about the videos concerned the screen size: also a deaf subject who strongly agreed about video understandability commented she would have preferred a bigger screen. As for the EM responders, the usefulness of the system emerged from deaf subjects' explicit ratings about it: seven deaf subjects agreed that the system helped them communicate with the EM responders. Finally, considering the completeness of the information, six deaf subjects agreed, three were neutral, and only one (the same who had issues in understanding the videos) disagreed. Deaf subjects provided less detailed comments about their ratings: most of them said it was an interesting new idea, one said only he misunderstood the sign for "ambulance", and one would have liked even more sign language communication with additional sentences, similar to those suggested by the EM responders.

7. CONCLUSIONS AND FUTURE WORK

This paper proposed a mobile system to support communication between deaf patients and EM responders who help them on the field. The involvement of EM responders and of members of the deaf community during the design phase helped us to develop a prototype that was positively rated by the users, while the lessons we learned during the evaluation will help us refine our system and make it available for regular use in emergency medical services. In particular, EM responders thought that the system helped them to communicate with deaf patients, since it could be useful to ask complex questions and fundamental to inform patients about the activities to perform on them. EM responders also suggested us to add a sentence about a monitoring device as well as sentences to calm down patients and get information about their relatives. The request for more sign language sentences arose also from deaf subjects, most of whom found the system helpful to communicate. Although no deaf subject was familiar with videos on mobile devices, half of them found sign language videos played on the device easy to understand, with only one subject disagreeing about this statement because the screen of the mobile device was too small for him to understand the videos well. Since screen size was too small also for another deaf subject, we will investigate with deaf subjects and EM responders if bigger mobile devices such as tablet PCs could be well suited for the system, at least when the users are on ambulance.

Some EM responders were very interested in testing future versions of the system, and provided us with interesting feedback for future research: for example, two EM responders requested us to integrate our system with a mobile application to fill in mandatory ambulance run reports. An EM responder said that the system taught her how to articulate sentences to ease communication with deaf people, while other three said that, after using of the system, they became interested in learning basic sign language. Unfortunately, attending general sign language courses for hearing people would be too time-demanding. However, since EM responders usually have spare time during their work shift if few emergencies occur, we have started thinking about a sign language learning system organized as a set of short lessons that EM responders can take during their work shift to learn the fundamental signs needed in medical emergencies. A mobile version of such learning system would also allow EM responders to revise basic sentences on ambulance, while they are traveling to reach a deaf patient. In this way, EM responders could learn to autonomously communicate basic sentences and exploit our system only for complex ones.

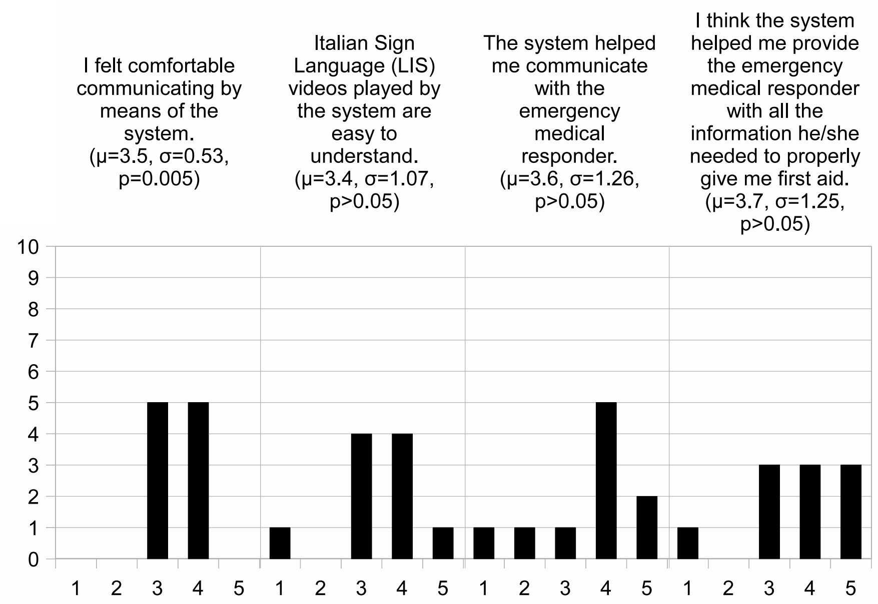

Figure 6: Ratings given to the system by deaf subjects (1=strongly disagree, 2=disagree, 3=neither agree nor disagree, 4=agree, and 5=strongly agree).

8. ACKNOWLEDGMENTS

We are particularly grateful to LIS experts Fabio Meneghel and Loris Botosso as well as to EM responders Giuliana Pantanali, Pasquale Albanese, Federico Roncastri, and Federico Nadalin. Our research is partially supported by the Friuli Venezia Giulia region under the project "Servizi avanzati per il soccorso sanitario al disabile basati su tecnologie ICT innovative" ("Advanced emergency medical services for the disabled based on innovative ICT technologies").

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