Design, Manufacture, and Acceptance Evaluation of APO: A Lip-syncing Social Robot Developed for Lip-reading Training Programs

Alireza Esfandbod · Ahmad Nourbala · Zeynab Rokhi · Ali F. Meghdari · Alireza Taheri · Minoo Alemi

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Abstract
Lack of educational facilities for the burgeoning world population, financial barriers, and the growing tendency in favor of inclusive education have all helped channel a general inclination toward using various educational assistive technologies, e.g., socially assistive robots. Employing social robots in diverse educational scenarios could enhance learners’ achievements by motivating them and sustaining their level of engagement. This study is devoted to manufacturing and investigating the acceptance of a novel social robot named APO, designed to improve hearing-impaired individuals’ lip-reading skills through an educational game. To accomplish the robot’s objective, we proposed and implemented a lip-syncing system on the APO social robot. The proposed robot’s potential with regard to its primary goals, tutoring and practicing lip-reading, was examined through two main experiments. The first experiment was dedicated to evaluating the clarity of the utterances articulated by the robot. The evaluation was quantified by comparing the robot’s articulation of words with a video of a human teacher lip-syncing the same words. In this inspection, due to the adults’ advanced skill in lip-reading compared to children, twenty-one adult participants were asked to identify the words lip-synced in the two scenarios (the articulation of the robot and the video recorded from the human teacher). Subsequently, the number of words that participants correctly recognized from the robot and the human teacher articulations was considered a metric to evaluate the caliber of the designed lip-syncing system. The outcome of this experiment revealed that no significant differences were observed between the participants’ recognition of the robot and the human tutor’s articulation of multisyllabic words. Following the validation of the proposed articulatory system, the acceptance of the robot by a group of hearing-impaired participants, eighteen adults and sixteen children, was scrutinized in the second experiment. The adults and the children were asked to fill in two standard questionnaires, UTAUT and SAM, respectively. Our findings revealed that the robot acquired higher scores than the lip-syncing video in most of the questionnaires’ items, which could be interpreted as a greater intention of utilizing the APO robot as an assistive technology for lip-reading instruction among adults and children.

Keywords Socially assistive robots · Hearing-impaired · Lip-syncing · Technology acceptance

1 Introduction
In contrast to the previous prevalent concept that considered speech processing an absolute auditory phenomenon, several studies have revealed that visual speech information is complementary to encoding the speech signal due to the multimodal characteristic of speech perception [1, 2]. For example, McGurk and MacDonald demonstrated that discrepancies between the auditory signals that individuals hear and the speakers’ visual articulation information could adversely affect auditors’ perception concerning the sound they have heard [3]. Accordingly, the audio and visual information acquired concurrently from analyzing speech and focusing on the speaker’s articulatory movements leads to
a fuller comprehension of the speech signals [4, 5]. This concept is in accordance with the preference of infants to concentrate on speech synchronized with articulatory gestures rather than improperly linked audio-visual compounds [6]. Hence, lip-reading, which is concerned with eliciting speech information from the movements of jaws, lips, tongue, and teeth within the articulation [7], enhances human speech perception [8]. Although lip-reading capability is considered a complementary skill to improve the auditory perception of hearing people, it plays a vital role throughout hearing-impaired communications [9, 10]. Additionally, the lack of this expertise restricts deaf people’s interlocutors solely to individuals who are accustomed to non-verbal communication channels such as Sign Language and Cued Speech. This issue leads deaf people to encounter significant barriers to various two-way communication activities such as university studies [11]. Hence, the accomplishment of deaf people’s independence throughout communication is subject to honing their lip-reading skills.

Lip-reading is intrinsically an arduous task. Furthermore, the resemblance between the articulatory elements’ activity while pronouncing some letters, such as /g/ and /k/, which are not evident on the lips, hinders the lip-reading procedure [12]. Easton and Basala conducted two experiments to assess participants’ speech recognition capability from facial gestures. Their examination showed that hearing-impaired observers could only attain an accuracy of $17 \pm 12\%$ for 30 one-syllable words and $21 \pm 11\%$ for 30 multi-syllable words [13]. Therefore, lip-reading is a challenging task that requires training and practice. Generally, lip-reading teaching approaches can be classified into two main categories, analytic and synthetic methods, which are sometimes deployed cooperatively. In analytical strategies, trainers are asked to analyze the speech’s constituents separately, while synthetic methods require participants to synthesize the message according to all presented clues [14].

Several studies have been carried out to determine effective educational programs and investigate the potential effects of the presented methods on learners’ achievements in lip reading. Creating instructional videos [14, 15] and developing various computer-based training, test software, and games [16, 17] are well-established techniques in this field. Most of the proposed training programs are comprised of pre-recorded sequences from tutors’ articulatory components’ activities while pronouncing letters, words, and sentences. Figure 1 depicts the content of a computer game developed for lip-reading instruction.

Thanks to current demographic trends, economic factors, and the growing desire for inclusive education, a flourishing demand for various educational assistive technologies has been generated. Furthermore, literature has indicated that social interaction enhances educational achievements [18, 19]. These premises and the evolution of robotic technology have led to the development of a new concept concerned with utilizing robots that socially interface with humans as teacher’s assistants [20]. Several studies conducted in the multidisciplinary field of Human–Robot Interaction (HRI) have highlighted that during interaction with physical robots, individuals’ perception and engagement levels are higher than interacting with virtual agents (on-screen characters) [21–23]. Kid and Breazeal explored and compared individuals’ responses to a robotic character, an animated character, and a human to examine the impacts of the robot’s presence on users’ perceptions. Their study revealed that the physical robot is perceived to be more credible, informative, engaging, and enjoyable to interact with compared to the animated character. Two factors of robots, physical presence and real entity, could be credited for the higher effectiveness of physical robots on users’ perception in educational scenarios compared to fictional animated characters [24]. Leyzberg et al. scrutinized the influences of the robot’s presence on individuals’ learning achievements through a robot tutoring task. The outcome of this investigation revealed that a physically-present robot leads to higher learning gains than on-screen characters and enhances participants’ performance during the activity [25]. In addition, the robot’s embodiment makes people more likely to follow its commands and heightens its authority [26, 27]. As well as the potential positive impacts associated with the physical presence of social robots in education, augmenting humanoid features on social robots that do not necessarily possess a fully human-like appearance improves Human–Robot Interaction [28].

The utility of socially assistive robots in the domain of education has been the subject of several studies performed in the field of HRI [29–31]. The outcomes of these examinations illustrated that social robots’ employment within several training subjects, including English as a Foreign Language (EFL) [32–34], Mathematics [35–37], Physics [38], and Programming [39, 40], can be beneficial and enhance the learners’ educational gains by keeping the participants engaged [41]. The remarkable results of social robots’ utility in the context of education could be extrapolated to teaching cognitive skills to individuals with special needs [42, 43]. Taheri et al. examined the efficacy of the NAO social robot in teaching music to children who were diagnosed with Autism Spectrum Disorder (ASD). The findings of this study revealed that the utility of the social robot as an assistive tool alongside the teacher throughout educational interventions considerably improves learners’ performance in information attainment compared with scenarios without the robot [44, 45].

Due to the encouraging prospects of deploying social robots within diverse training programs, in this study, we endeavor to make use of this promising educational technology to enhance hearing-impaired individuals’ lip-reading
skills. As previously mentioned, hearing-impaired people struggle to master speech reading skills because of the ambiguity of visual speech cues. This issue, compounded with the lack of attractive instructional tools, makes the training process tedious. Therefore, due to the aforementioned merits of physically-present robots compared to animated characters with respect to improving students’ learning performance [25, 46], in this study, an educational assistive robotic platform with capabilities that suit lip-reading training programs was designed to lessen the monotony of the instructional procedure by maintaining participants’ level of engagement during the educational scenario.

One of the fundamental issues that should be considered in designing a novel robotic platform is its cost-efficiency, making the robot affordable for its users. Furthermore, the robot should possess assorted complex attributes and dynamic features to maintain participants’ engagement throughout long-term interaction [47]. Thus, there is a trade-off between the cost-efficiency aspect and the robot’s capacity to perform diverse behaviors. These criteria, alongside the robot’s capabilities in terms of accomplishing the desired purposes, determine the appropriate type of robotic head and the required degrees of freedom that should be considered to achieve an effectual design.

The social robot, APO, designed in this study is a tablet-face non-humanoid robot with two degrees of freedom intended to attract and keep learners’ attention throughout training programs by performing simple motions. The proposed robot’s main features include being cost-effective, easily portable, having a cute design, and possessing an LCD screen to perform lip-reading exercises during interaction with hearing-impaired individuals. A precise lip-syncing system with the capacity to lip-sync any utterance without being formerly registered was also designed and implemented on the robot to achieve APO’s instructional purposes and develop a human-like articulation.

The current study comprises two experiments: evaluating the proposed lip-syncing system, which determines the robot’s capacity to be employed in educational scenarios, and investigating the acceptance of the APO, which affects participants’ cognitive performance and compliance behaviors during interaction with the robot [48]. In the first experiment, a video of a normal-hearing individual pronouncing a set of words was first given to a group of adults, who were asked to watch, identify, and write the pronounced words. Afterward, to assess the robot’s visual articulation performance, the participants were asked to sit in front of the APO robot while it articulated the same set of words and then write the words they recognized from the robot’s articulation. The success of the lip-syncing system was measured by comparing the participants’ perceptions of the lip-synced words in the two scenarios. In this examination, children were excluded from the research participants because they are generally less competent in lip-reading than adults. In the second experiment, the APO robot with the approved lip-syncing capability was involved in interventions to compare the acceptance of two lip-reading training tools (the proposed robotic platform and the silently recorded video). This experiment utilized the Unified Theory of Acceptance and Use of Technology (UTAUT) [49] and the Self-Assessment Manikin (SAM) questionnaires [50] to investigate the robot’s acceptability to hearing-impaired adults and children, respectively. Figure 2 depicts the study’s contents schematically.

The rest of this paper is organized as follows. Section 2 is dedicated to various aspects of designing a new domestic robotic platform, the APO social robot. In Sect. 3, the proposed lip-syncing system is delineated. Section 4 addresses the approach adopted to assess the developed lip-syncing system. The intervention scenario arranged to examine the acceptance of the robot is also covered in this section. In Sects. 5 and 6, the experiments’ results and discussion are
Section 7 is devoted to the limitations of the current study. Finally, in Sect. 8, the concluding remarks are declared.

2 The “APO” Robotic Platform

2.1 Conceptual Design

Providing individuals with a high-quality education is one of the principal concerns of developed societies. The COVID-19 pandemic not only led to burgeoning demands for remote training programs but also demonstrated the necessity of developing assistive technologies. The use of social robots as assistive tools for educational applications has attracted growing attention among researchers due to their potential to engage students and enhance their learning achievements [51]. This section is dedicated to designing a simple non-humanoid social robot named APO for educational purposes. The primary objective of developing the APO robot was to perform the role of hearing-impaired individuals’ playmates through a lip-reading educational game. Nevertheless, APO could be utilized within wide-ranging tutoring applications outside of the original intent. Cuteness, cost-effectiveness, mobility, and practicality were the main factors in the APO robot’s design. Figures 3 and 4 depict simple initial sketches and the conceptual design of the APO robot, respectively.

2.2 APO robot’s Hardware Design

The APO robot’s platform comprises three primary compounds, a tablet-face head, the robot’s upper body, and lower body parts. Figure 5 demonstrates the APO robotic platform’s final 3D model and exploded view.

The robot includes two rotary degrees of freedom (DOFs); the first one concerns the relative rotation between the robot’s upper and lower parts with respect to the roll axis, and the second relates to the pitch rotation of the robot’s head, stated in relation to the upper body part. Hence, provided that the APO’s lower body is fixed, the robot is capable of looking at any desired points located in the robot’s surroundings. The proposed robotic platform is equipped with a camera and a microphone, considered as the audio and visual input devices, as well as a 5-inch tablet face and speakers, regarded as output hardware that enhances the robot’s capabilities to conduct both verbal and non-verbal communications with users. Moreover, a Raspberry Pi computer performs the robot’s internal processing. Table 1 summarizes the robot’s features.

2.3 APO robot’s Software Design

A Graphical User Interface (GUI) was developed for the APO robot to customize the robot’s operational system to be controllable by non-expert users. Through the designed GUI, the users would be able to control the APO robot’s motions, stream its camera on computers or tablets, change the robot’s facial expressions, vary the color and the brightness of LEDs, and ultimately type any utterance to be lip-synced by the robot. Figure 6 depicts the environment of the GUI developed for the APO robot.
Fig. 3 The simple initial sketches of the APO robot

Fig. 4 The conceptual design of the APO robot

Fig. 5 a The APO robot’s 3D and b exploded view
Table 1 The specifications of the APO social robot

| Specification       | Value                                      |
|---------------------|--------------------------------------------|
| Dimension           | $23 \times 23 \times 21.2$ (cm$^3$)        |
| Weight              | 2.7 kg                                     |
| Actuators           | 2 Servomotors                              |
| Sensors             | Camera (Raspberry Pi Camera Module 2)      |
|                     | Microphone                                 |
| DOFs                | 2 degrees of freedom                       |
| Operating section   | Raspberry Pi 3                             |
| Operating system    | ROS on Ubuntu 15                           |
| Power section       | 12 DC Voltage                              |

3 Lip-syncing System

3.1 Lip-syncing Shapes Design

Adding the lip-syncing capability to a social robot may augment users’ perception of the robot’s verbal communication and enhance the potential for tutoring word pronunciation. This characteristic becomes even more crucial when the robot interacts with hearing-impaired individuals. Hence, a realistic design of articulatory visual elements is consequential. In an effort to produce the most sensible lip shape design, an Iranian Sign Language (ISL) interpreter was hired to exaggerate the pronunciation of the letters of the alphabet. While he was pronouncing each letter (including vowels and consonants), several images were captured in a straight-ahead position. The most detailed image of each letter was used to design the visual parts of the robot’s mouth. Figure 7 shows the design procedure performed for each letter.

Individual designs were produced in this manner for all letters of the alphabet, including consonants and vowels. Figure 8 demonstrates the designed alphabet shapes.

3.2 Lip Morphing

Developing a dictionary comprised of several sequences for each word is a lengthy process and requires massive computer memory. Hence, developing an algorithm that can receive a word as an input, disassemble it into its constituent letters, and then smoothly morph the letters into each other would be a more efficient way. A principal consideration in developing an algorithm that will morph the mouth’s elements into their equivalents in successive frames to attain natural verbal communication is that the deformation of the mouth’s features should be minimized.

The transition problem is daunting in the animation field [52]. It should be noted that although a spectator can disregard flaws in drawing and schematic elements, unnatural or discrete motions are not permissible [53]. The change between the initial and final point forms the fluidity of a movement, and following the path between the initial and final points in a linear manner leads to an unnatural transition [53]. Adding acceleration terms produces a dynamic tween that enhances the transition’s degree of goodness [54]. In animation jargon, easing is equivalent to morphing, which is a combination of several tools used to specify the manner in which elements transition into their corresponding elements in consecutive frames. An Easing Function is a function that determines the way that the transition from the initial point to the final point occurs with respect to terms of velocity and acceleration. Several functions can be employed to fulfill this purpose. Figure 9 shows some of these functions.

Following an investigation of the diverse easing functions shown in Fig. 9, the InOutExpo function was chosen due to its ability to naturally and smoothly transition the elements of the robot’s mouth. As Fig. 9 depicts, the velocity at the beginning and the end of the time interval is zero in the InOutExpo...
Fig. 8 The designed lip shapes for each letter of the Persian alphabet.
described in Eq. (1) for each point to smooth the transition curve into numerous points and utilize the easing function state to another within successive frames is to divide each operational method of making the transition from one mouth tally composed of curved lines that form closed curves. An function that describes this issue is as follows:

where the penalty points should be chosen to minimize the sum of the tracks the articulators’ deformation; consequently, corresponding points should be chosen to minimize the sum of the tracks followed by the points during the transition. The penalty function that describes this issue is as follows:

As Fig. 8 depicts, the mouth’s elements are fundamentally composed of curved lines that form closed curves. An operational method of making the transition from one mouth state to another within successive frames is to divide each curve into numerous points and utilize the easing function described in Eq. (1) for each point to smooth the transition process. The subsequent challenge is to find corresponding points between two shapes within successive frames. Achieving a natural form of speech is subject to minimizing the articulators’ deformation; consequently, corresponding points should be chosen to minimize the sum of the tracks followed by the points during the transition.

Thus, the transition problem is simplified to minimize the above cost function. The more the number of chosen points increases, the better the transition smoothness is and the greater the computational cost accrues.

Ordinarily, the term easing alludes to animation made for games and HTML applications. Qt and jQuery libraries are also utilized to implement transition functions. This study used JavaScript and HTML and benefitted from the KUTE library to implement the transition function. Also, Adobe Illustrator was used to draw the articulators’ scheme. The developed module takes any word, phrase, sentence, and time parameter as inputs and performs the lip-syncing in that time. The nature of the transition was assessed by a visual examination by the sign language interpreter who cooperated with our research group. Figure 10 illustrates the way that the developed algorithm executes.

4 Methodology

The current study is composed of two principal experiments. The first experiment evaluates the developed lip-syncing system by comparing the participants’ perception of a set of words articulated by the robot and a human tutor, and the second experiment investigates the acceptance of the robot through interaction with adults and children.

4.1 Participants

To appraise the explicitness of the robot’s visual articulation performance, a group of Iranian adults studying at Fereshte International Branch of the Islamic Azad University and skilled in lip-reading and sign language took part in the first experiment. The under-investigation group was composed of seven deaf individuals (three men, four women, mean age = 20.43, standard deviation = 1.72), seven hard-of-hearing persons (four men, three women, mean age = 20.29, standard deviation = 1.80), and seven normal hearing students (four men, three women, mean age = 20.14, standard deviation = 1.35). Another group of 34 Iranian hearing-impaired individuals participated in the second experiment. This group, composed of 16 children (nine boys, seven girls, mean age = 7.63, standard deviation = 1.15) and 18 adults (ten men, eight women, mean age = 20.78, standard deviation = 1.87), helped explore the acceptance of the APO robot through interaction with its target groups. All participants had no previous experience interacting with social robots.

4.2 Assessment Tools

In the first experiment, two types of tests, descriptive and four-choice, were adopted. Both tests were comprised of twenty-eight questions concerned with the lip-synced words. Throughout the descriptive test, participants were asked to guess and write the articulated words, while in the four-choice test, they were required to choose the correct answer among four semi-syllable words. The collection of words was composed of fourteen one-syllable and fourteen multi-syllable words. Each of the sounds (consonants and vowels) was repeated more than three times throughout the set. In both trials, normalized scores, defined as the ratio of the participants’ correct responses to the total number of questions, were utilized as metrics to compare the perceptibility of the utterances lip-synced by the robot and the human teacher.

Furthermore, the UTAUT [55] and SAM [50] questionnaires were utilized to evaluate the adults’ and children’s acceptance of the APO robot, respectively. The UTAUT questionnaire is a well-established test developed to quantify the acceptance of technology by older adults. This model aims to assess the users’ intention to employ a novel technology according to performance expectancy, effort expectancy, social influence, and facilitating conditions. Individual attributes, including gender, age, experience, and voluntariness, are the main moderating influences [56]. The UTAUT model requires some modification to fit the field of the technology it is applied in; therefore, we employed the version modified by Heerink et al., which is suitable in the social robotics context [49]. This modified version investigates twelve constructs, including Anxiety (ANX),
Fig. 9 Penner’s easing functions [53]

Attitude Towards Technology (ATT), Facilitating Conditions (FC), Intention to Use (ITU), Perceived Adaptiveness (PAD), Perceived Enjoyment (PENJ), Perceived Ease of Use (PEOU), Perceived Sociability (PS), Perceived Usefulness (PU), Social Influence (SI), Social Presence (SP), and Trust. The second questionnaire, i.e., the SAM model, was used to assess the robot’s acceptability by children. This test measures pleasure, arousal, and dominance concerned with the social robot [50]. Both questionnaires, UTAUT and SAM, were scored via Five-Likert pictorial scales (range:1–5) [48, 57].

4.3 Procedure

4.3.1 Experiment one: Evaluation of the Proposed Lip-Syncing System

In the study’s first phase, an educational lip-reading game was designed to evaluate the proposed lip-syncing system’s capacity for conveying messages to hearing-impaired people. The objective of this game was to compare the APO robot with human articulations. To this end, we asked a tutor working at the Fereshtegan University to lip-sync a set of Persian words and recorded a video while she was articulating them. The robotic platform also lip-synced the same set of words in a different succession. Subsequently, the adult participants were asked to watch the silent sequence and specify the terms they had recognized due to their greater expertise in lip-reading compared to children. Then, they were asked to take the words perception test with the APO robot in the same manner. Afterward, the students were scored according to the number of words correctly identified in each of the two lip-reading scenarios. The lip-reading games were carried out twice to provide the participants with clues about the correct answers. The first time, they were asked to note down the words they saw, while the second time, they were required to choose the correct answers from a four-choice test. Furthermore, the counterbalancing technique was used to eliminate the order effect. In this regard, half of the participants first encountered the robot and then the lip-reading video, while others underwent the reverse order.

4.3.2 Experiment Two: Investigation of the Robot’s Acceptability

The second phase of the study was devoted to comparing the acceptability of the two lip-reading training programs, the lip-reading tutoring program taught by the APO robot and the one performed by the video of the tutor while she was lip-syncing the same words. The investigation was conducted on both adults and children. In this regard, first, the adult participants were asked to complete the UTAUT questionnaire. Afterward, the acceptability test was performed through interaction with the children. The SAM questionnaire was employed in this examination to quantify the children’s emotional responses. Following the meeting and playing with the APO robot. Figure 11 depicts the experimental setup in the two experiments.

5 Results

5.1 Experiment one: Evaluation of the Proposed lip-syncing System

The first experiment was dedicated to comparing the participants’ perception of the APO robot’s visual articulation and the video of the tutor lip-syncing the same set of words. In
the first step of the experiment, the participants were asked to write the utterances they had recognized in the two lip-reading games, while in the second step, they were asked to choose correct answers from a four-choice questionnaire. To check the quality of the robot’s articulatory system, the participants’ normalized scores in the two lip-reading scenarios were first statistically analyzed ($t$-test) using Minitab software. Then, the resulting $p$-values were utilized as metrics to determine whether participants’ perceptions of the two lip-reading games had significant differences.

Furthermore, a similarity score that states the number of words identically labeled (correctly or incorrectly) in the lip-reading games was also defined to measure the comparability of the robot’s lip-syncing system and the human articulation. In other words, the similarity score explains the number of words similarly identified in the two games, regardless of their correctness, normalized by the total words. Table 2 summarized the participants’ normalized scores in this experiment.

5.2 Experiment Two: Investigation of the Robot’s Acceptability

In the second experiment, the acceptance of the APO robot among adults and children was investigated in comparison with the recorded lip-syncing video throughout the designed lip-reading games. Following the end of the two games, the children were asked about their preference between the two educational games to investigate the Child-Robot interaction. The SAM questionnaire was given to the children following the end of the two games, and they were asked to answer each item via Likert scores ranging from one to five. The participants’ scores concerning the robot and the recorded video, as well as the statistical analysis ($t$-test) results, are summarized in Table 3.

To scrutinize the robot’s acceptability to the adult participants, the UTAUT questionnaire was employed. Like the previous procedure, the adults were asked to declare their preference for the APO robot and the recorded video following the two games. Afterward, the participants were asked to complete the UTAUT test via the Five-Likert scale. To probe into the differences between the acceptance of the robot and the recorded video, statistical analysis was performed. Table 4 presents the results concerned with the robot and the video acceptance scores.

6 Discussion

6.1 Experiment One: Evaluation of the Proposed Lip-syncing System

Throughout the first experiment, certain words were correctly recognized in the human tutor’s video and the APO robot lip-syncing, while other items were misunderstood in lip-reading games. Interestingly, most of these misconceptions about the articulated words were the same. The statistical analysis ($t$-test) of the above results (for an alpha of 0.05) revealed that the scores corresponding to the participants’ recognition of monosyllabic words in the lip-syncing video were significantly higher than the APO robot’s articulation ($p < 0.05$). However, their comprehension of multisyllabic words was not significantly different in the two games ($p > 0.05$). Therefore, we concluded that the robot’s articulation of words composed of two or more syllables is comparable with the human tutor. However, a power analysis using G*Power 3.1 Software [58] revealed that determining a statistically significant difference requires at least $N = 35$ participants for this experiment based on the medium effect size of 0.5, a power level of 0.8, and a significance level of 0.05. Hence, our findings, with respect to the comparability of the robot and the human tutor articulation of multisyllabic words, should be reported cautiously due to the limited number of participants. Additionally, the preliminary exploratory findings of the first experiment demonstrated that the hard-of-hearing participants were more competent at both lip-reading games than the other groups.
Table 2 The participants’ scores in the two lip-reading scenarios (the APO robot and the human tutor)

| Group                  | Items          | Test type   | Score’s mean (SD) | Similarity | p-value |
|------------------------|----------------|-------------|-------------------|------------|---------|
|                        |                |             | Robot             | Video      |         |
| Deaf group             | Monosyllabic   | Descriptive | 0.3163 (0.0382)   | 0.4184 (0.1046) | 0.4538  | 0.032  |
|                        | Four-Choice    |             | 0.5408 (0.0998)   | 0.6531 (0.0764) | 0.5936  | 0.036  |
|                        | Multisyllabic  | Descriptive | 0.5816 (0.0961)   | 0.6327 (0.0643) | 0.5714  | 0.266  |
|                        | Four-Choice    |             | 0.6735 (0.0382)   | 0.7143 (0.0583) | 0.7032  | 0.147  |
| Hard hearing group     | Monosyllabic   | Descriptive | 0.3571 (0.0825)   | 0.4694 (0.1080) | 0.5128  | 0.049  |
|                        | Four-Choice    |             | 0.6020 (0.0998)   | 0.7245 (0.0764) | 0.7593  | 0.024  |
|                        | Multisyllabic  | Descriptive | 0.6531 (0.0961)   | 0.6735 (0.0697) | 0.7863  | 0.657  |
|                        | Four-Choice    |             | 0.7449 (0.0909)   | 0.7755 (0.0868) | 0.8542  | 0.531  |
| Normal-hearing group   | Monosyllabic   | Descriptive | 0.2857 (0.0922)   | 0.3878 (0.0810) | 0.4126  | 0.048  |
|                        | Four-Choice    |             | 0.4796 (0.1069)   | 0.6020 (0.0818) | 0.4921  | 0.033  |
|                        | Multisyllabic  | Descriptive | 0.5306 (0.0697)   | 0.6020 (0.0909) | 0.5574  | 0.125  |
|                        | Four-Choice    |             | 0.6429 (0.0583)   | 0.6939 (0.0795) | 0.6828  | 0.196  |

Table 3 The SAM test results and analysis comparing the children’s acceptance of the APO robot and the recorded video

| Item      | Score’s mean (SD) | p-value |
|-----------|-------------------|---------|
|           | Robot             | Video   |         |
| Pleasure  | 4.467 (0.443)     | 3.883 (0.472) | 0.011  |
| Arousal   | 3.783 (0.846)     | 3.100 (0.545) | 0.046  |
| Dominance | 3.867 (0.864)     | 3.300 (0.706) | 0.126  |

6.2 Experiment Two: Investigation of the Robot’s Acceptability

A review of the children’s acceptance of the robot during their interaction in the study showed that the APO achieved higher scores than the recorded video on all items of the SAM questionnaire. Additionally, according to the statistical analysis (for an alpha of 0.05), significant differences were observed for the metrics concerned with pleasure and arousal in the two scenarios (p < 0.05), while the dominance item showed no significant difference between the two games (p > 0.05). The acceptance of the robot among adults, measured via the UTAUT questionnaire, indicated that the average scores of the APO robot for the ATT, FC, ITU, PAD, PENJ, PS, PU, SI, and SP items, were higher than the recorded video, but significant differences were only observed (p < 0.05) for the ATT, ITU, PAD, PENJ, PS, SI, and SP constructs. The robot’s significantly higher scores in the PAD and PENJ items are due to the APO robot’s enjoyability and easiness of use. The SP and PS constructs correspond to the robotic platform’s adaptability and sociability, leading to a positive image of the APO characteristics. Higher scores on the ATT and ITU items show a higher engagement level for the social robot compared to the video throughout the lip-reading training procedure. The significant difference in the SI item describes the participants’ preference to share this technology with others. The outcome of this examination should be reported with caution due to the limited number of participants calculated by the conducted power analysis.

7 Limitations and Future Work

The robotic platform developed in the current study utilized an LCD screen to lip-sync the words. One of the robot’s limitations is the 2D trait of the proposed lip-syncing system. This issue complicates the participants’ perception of the APO characteristics.
robot’s utterances. Another limitation of our study was the number of volunteers. Due to the COVID-19 pandemic, only a small number of people agreed to take part in our examination. Our future work objective is to enhance the lip-syncing system to be more analogous to the articulation of a human tutor. Additionally, future studies will focus on designing an attractive collaborative game to increase hearing-impaired people’s lip-reading skills by developing a lip-reading system using CNN and RNN models to improve the lip-reading capability of the APO robot. In this way, the robot will be regarded as the playmate of learners playing the interactive lip-reading game. This interaction engages individuals through learning procedures and assesses their performance while lip-syncing the target words. Furthermore, comparing the lip-reading attainments through Robot-Assisted Therapy (RAT) sessions and conventional lip-reading instructions is another possible subject for future experiments.

8 Conclusion

This study proposed a new tablet-face robotic platform, APO, that benefits from a lightweight and portable platform designed to enhance lip-reading training programs for hearing-impaired individuals. In this regard, a lip-syncing system based on the visual articulation of a sign language interpreter was developed and implemented on the robot to accomplish the robot’s educational objective. To assess the efficacy of the developed robotic platform’s desired objective, two main experiments were conducted, evaluating the proposed lip-syncing system and investigating the acceptability of the robot among children and adults. The first experiment’s analysis indicated that the proposed lip-syncing system performed appropriately regarding the articulation of compound words. Moreover, the exploratory outcomes of the investigation revealed that hard-of-hearing participants were more adept at comprehending lip-synced words. The outcome of the second experiment, the examination of the acceptance of the robot among both adults and children, also demonstrated that the robot scored higher acceptance than a recorded video when employed as assistive technology for hearing-impaired individuals. In this regard, the lip-reading attainments through Robot-Assisted Therapy (RAT) sessions and conventional lip-reading instructions is another possible subject for future experiments.

The first draft of the manuscript was written by Alireza Esfandbod and Zeynab Rokhi. All authors read and approved the final manuscript.

Data availability All data from this project (videos of the sessions, results of the questionnaires, scores of performances, etc.) are available in the archive of the Social & Cognitive Robotics Laboratory.

Code availability All of the codes are available in the archive of the Social & Cognitive Robotics Laboratory. In case the readers need the codes, they may contact the corresponding author.

Declarations

Conflict of interest Author Alireza Taheri has received a research grant from the Sharif University of Technology (Grant No. G980517). The authors Alireza Esfandbod, Ahmad Nourbala, Zeynab Rokhi, Ali F. Meghdari, and Minoo Alemi assert that they have no conflict of interest.

Ethical approval Ethical approval for the protocol of this study was provided by the Iran University of Medical Sciences (#IR.IUMS.REC.1395.95301469).

Consent for publication Informed consent was obtained from all individual participants included in the study.

Consent for publication The authors affirm that human research participants provided informed consent for the publication of the image in Figs. 6 and 11. All of the participants have consented to the submission of the results of this study to the journal.

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Alireza Esfandbod is a Ph.D. candidate at the Mechanical Engineering Department of the Sharif University of Technology, Tehran, Iran. His research interests include Mechatronics, Robotics, Social Robotics, Pattern Recognition, Computer Vision, Artificial Intelligence, Machine Learning, and their applications in Human-Robot Interaction.

Ahmad Nourbala graduated with a Mechanical Engineering M.Sc. from the Sharif University of Technology. His research interests are Mechanical Design, Manufacturing, System Dynamics, and Control.

Zeynab Rokhi received her M.Sc. degree in Mechanical Engineering from the Sharif University of Technology. Her research interests are Social Robotics, Computer Vision, Deep learning, Machine learning, and Human-Robot Interaction.

Ali F. Meghdari is a Professor Emeritus of Mechanical Engineering and Robotics at Sharif University of Technology (SUT) in Tehran. Professor Meghdari has performed extensive research in various areas of robotics; social and cognitive robotics, mechatronics, bio-robotics, and modeling of biomechanical systems. He has been the recipient of various scholarships and awards, the latest being: the 2012 Allameh Tabatabaei distinguished professorship award by the National Elites Foundation of Iran (BMN), the 2001 Mechanical Engineering Distinguished Professorship Award from the Ministry of Science, Research & Technology (MSRT) in Iran, and the 1997 ISESCO Award in Technology from Morocco. He is the founder of the Centre of Excellence in Design, Robotics, and Automation (CEDRA), an affiliate member of the Iranian Academy of Sciences (IAS), a Fellow of the American Society of Mechanical Engineers (ASME), and the Founder and Chancellor of Islamic Azad University- Fereshtegaan International Branch (for students with special needs; primarily the Deaf).

Alireza Taheri is an Assistant Professor of Mechanical Engineering with an emphasis on Social and Cognitive Robotics at Sharif University of Technology, Tehran, Iran. He is the Head of the Social and Cognitive Robotics Lab at Sharif University of Technology.
Minoo Alemi received her Ph.D. in Applied Linguistics from Allameh Tabataba’i University in 2011. She is currently an Associate Professor and Division Head of Applied Linguistics at the Islamic Azad University, West-Tehran Branch. She is the cofounder of Social Robotics in Iran, a title she achieved as a Post-Doctoral research associate at the Social Robotics Laboratory of the Sharif University of Technology. Her areas of interest include discourse analysis, interlanguage pragmatics, materials development, and RALL. Dr. Alemi has been the recipient of various teaching and research awards from Sharif University of Technology, Allameh Tabataba’i University, Islamic Azad University, and Int. Conf. on Social Robotics (ICSR-2014).