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Development and Evaluation of Remote Articulation Test System to Support Collaboration Between Special Education Classes and External Experts

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Abstract

We developed a remote articulation test system with which external expert remotely inspected the speech pronunciation of language-disabled students in special education classes. Our system was configured using Web Real-Time Communication and satisfied the requirements to qualify as a support system for special education classes. To confirm whether a remote articulation test's performance with our system is comparable to a face-to-face test, we compared the performances of the remote test using our system with face-to-face and remote tests using an existing web video system. External experts and teachers conducted articulation tests and rated their diagnostic confidence. The strength of agreement in the diagnostic results was sufficiently high between the face-to-face and remote sessions and between the inspectors. The diagnostic confidence of the remote test with our system was significantly better than the face-to-face and existing web video system sessions. Our system was also evaluated as having higher usability than the existing web video system. Similar results were obtained in related experiments on severe hearing-impaired children, suggesting that the proposed system is also applicable to them. This research achieved a remote articulation test system that provides sufficient performance, privacy and copyright protection, and ease of use for inspectors.

Keywords: Remote diagnostic system, Articulation test, Special education class, WebRTC

1 Introduction

In Japan, special education classes in regular elementary schools support children whose language development lags behind their peers due to language and speaking disorders or developmental disabilities. The number of students in such classes continues to increase, and in 2019 it exceeded 130,000. When compared by type of impediment, language disorders are the largest category, with approximately 40,000 students [1].

In 2018 Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT) revised a part of the School Education Law Enforcement Regulations, and ordered each school

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to create an "individualized educational support plan," even in special education classes [2]. In the United States, which implemented individualized education plans (IEPs) before Japan, an IEP must be created by a team consisting of persons with specialized knowledge, the student, and the parents [3]. On the other hand, according to a survey by MEXT [4], the implementation rate of individualized educational support plans in Japan was 66.1% in 2017. To grasp the actual situations under which plans are being made, observations by teachers and educational coordinators accounted for 91.4% of them, and those in collaboration with external organizations accounted for 51.1%; the implementation of various tests was only 36.3%.

Teachers in special education classes in Japan are not required to have a special license. More than half of the teachers in such classes lack specialized knowledge and skills regarding hearing and speech disabilities. This also applies to special education coordinators [5].

MEXT pointed out that such specialists as speech therapists must be used or cooperate with external organizations in special needs education [6]. To encourage such cooperation, using information and communication technology (ICT) has been attempted. Matthews et al. [7] examined the validity of speech-hearing therapy by Skype and showed its effectiveness. Ashburner et al. [8] developed a system in which autistic children and their parents receive support from remote external experts.

So far, most studies for supporting articulation disorder children have been based on automatic articulation assessment systems as alternatives to assessment by speech therapists. Dudy et al. [9] proposed new a Goodness of Pronunciation (GOP) technique based on statistical learning approaches like support vector machines. Hidden Marcov Model based automatic speech recognition (ASR) schemes have also been frequently used to evaluate disordered speech sounds [10][11]. Vijayalakshmi and Priya [12] used linear predictive coding, Su et al. [13] proposed an adapted acoustic model in ASR, and Chen et al. [14] used ASR with a dependency network to evaluate disordered speech. Recently, Ng and Lee [15] attempted to automatically detect phonological errors using a recurrent autoencoder.

Undoubtedly, automatic speech assessment techniques will contribute to the pronunciation training of speech disorders. However, the role of speech therapists is not limited to pronunciation evaluation. They also work with teachers to develop individualized education plans for specific children. Collaboration between speech therapists and educational institutions must also be supported. We provided support systems for pronunciation instruction and practice in special education classes for language-disabled children [16]. Our system also provided a framework that allows the active involvement of external experts. While students practiced their pronunciation, the system automatically evaluated it and fed back the results. In addition, the students' speech sounds for the articulation tests were automatically recorded, allowing external experts to access them through the internet anytime and anywhere and for articulation tests. Our system simplified not only articulation tests but also the observation of the processes of the students' pronunciation improvement; the results can be used in collaboration with teachers. Unfortunately, the previous system for articulation testing suffered from two main testing defects. It presented written words instead of picture cards to the students to promote their utterances. External experts had to perform articulation tests using only speech sounds.

From such a background, we developed a remote articulation test system with multimedia communication for external experts to examine the pronunciation of students more formally in special education classes. In addition to encouraging cooperation between teachers and external experts using this system alone, more flexible and effective support can be provided by using it in combination with our previously developed system [16].

2 System Requirements

Vidul et al. [17], who developed a telemedicine system for emergency care management using Web Real-Time Communication (WebRTC) [18], explained why they did not use existing video chat applications. First, most of them require plug-ins, downloads, or client software installation. Since they are maintained by a third party, the possibility of undisclosed recording of video sessions by a third party raises privacy concerns. The transmitted data pass through an outside server where they are sometimes stored. In addition, many organizations want to add their own functionality to the existing application or integrate it with their legacy system. But no such flexibility is provided.

In this study, for the same reasons, we determined that existing web video systems were unsuitable for a remote articulation test. The following are the requirements for a remote articulation test system that supports special education classes:

(1) It must be simple enough for those who lack high PC skills and require no installation.
(2) Its video and audio quality must be high.
(3) It must protect personal information and privacy.
(4) Picture cards protected by copyright may only be used by authorized persons.
(5) It must have high expandability.

To satisfy these requirements, our system was configured with WebRTC technology, which performs real-time communication with a web browser using P2P communication with video, audio, and other kinds of data. Requirement 1: Since standard web browser functions are used, no application software or plug-ins are required. Requirement 2: transmitting and receiving high-quality video and audio are possible in real time. Requirement 3: Communication is encrypted by default, and various messages and files are transmitted directly without passing through a server.

Since the picture cards generally used in articulation tests are protected by copyright [19], only those who have permission may use them. Requirement 4: WebRTC allows the creation of a simple mechanism that enables image files stored on the client PC to be directly sent to the browser of the communication partner and displayed using P2P data communication. Inevitably, the picture cards cannot be used by anyone who does not have image files of them.

This paper presents a writing-board implementation as an example that satisfies Requirement 5. In the future, we will implement a function that assists pronunciation assessment by inspectors like our previous system [16].

3 Usages and System Configuration

3.1 Usages

Our system adopted a web conference room model for communication between a special education class and an external expert. Partners who can communicate are limited to those in the same room. The teacher (or the student) and the external expert (inspector) access a web server (Figure 5, ①) and the teacher (or the student) and the inspector input their IDs and the room name on a website to enter it (Figure 1). The inspector selects his/her partner's ID and establishes a session with him/her (Figure 2).

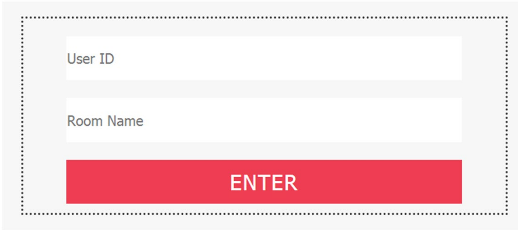

Figure 1: Screen for entering conference room. Only those who enter same conference room name can connect with each other.

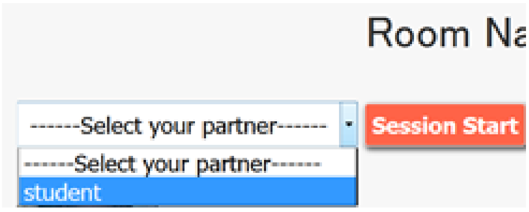

Figure 2: Part of inspector' screen. Inspector selects person with whom he/she wants to connect from list of IDs in same conference room.

Figure 3 shows a web browser screen from the inspector's side during an articulation test, and Figure 4 shows it from the student's side.

The inspector can record the student's audio and video and save them to a local file by the "recording start," "recording stop," and "download" buttons on the inspector's web browser (Figure 3, ①). The inspector can refer to the image files required for testing on the local disk by clicking the "browse" button (Figure 3, ②) on the web browser screen. If multiple image files are selected in advance, each time the inspector clicks the "send image" button (Figure 3, ③), images are sent in sequence and displayed on the student's web browser (Figure 4, ①). Then the inspector asks the student to name the objects in the images and assesses his/her pronunciation.

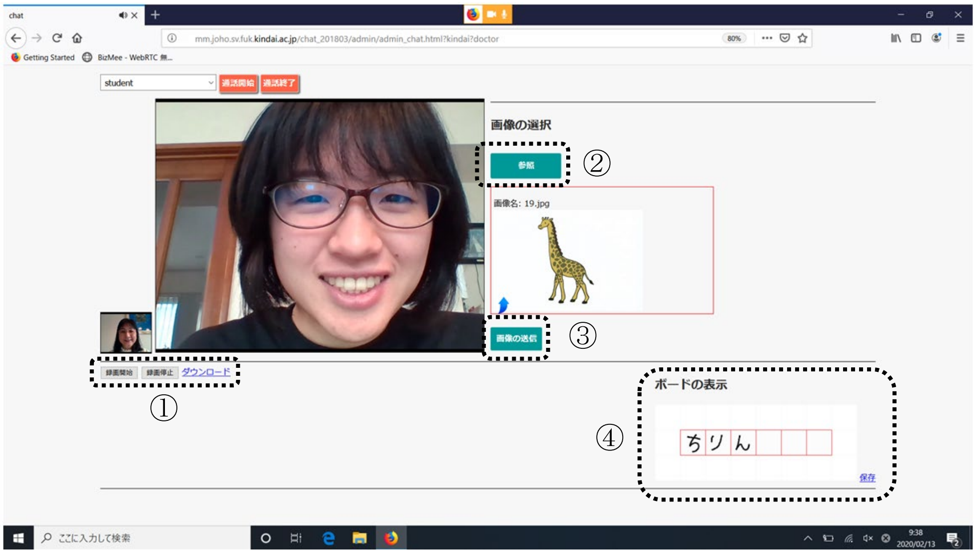

Figure 3: Web screens of inspector during a remote articulation test.
To protect participant's privacy, woman in this figure is not an actual subject.

In a face-to-face articulation test, the inspector sometimes asks the student to write a word or an example that contains a particular syllable to confirm whether the pronunciation error was caused by another problem other than articulation, such as dyslexia. Although such a written test is unnecessary for articulation tests, we implemented a writing board (Figure 4, ②) to remotely perform a similar test because such an extra test is also important for educational consultations. The student's handwriting is displayed in real time on the inspector's screen (Figure 3, ④). The boards can also be saved as images. In the example in Figure 4, a student wrote "chirin" instead of "kirin" (the Japanese word for giraffe) while looking at a picture of a giraffe. This student failed to distinguish between syllables "ki" and "chi." In this case, pronunciation errors are no longer an articulation issue.

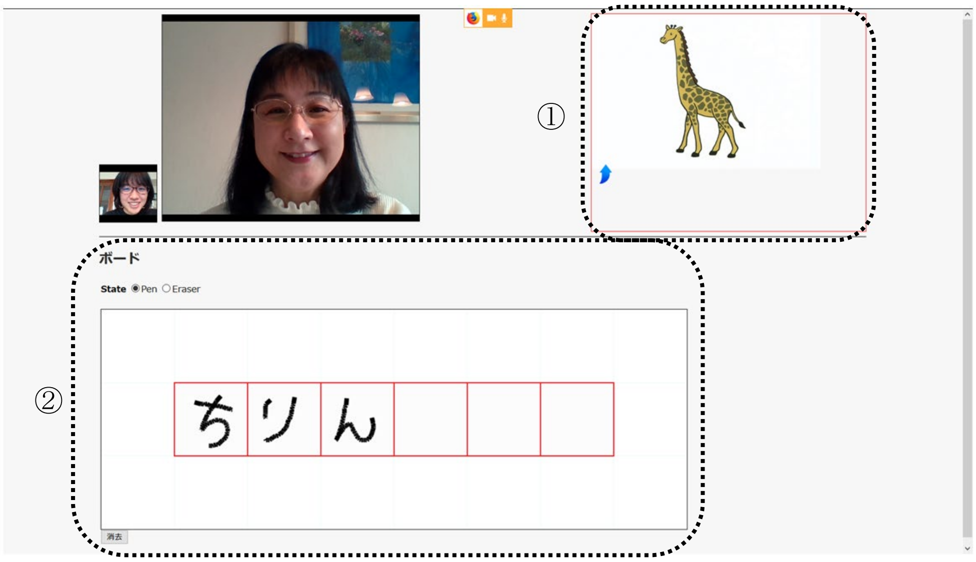

Figure 4: Web screens of students during remote articulation test

3.2 System configuration

Our proposed system has video and voice communication and image transmission functions based on WebRTC. Peer to peer (P2P) communication is achieved between external experts and a special education class. Using audio/video communication, the external expert confirms the student's voice and articulation movements. Using image transmission, the external expert can display picture cards for articulation tests on the student's screen on which a writing board is also implemented. When the student writes on it, the letters are displayed on the external expert's screen in real time by image transmission.

To establish a peer connection, computers of the external expert and the special education class must exchange such information about their session, as offer/answer messages of the Session Description Protocol (SDP). A signaling server is required to mediate such information. Signaling is responsible for the negotiation and the configuration of media capabilities, session participant identification and authentication, media session control, and session modification and termination. In this research, a signaling server was developed using socket.IO, which is a library of Node.js. Offers/answers from SDP are exchanged on a signaling channel, and media negotiation is performed between browsers (Figure 5, ②).

Local media is called by a WebRTC's javascript method named getUserMedia. Several media are then combined to create a MediaStream object that is sent to the peer.

WebRTC, which uses P2P media flows, should establish connections that allow direct communication of audio, video, and data between browsers. However, NAT and firewalls prevent this connection. For communication outside the Network Address Translation (NAT), a global IP address and a port number allocated by NAT must be acquired. We obtained this information using Google's publicly available STUN server (Figure 5, ③). After learning their own information as seen from outside, they exchange information about multimedia sessions and their candidate addresses for hole punching by a signaling server. This signaling is encrypted by SSL/TLS. In this way, mutual P2P communication of video, audio, and data starts (Figure 5, ④).

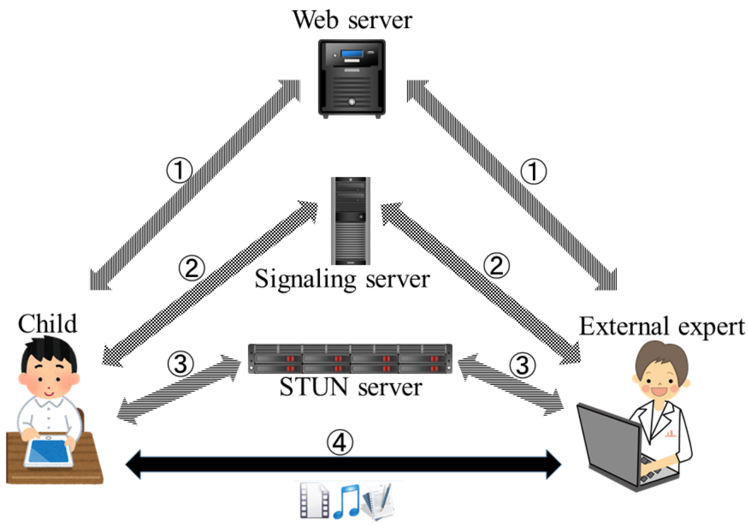

Figure 5: Interaction with various servers for P2P communication

4 Evaluation in Special Education Classes for Language-Disabled Children

We must confirm whether the performance of a remote articulation test with our system is comparable to a face-to-face articulation test. In this study, we compared the articulation test performances of face-to-face and remote tests using our system and those between our system and the existing web video system.

Our experiment was incorporated into an activity in a special education class in which an external expert conducted articulation tests and provided an educational consultation service to their teachers and their parents based on the results. The external expert and the class teachers performed both face-to-face articulation and remote tests using our system or the existing web video system with each student. This experiment was reviewed and approved by the Bioethics Committee of Faculty of Humanity-oriented Science and Engineering, Kindai University.

4.1 Participants

Sixteen students participated: ten first graders, three second graders, two fourth graders, and one fifth grader. A 2nd grader was removed because he did not participate in the remote session. In advance, we explained the purpose of the experiment, the rights of the participants, and the handling of personal information. Then we obtained consent from both the students and their parents for participation.

One external speech therapist and eight teachers involved in pronunciation instruction in the special education classroom conducted articulation tests. For each student, the speech therapist and one or two teachers simultaneously performed articulation tests.

4.2 Methods

The students underwent face-to-face and remote sessions. Seven students did the remote session using our system, and the rest did it using the existing web video system. Approximately half did the face-to-face session first, and the rest did the remote session first. The test was a word articulation type. The inspectors presented picture cards to the students, asked them to say the name of the object on each card, and assessed their pronunciation. In the face-to-face sessions, the inspectors gave the test to the students in the same soundproof room. In remote sessions, the inspectors gave remote tests to the students in a different soundproof room by internet (LTE mobile router: Fuji SOFT FS030W). Both the inspectors and the students used notebook PCs with a built-in web camera, headphones (inspectors: Audio-Technica ATH-SX1 or SONY MDR-Z150, students: SONY MDR-SA1000) and microphones (Audio-Technica AT9903). BizMee (https://bizmee.net), which used the same WebRTC as our system, was used as a web video system. In both the face-to-face and remote sessions, after the test, the inspectors rated their diagnostic confidence for each of the 26 phonemes on a five-point scale from "not very confident" (1) to "very confident" (5).

4.3 Results

4.3.1 Strength of diagnosis agreement between face-to-face and remote sessions

To confirm the strength of the agreement of the pronunciation diagnoses between the face-to-face and remote sessions, we calculated the AC1 statistics [20] for the same inspector and the same student and verified whether the diagnoses matched word by word; when the pronunciation diagnoses of all the phonemes in a word were identical, the diagnoses were considered consistent. Figure 6 shows the strength of the agreement between the face-to-face and remote sessions using our system and between the face-to-face and remote sessions using the existing web video system. From the guidelines of the strength agreement by Landis and Koch [21] (Table 1), both cases exhibit considerable agreement. The z-transformation of the rates and a Welch's bilateral t-test (no correspondence) of the differences between their averages revealed that $t(28.5) = -1.47$, $p = 0.1537$, which denotes no significant difference.

Table 1: Strength of agreement [21]

0.0～0.2	Slight
0.21～0.40	Fair
0.41～0.60	Moderate
0.61～0.80	Substantial
0.81～1.0	Almost perfect

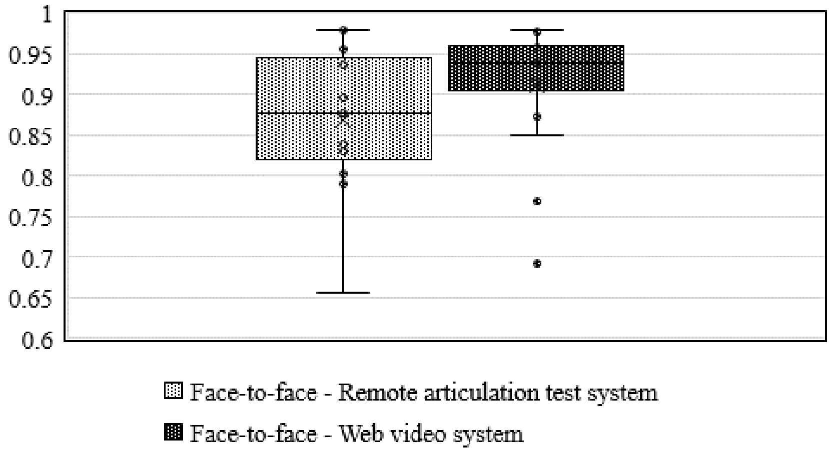

Figure 6: Strength of diagnosis agreement between face-to-face and remote sessions using our remote articulation test system and between face-to-face and remote sessions using existing web video system

4.3.2 Strength of diagnosis agreement between inspectors in remote sessions

To determine how much the diagnosis results matched among the inspectors in the remote sessions, we calculated the strength of the diagnosis agreement between the inspectors for the same student and the same method. The students were divided into group α, which was inspected by the remote articulation test system, and group β, which was inspected by the web video system. Then their AC1s were calculated. The strength of the diagnosis agreement of group α averaged 0.83 ($\sigma = 0.08$), and that of group β averaged 0.89 ($\sigma = 0.11$). From the guidelines of the strength agreement by Landis and Koch, both cases exhibit quite consistent results.

4.3.3 Statistical test for diagnostic confidence

Figure 7 shows the average diagnostic confidence and the 95% confidence intervals for each session. The results of the Welch's bilateral t-tests (no correspondence) of the differences between the averages showed that the diagnostic confidence of the remote test using our system was significantly higher than the face-to-face session ($t\ (1242.3) = -2.05$, $p = 0.04027$ *) and the session using the existing web video system ($t\ (683.6) = 2.48$, $p = 0.01347$ *).

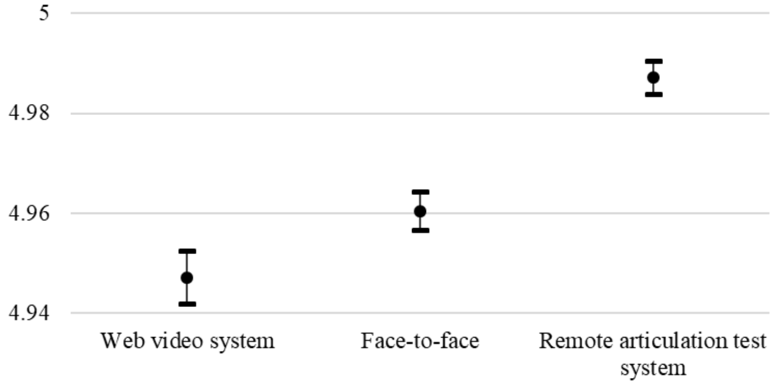

Figure 7: Average diagnostic confidences and 95% confidence intervals for face-to-face and remote sessions of our remote articulation test system and existing web video system

4.3.4 Evaluation of usability

After the experiments, the inspectors rated the usability of our remote articulation test system and the existing web video system on a four-point scale: "unusable," "somewhat unusable," "somewhat usable," and "usable." Although the ratings are on an ordinal scale, we calculated the average by a rating value of 1 to 4 for convenience. Table 2 shows the question items and the score averages. The usability score of the remote articulation test system exceeds the existing web video system in all items.

Table 2: Usability scores

	Remote articulation test system	Existing web video system
Operability	3.2	2.7
Easy to understand operation	3.2	2.8
Inspection while operating	2.7	1.8
Image clarity	3.2	2.5
Sound clarity	3.5	3.3

4.4 Discussions

Remote tests with our remote articulation system had significantly higher diagnostic confidence than those with existing web video system and face-to-face tests. First, we compare remote tests with our system to face-to-face test. The evaluation result of usability showed that both remote systems were highly rated for their sound quality. Comments in the free description section stated that using these systems (rather than face-to-face) allowed them to listen to the voice better. This seems to have led to high diagnostic confidence in remote tests with our system than face-to-face tests.

On the other hand, Table 2 shows that the existing web video system has lower usability than our remote articulation test system. With the former, the inspector did the following tasks while evaluating the student's pronunciation: turning the picture cards and verifying that they had been clearly presented to the student. With our system, these tasks can be accomplished with a simple mouse click or a panel touch. Based on the comments in the free description section, the load on the inspector differences seem related to the variations in the diagnostic confidence and usability evaluations between the existing web video systems and our remote articulation test system.

No other remote articulation test system has been found, although telemedicine systems may be included in similar systems. Unfortunately, the COVID-19 pandemic has promoted the spread of telemedicine. Anthony [22] reviewed the efforts of the countries that rapidly adopted telemedicine as a pandemic response, especially the United States, China, and Australia. Some popular video conferencing applications were not supported by the Health Insurance Portability and Accountability Act (HIPAA) because they were unsuitable for telemedicine. Nevertheless, since telemedicine is providing emergency responses, the Office for Civil Rights at the Department of Health and Human Services in United States did not penalize noncompliance with HIPAA rules. The rapid spread of telemedicine may also cause an unsuitable environment for diagnosis. Anthony also noted that some system requirements for telemedicine must be satisfied. Patient's data confidentiality must be established, and telemedicine's effectiveness depends on the quality of the images and video. The virtual software that is deployed for telemedicine should be user-friendly and also provide online assistance for patients with low technological proficiency. Our system meets all of these requirements. Our research may contribute to software development guidelines not only for remote articulation tests but also for more general telemedicine that is rapidly becoming more widespread.

5 Preliminary Experiments to Expand Application to Hearing-Impaired Children

Our system was targeted at language-disabled children in special education classes. A preliminary experiment, which investigated whether it could be applied to the pronunciation evaluation of severely hearing-impaired children, was conducted in after-school daycare for such children. As in previous experiments in special education classes for language-disabled children, the experiment was also incorporated into a consulting activity in which an external expert conducted articulation tests and provided educational consultation services to their parents based on the results.

5.1 Participants and methods

Fifteen children participated in the experiment: a five-year-old preschooler, a first grader, a second grader, two third graders, four fourth graders, five fifth graders and an eighth grader. In advance, we explained the purpose of the experiment, the rights of the participants, and the handling of personal information. Then we obtained their own consent as well as that of their parents for participation. The inspector was an experienced speech therapist.

Remote tests using our remote articulation test system, face-to-face tests, and interviews with their parents were conducted in this order with all 15 participants to smoothly carry out consulting activities in a limited place and time. In the remote tests, both the inspector and the children used a 2 in 1 PC (DELL Inspiron 15) with a built-in web camera and external microphones (Audio-Technica AT9903). The inspector used closed-type headphones (Audio-Technica ATH-SX1a), and the children used open-type headphones (SONY MDR-SA1000) while wearing their hearing aids or cochlear implants. The ear pads of the open-type headphones were large enough to wear in conjunction with hearing aids or cochlear implants. When testing the students with severe hearing impairment, the inspector sometimes interacted by sign language face-to-face or through video communication.

5.2 Results and discussion

In our previous experiments with language-disabled students in special education classes, we calculated diagnosis agreements based on word-by-word diagnostic agreements. Many students in special education classes were prone to make mistakes in specific phonemes. Since multiple pronunciation mistakes were rare in one inspection word, there was no problem investigating word-by-word agreement. However, the pronunciation of children with severe hearing impairment is very unclear, and errors often appear in multiple syllables in one inspection word. Therefore, in this experiment, we calculated the degree of diagnostic agreement by syllables. An articulation test [19] contains a sheet for reorganizing pronunciation evaluations for each syllable in the inspection words. In this experiment, we evaluated the diagnosis agreement of 120 syllables from the sheet. Figure 8 shows the AC1 statistics between the face-to-face and remote sessions using our system. The average was 0.93, and the minimum value was 0.61. From the strength agreement guidelines by Landis and Koch, the strength of agreement for all participants was substantial or almost perfect.

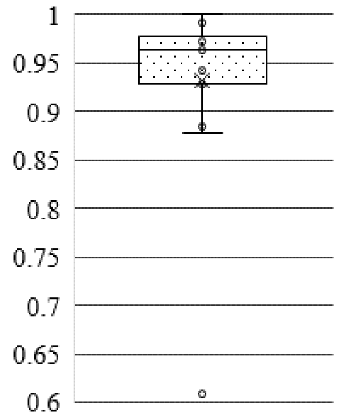

Figure 8: Strength of diagnosis agreement between face-to-face and remote sessions using our system

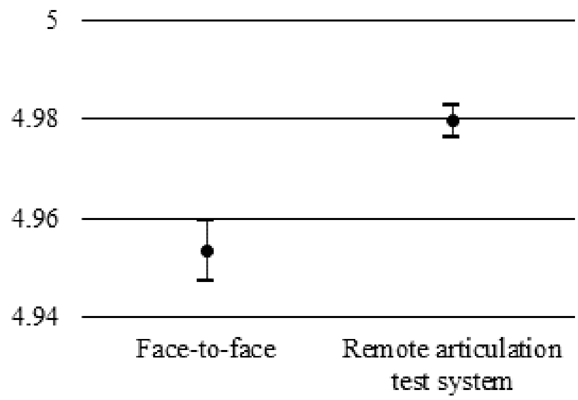

Figure 9: Average diagnostic confidences and 95% confidence intervals for face-to-face and remote sessions of our system

The inspector also rated the diagnostic confidences. Figure 9 shows the average diagnostic confidence and the 95% confidence intervals for each session. The confidence rating of one participant's face-to-face test was skipped and excluded from the total. The diagnoses were made with high confidence under both conditions.

The diagnosis agreement and diagnostic confidence results in this experiment are comparable to those of the students in the special education class, suggesting that our system is also applicable to severely hearing-impaired children.

6 Conclusions

We developed a remote articulation test system to support special education classes for language-disabled children. We compared the test performances of remote articulation tests using our system with face-to-face and remote tests using the existing web video system. External experts and teachers conducted articulation tests and rated their diagnostic confidence for each phoneme. The strength of agreement in the diagnostic results was sufficiently high between the face-to-face and remote sessions and between the inspectors. The diagnostic confidence of the remote test using our system, which was significantly higher than the face-to-face session, exceeded the session using the existing web video system. Our system was also evaluated as having higher usability as a remote articulation system than the existing web video system. Similar results were obtained in a preliminary experiment on children with severe hearing impairment, suggesting that the proposed system is also applicable to them. This research achieved a remote articulation test system that provides sufficient performance, privacy and copyright protection, and ease of use for inspectors.

Acknowledgement

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