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# Face Recognition and Rehabilitation: A Wearable Assistive and Training System for Prosopagnosia

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***Abstract*—The design and implementation of an integrated wearable face recognition and training system for prosopagnosia patients are presented. The purpose of this assistive technology is to provide real-time memory assistance and long-term rehabilitation. The real-time face recognition mode provides audio and visual notification of people who interact with the subject, while the at-home training mode combines features of mnemonic and perceptual training to help with prosopagnosia rehabilitation. In addition, a custom eye tracker is developed to determine the person whom the subject is making eye contact with within a crowd. Using the inverted face effect to mimic the difficulties of prosopagnosia patients, clinically healthy participants have shown improvements in their face-naming abilities. Early results indicate the system's potential to enrich the well-being of prosopagnosia patients.**

***Index Terms*—Assistive technology, wearable technology, human-computer interaction, visual memory prosthetic, prosopagnosia.**

## I. Background and Introduction

Recognizing familiar faces of acquaintances, families, and friends, even one's partner is an essential and critical ability in social interactions. Lacking such ability, known as a disorder called prosopagnosia can cause severe limitations in people's social life.

Prosopagnosia is a cognitive disorder characterized by deficiencies in recognizing the faces of familiar people. It affects as many as 2 % of the population [1]. There are two types of prosopagnosia, acquired and developmental. Although few studies have investigated prosopagnosia rehabilitation, convincing evidence exists to show that rehabilitation is effective for developmental prosopagnosia patients [2].

Common rehabilitation approaches focus on the enhancement of mnemonic and perceptual abilities. Some training programs are designed to emphasize the perception of facial features [3]. An effective technique is "feature naming" which has shown remarkable improvements in patients' ability to recognize familiar faces [3]–[6]. Results from larger-scale studies have confirmed that the effects of perceptual training can be generalized for a large population of developmental prosopagnosics [4], [7].

Due to their inabilities, prosopagnosics' face social difficulties include limited social involvements and employment opportunities [8]. Consequently, these challenges lead them to anxiety and depression and severely impact their mental well-being [9], [10]. Therefore, we propose that an assistive and rehabilitation system is essential to improve their social interaction and mental health.

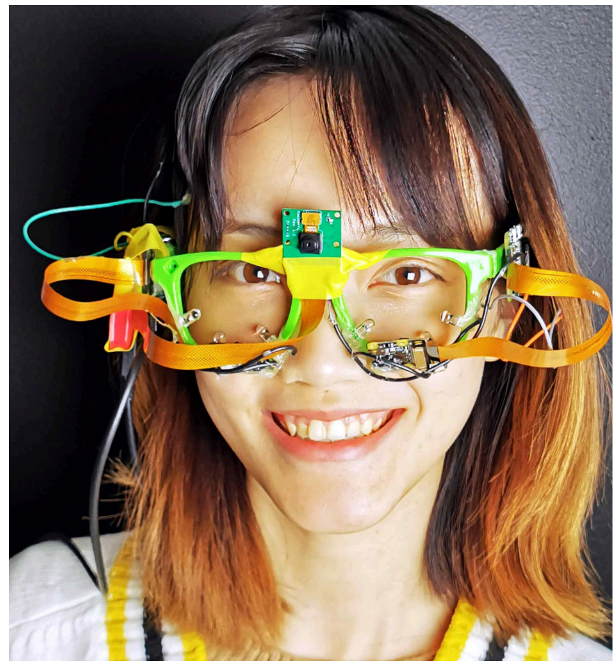


Fig. 1: The wearable glass design for prosopagnosia worn by a subject.

Early researches proposed wearable devices as a "personal visual assistant" and "visual memory prosthetic" for the visually-impaired to improve their social activities [11]–[14]. An existing portable vision commercial device is MyEye 2.0, produced by OrCam [13]. This product allows a visually impaired user to identify objects and recognize faces in front of them through hand gestures and audio notifications. Another study proposed a face recognition smartphone application with a wearable camera by the chest to record and report contextual information from previous interactions [15]. The majority of visual assistive systems are designed for general visually-impaired people, i.e. low vision or blind individuals. Besides, the face recognition system proposed for prosopagnosia and Alzheimer's Disease [16] does not include the capability of rehabilitation for developmental prosopagnosics [17].

This paper proposes the first wearable system that can act both as a real-time memory assistant and a long-term at-home self-training tool. The architecture of the proposed system is inspired by "WearCam™" [11]: a face image of the human subject is taken through a wearable camera, and these images are used during face-naming training for the user.

As proof of concept, preliminary experiments were per-

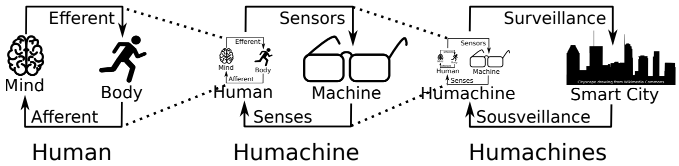



Fig. 2: Fractal nature of human-computer communication. The human brain and body interact in a feedback loop of efferent and afferent nerves. In a HUMACHINE (human-machine symbiosis), the human and machine interact, e.g. through senses (human) and sensors (machine). A city is a machine of sorts. Multiple HUMACHINES interact in a smart city that itself has sensors conducting surveillance. Thus sousveillance is a necessary element to a continuation of this symmetrical feedback loop. Equiveillance (equality between surveillance and sousveillance) is essential to the proper functioning of a smart society, e.g. a smart city.

formed on clinically healthy participants. To mimic prosopagnosia's deficits in facial perception, we used inverted face images for the experiment. According to a face inversion effect, clinical healthy individuals require a longer time and more cognitive effort during the processing of upside-down faces [18]–[21]. Neuroimaging revealed that recognizing inverted faces activates both face-selective and object recognition regions [22]. One hypothesis is that an inverted face is processed as facial features rather than a holistic face [23]. This effect is similar to prosopagnosics' disrupted structural encoding, holistic processing and configural processing abilities [3], [7], [24], [25]. Therefore, the challenge for clinically healthy participants in processing inverted faces is analogous to prosopagnosics in processing regular faces.

## II. Priveillance

Before proceeding forward with the technical details of our implementation, we consider the broader intellectual landscape in which our work exists.

### A. *Fractal nature of humachine communication*

The human body may be regarded as a machine of sorts. The mind and body together form a feedback loop. Efferent nerves carry signals from the brain to the body. Afferent nerves carry signals from the body to the brain.

Humans and machines can interact in a similar symbiotic way. When we use a technology constantly, it becomes very much a part of us, i.e. something we don't think as being separate from us.

Wearables, implantables, and other technologies that "become part of us" form the basis for "bionic" or "cyborg" or other forms of "humachine". The humachine is created by an almost inseparable feedback loop between human and machine that is analogous to the feedback loop between the mind and body. Thus there is a kind of self-similar (fractal) nature of this symbiosis as illustrated in Fig. 2.

Multiple such humachines interact similarly in an enviroment having many sensors. In smart cities we're often under surveillance, and it makes sense for us to sense, i.e. it makes sense for humans to sense, as well as buildings and cars and other entities sense. Thus human-sensors (sousveillance) are as important (or more important) than a building's sensors.

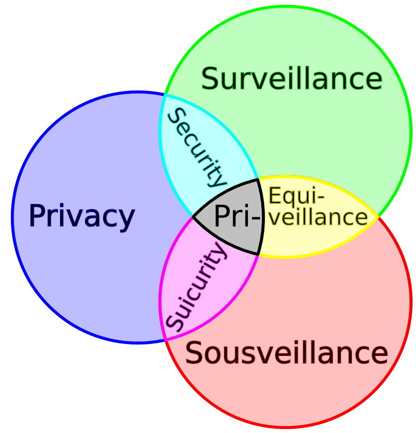



Fig. 3: Whereas surveillance (oversight) is a well-known area of research and practice, wearables give rise to the new phenomenon called "sousveillance" ("undersight"). Surveillance and sousveillance intersect to define "Veillance". For example, a person wearing a camera might also be under surveillance from cameras installed on or in a building. Each of these two "veillances" interact with the concept of privacy. The interplay between privacy and surveillance is known as security, wheareas the interplay between privacy and sousveillance gives rise to a relatively new concept called "suicurity" (self-care) [26]. Priveillance$^{TM}$uses Videscrow$^{TM}$technology to achieve an optimum in the competing space of surveillance, sousveillance, preservation of personal privacy (of the wearer and others) and a fundamental human need to see and understand the world around us.

Sousveillance is thus as necessary, or even more necessary than surveillance.

We cannot legally deny a person the right to use a seeing aid or a memory aid, and thus sousveillance cannot legally be banned or prohibited.

Importantly therefore, we must design a system that provides privacy in the face of veillance. We have created an "Equiveillance Working Group" and related series of projects funded/commissioned by the McLuhan Centre for Culture and Technology. The aim of this group is to understand the interplay between privacy, surveillance, and sousveillance – a project that our lab has been working on for many years. See Fig. 3.

## III. Wearable Assistive Techonology for Prosopagnosia

The goal of our design is to provide a wearable assistive and training solution for prosopagnosia that acts as a "visual-memory prosthetic" [11]. The system is an Android application that has two modes (an assistive mode and a training mode) with an optional wearable hardware set.

### A. *Wearable Eyeset*

The wearable hardware eyeset streams video input for the real-time recognition mode. The application supports Android phone's built-in camera, external USB webcams and a custom eyeset, as illustrated in Fig. 5.

The wearable eyeset consists of three cameras, eight infrared LEDs, and three compute boards. The first camera on top of the eyeset is an environment-facing PI V1 camera that streams video from the user's point of view with 5 megapixels still resolution. Every frame of the video stream at the rate of

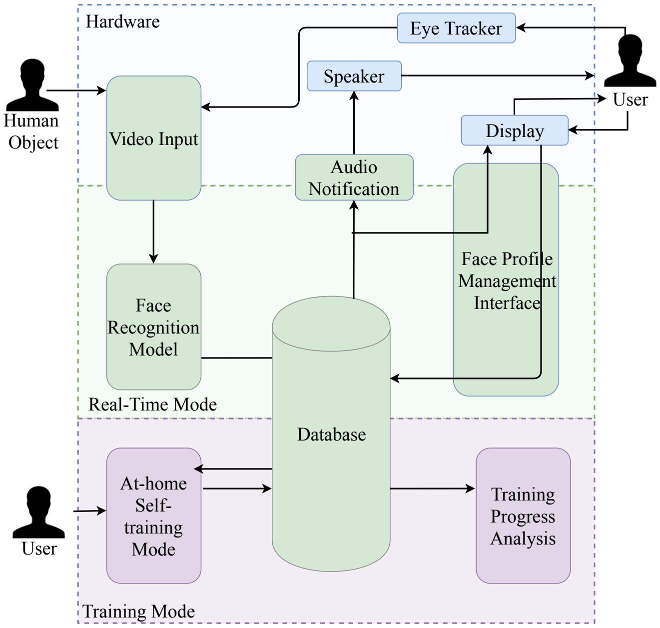



Fig. 4: A data flow diagram showing two modes of operations and a three-part system.

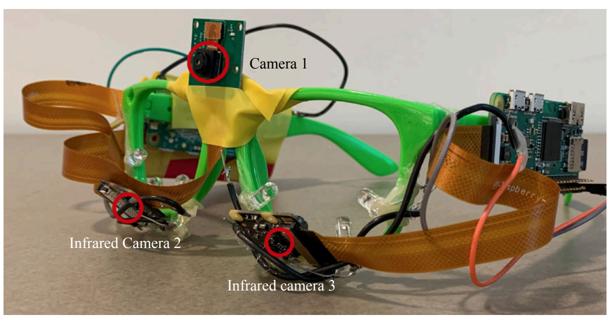


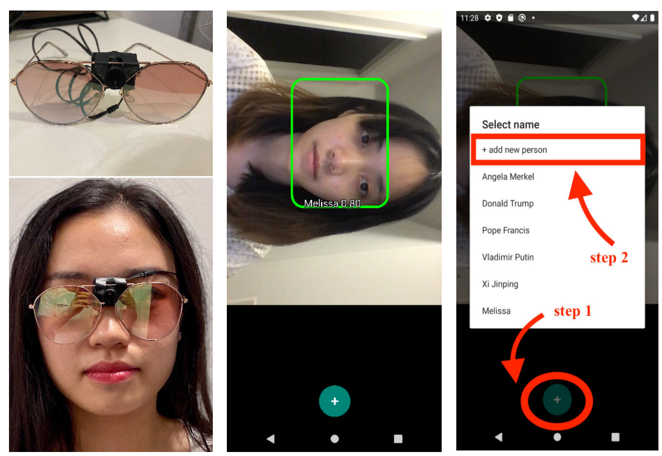

Fig. 5: The wearable Glass Design for Prosopagnosia.

24 frames per second that contain faces are then captured as the subject interacts with other people. The other two infrared PI cameras placed below the eyeset with infrared LEDs positioned around the eyeglasses frame are used for tracking the eyes' visual focus so that only the person that the user is looking at gets detected in a crowd.

To facilitate the real-time mode during the user's interaction with multiple human subjects, an eye tracker for detecting pupil positions was implemented using the other two infrared cameras placed below the eyeset and hence the user's pupil positions are used for tracking the eyes visual focus. The infrared LEDs that are positioned around the eyeglasses frame shine light on the eye and the pupil for eye tracking. The system targets a specific face from the environment based on the wearer's pupil position. The eye-tracker uses a custom blob detection algorithm for pupil detection. To identify the pupil, the system, first, masks the video frame at various brightness threshold values. For each threshold value, all pixels of higher brightness will be rendered to the color white, at 255, whereas other pixels are rendered to the color black, at 0. Secondly, each round of masking produces various contours that are filtered by area and circularity. Each round of threshold masking contributes to a "vote" on multiple contours that qualify for the criteria of a pupil. In the end, the contour that amasses the most "votes" from all threshold masking is detected as the pupil. The coordinate of the pupil is compared with the coordinate of "the front direction" calibrated at the beginning phase. Gazing directions are sent via a socket to the real-time facial recognition system.

### *B. Real-time Face Recognition Mode*

In real-time recognition mode, videos are streamed through an environment-facing camera from the perspective of the user. The camera captures the face of the person that the user is interacting with. Fig. 6a is another implementation of Fig. 5 on a sunglasses without eye-tracking cameras. The face recognition module detects faces present in each frame and generates unique face encodings. The face encoding is compared with a list of encodings generated for the contacts during the model training procedure. If a match is found, the system provides an audio and a visual output of the predicted human subject's name and the accuracy rate. A sample of the visual output is shown in Fig. 6b. If no matching contact is found, the face recognition module will fire up the new contact handling logic, as illustrated in Fig. 6c. The state-of-art face detection model BlazeNet [27] and the face encoding mode FaceNet [28] are used to perform the above functionalities.




(a) (b) (c)

Fig. 6: The user interface of the Android application operating in real-time recognition mode. a) shows a USB webcam assembled on a sunglasses. b) shows the real-time face recognition mode's main interface during run time. c) shows the interface for adding a new contact into the system.

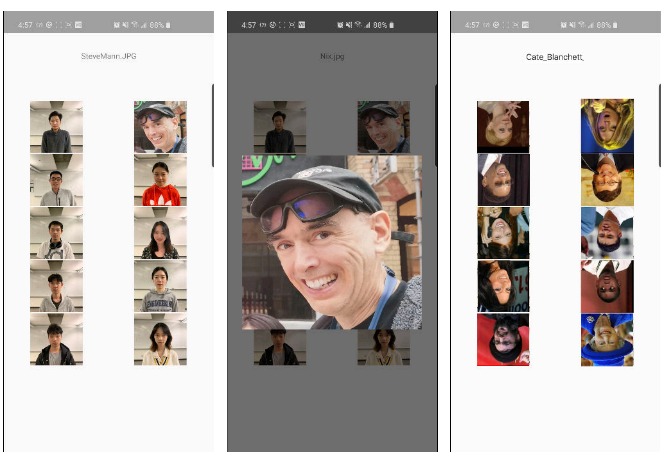
Besides a recognition model for the contacts, the system has a second model to handle the unknown faces, which ensures that no duplicate unknown faces will be recorded in the system. If the contact model detects an unknown face during run-time, the system will compare this face encoding with all the unknown records before saving the first image frame of the unknown face. The second recognition model will be trained to learn the new unknown face during run-time.

Having a record to keep track of unknown faces promotes seamless and uninterrupted social interaction for the user. This allows users to add new people that they have just met as a contact after greeting and conversation with the image that the system has taken. A button is available in the interface of the recognition mode for the user to click on to add contacts as shown in Fig. 6c. The user needs to select at least one face image from any album for the contact model to be trained on. It is highly recommended for the user to select five face images as it increases the prediction accuracy of the model [29].

The face profile management module displays a list of contacts in the application. Once the user clicks into a displayed name, a face image with annotation(s) is shown on the screen if available. Then the user can rename or edit the annotations. This feature allows the user to record facial features description for each contact, which can improve the face-naming ability through the process of feature-naming, recall, and memorization [4], [30].

### C. The At-Home Self-Training Mode

The at-home self-training mode is an interactive interface for users to learn and self test the face-naming association using face images of the contacts selected during the real-time face recognition mode. It is a standalone mode, which the user can use either before or after the real-time mode. The training design is inspired from a common methodology used in prosopagnosia rehabilitation studies [3]–[6], [30]. The training process also involves a feature-naming step. This additional task helps the user to focus on the face's internal features and improves the user's structural encoding ability. Previous studies have shown promising evidence for improvement following the feature-naming task [3]–[6].




(a) (b) (c)

Fig. 7: The user interface of the Android application operating in self-training mode. Fig. 7a shows a set of face images in a training round for training mode. Fig. 7b shows a pop-up of a correct reference image when an incorrect choice is made during training mode. Fig. 7c shows the training Mode on Android App with the inverted face effect for the experiment.

One training session consists of fifteen rounds and for each training round a set of ten face images from the contact list shows up on the screen, as illustrated in Fig. 7a. In the training session, the user is asked to identify the face that corresponds to the name displayed at the top of the screen. When a wrong face is selected, the correct face is displayed on the screen until the user taps the screen to enter into the next round, as shown in Fig. 7b. The user should name three face features of the correct face before proceeding forward. When the correct face is selected, the next round is displayed right afterwards. The app tracks the accuracy of the user and the length of the training session.

## IV. Experimental Procedures

### A. Real-Time Face Recognition With Eye Tracker

As the accuracy of the pre-trained recognition models is known, the performance of the eye tracker was tested in real-time recognition mode. A series of experiments were performed, in which social distance and face angle were controlled. The subjects were ten undergraduate students: five males and five females. The contact list was populated with 4 pictures of each subject, including one picture of their front face with no facial expression, one picture of the subject smiling, two pictures taken from 30° to the left, and to the right respectively. The pictures were taken in the same environment with the same camera resolution.

To test the performance of the eye tracker specifically, 2 subjects were standing side by side at a fixed distance to the perceiver wearing the eye tracker, as demonstrated in Fig. 8.

For the first task, the subjects stood $2\,\mathrm{m}$ away from the perceiver and showed their front face to the perceiver. For the second task, the two subjects stood $2\,\mathrm{m}$ away from the perceiver, but each subject faced 30° to a different side showing their side face. For the third task, the subjects stood $0.5\,\mathrm{m}$ away from the perceiver and showed their front face.

During each task, the perceiver kept his head still and moved his eyes looking at each subject alternately for 10 trials. The face recognition was expected to only detect the person being stared at. The accuracy rate(the percentage of correct recognition) and mismatch rate(the percentage that the wrong subject not being stared at were recognized) were recorded. $3 \times 10$ trials were performed by each pair of subjects. A total of 150 trials were performed on 5 pairs of subjects.

### B. At-Home Self-Training Mode

As for the experiment of the training mode, the participants were ten clinically healthy people. To mimic the training process of prosopagnosia patients, we displayed upside-down photos during the training process, as illustrated in Fig. 7c. Note that for the purpose of our experiment, we explicitly replaced the real-time captured face images in the database with celebrities' faces. The reason that celebrity images are used as the training images is that we want to mimic the effect of prosopagnosia patients where they know the subject as a person but have difficulty in processing the entire face. Thus, celebrity faces are the optimal option as a control to ensure that most participants know the training faces. A total of 20 images were selected from *Labeled Faces in the Wild*

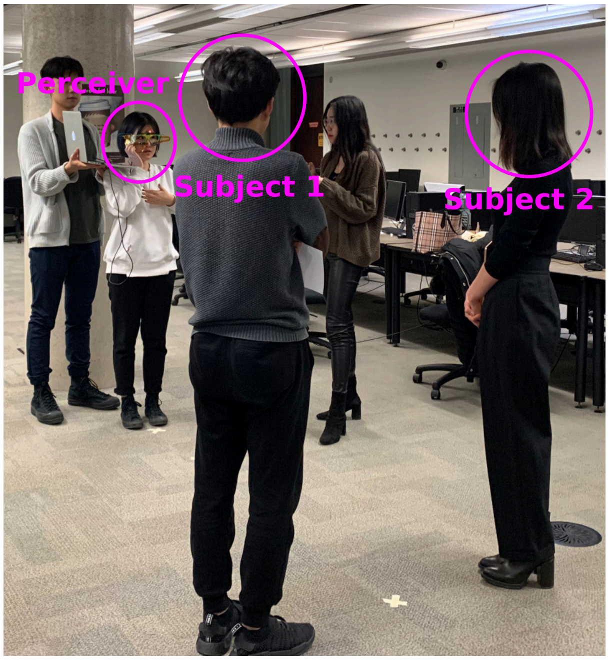



Fig. 8: The participant position set up during the experiment for real-time face recognition using the eye tracker.

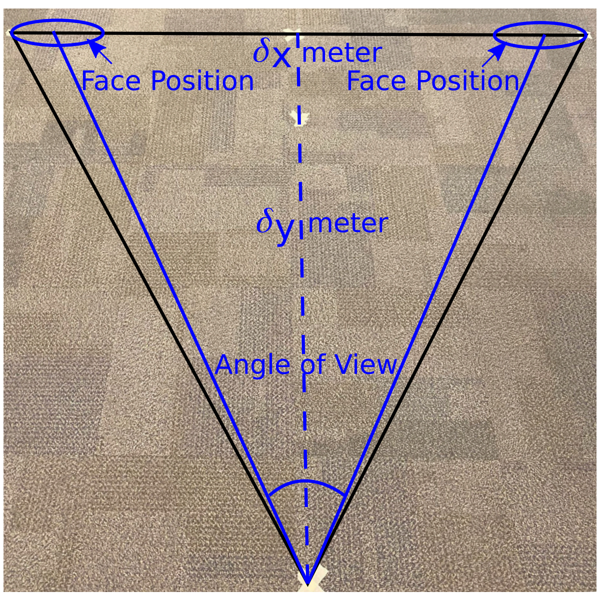



Fig. 9: The experiment floor set up, where $\delta_y$ represents the social distance and $\delta_x$ represents the maximum distance apart

(LFW) face database. All images are face of celebrities, and we carefully mixed races to avoid a cross-race effect [31].

The participants were divided into one experimental group and one control group, where each group had five participants. Each participant performed five blocks of ten trials of the training using the interactive interface as described in section III-C. For the experimental group, the participants were asked to name facial features of the celebrities' face when their selection was wrong. The participant had five seconds to list three facial features of the correct image. For the control group, the participants did not perform the feature-naming task where they learn the correct face for five seconds on their own. The hypothesis is that face-feature naming allows the participants to acquire a better holistic understanding of the training face image.

## V. Results and Discussion

### A. Results from the Facial Recognition Experiment

TABLE I: Table of Accuracy for Facial recognition

| Conditions | Accuracy [%] Front 0.5 m | Front 2 m | Side 2 m |
|---|---|---|---|
| Subject Pair 1 | 100.0 | 80.0 | 70.0 |
| Subject Pair 2 | 100.0 | 80.0 | 90.0 |
| Subject Pair 3 | 90.0 | 80.0 | 90.0 |
| Subject Pair 4 | 100.0 | 90.0 | 70.0 |
| Subject Pair 5 | 90.0 | 90.0 | 70.0 |
| Average | 96.0 | 84.0 | 78.0 |

Table I presents the accuracy of facial recognition tasks in different conditions. Detection and recognition of a correct subject count as a success, while a mismatch or failure to recognize the subject count as a failure. A generic finding is that a closer distance of the subject's face leads to better recognition accuracy. According to the experiment results, the accuracy of the real-time face recognition system is considerably high because it is a probabilistic product of the accuracy for the eye tracker and the face recognition system.

During the preparation of the experiment, we discovered that the real-time recognition system has a range of effective distance and angles. With respect to the environment-facing camera's field of view, the user's maximum head movement angle towards the human subject's position is $22.60°$ for an average social distance [32] [33] of $0.5\,\mathrm{m}$ apart and $46.05°$ for camera's maximum depth of $2\,\mathrm{m}$. The calculation for the experiment distance setup is shown in Fig. 9.

### B. Results From the Training Experiment

TABLE II: Training experiment accuracy for each trial

| Experiment Group | Trial No. (Accuracy [%]) 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Experimental 1 | 73.3 | 100 | 100 | 100 | 100 |
| Experimental 2 | 73.3 | 80.0 | 80.0 | 100 | 100 |
| Experimental 3 | 80.0 | 73.3 | 80.0 | 80.0 | 86.7 |
| Experimental 4 | 80.0 | 80.0 | 80.0 | 100 | 100 |
| Experimental 5 | 73.3 | 73.3 | 93.3 | 100 | 100 |
| Experimental Average | 76.0 | 81.3 | 86.7 | 96.0 | 97.3 |
| Control 1 | 66.7 | 73.3 | 73.3 | 73.3 | 86.7 |
| Control 2 | 66.7 | 80.0 | 93.3 | 100 | 86.7 |
| Control 3 | 73.3 | 86.7 | 93.3 | 93.3 | 100 |
| Control 4 | 40.0 | 53.3 | 53.3 | 80.0 | 86.7 |
| Control 5 | 80.0 | 80.0 | 73.3 | 100 | 80.0 |
| Control Average | 65.3 | 74.7 | 77.3 | 89.3 | 88.0 |

The primary outcome variables are reaction time and accuracy, which were recorded for each block of the face recognition task. There were five blocks of training and assessment

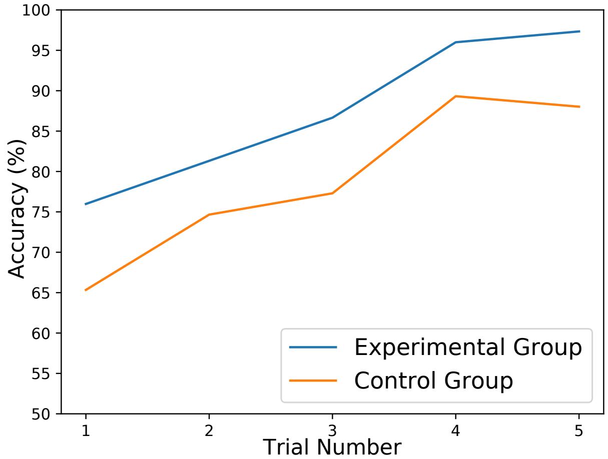



Fig. 10: A graph of the average accuracy of each trial. Each subject's accuracy data is presented in Table II.

for each participant. Table II and Table III shows participants' accuracy and reaction time in each block of trials.

TABLE III: Training experiment reaction time for each trial

| | Block Trial No. (Reaction Time [s]) | | | | |
|---|---|---|---|---|---|
| Experiment Group | 1 | 2 | 3 | 4 | 5 |
| Experimental 1 | 84.6 | 66.1 | 54.5 | 46.8 | 61.1 |
| Experimental 2 | 119.0 | 79.5 | 57.9 | 67.6 | 37.2 |
| Experimental 3 | 67.2 | 42.8 | 57.0 | 62.7 | 46.0 |
| Experimental 4 | 109.0 | 46.0 | 65.1 | 47.6 | 67.1 |
| Experimental 5 | 119.9 | 96.8 | 107.3 | 96.0 | 60.9 |
| Experimental Average | 99.9 | 66.2 | 68.4 | 64.1 | 54.5 |
| Control 1 | 99.2 | 102.2 | 80.3 | 79.0 | 65.8 |
| Control 2 | 75.3 | 87.7 | 59.2 | 67.7 | 39.7 |
| Control 3 | 87.0 | 54.9 | 65.0 | 60.0 | 48.0 |
| Control 4 | 149.0 | 86.6 | 135.6 | 101.9 | 83.3 |
| Control 5 | 86.0 | 71.6 | 85.3 | 50.4 | 40.6 |
| Control Average | 99.3 | 80.6 | 85.1 | 71.8 | 55.5 |

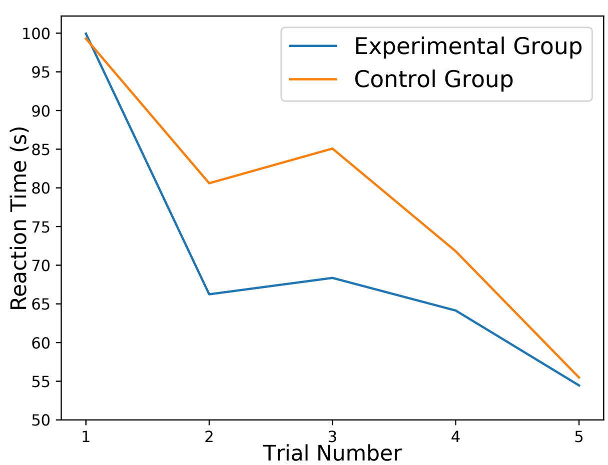



Fig. 11: A graph of the average reaction time of each trial. Each subject's accuracy data is presented in Table III

*1) General Improvement:* Fig. 10 and Fig. 11 shows the average accuracy and reaction time in each trial. It can be seen from our results that there was a general improvement in accuracy and reaction time for both the experimental and the control group along with training in later blocks as expected. These results indicate that face recognition ability can be improved on an inverted face. This is in accordance with the results from previous studies that human facial recognition ability is plastic, therefore, it is possible to improve facial recognition ability through proper training.

*2) Experimental Group vs. Control Group:* The results also indicate the experimental group performs better on average than the control group both in terms of accuracy and reaction time. From the participants' self-reported surveys, participants from the experimental group said they focused more on the facial features of face images during the training procedure. This help to explain why the experiment group had a better performance. However, since the sample size is small, the improvement could be caused by the fact that the participants from the experimental group have better facial recognition ability. Therefore, the conclusion that the feature-naming procedure helps rehabilitation still lacks a strong evidence.

*3) Improvement Rate:* Before the experiment, We expected a faster increasing rate in performance from the experimental group, to indicate that the feature-naming procedure is effective in improving facial memory and recognition ability. However, this is not shown in our results. By fitting a line into the data, it is shown that the two groups improved at approximately the same rate.

## VI. Conclusion

The paper presents an integrated solution consisting of a real-time facial recognition system and an at-home training system. The results from the experiments not only showed the real-time face recognition mode has a relatively high accuracy rate especially when the subject showed their front faces to the perceiver at a closer distance, but also confirmed the hypothesis that training can be used to improve facial recognition performance.

## VII. Future Work

### A. Trials With Prosopagnosia Patient

Since the preliminary experiment was done on clinically healthy participants. The assumption of our methods is built upon the face inversion effect to mimic the difficulty in recognizing faces for prosopagnosia patients. As the face inversion effect diminished through incremental training, this result may reflect the improvement of holistic face processing skills. However, determining if the experimental results can be generalized to prosopagnosia patients will need further investigation.

The next step is to determine if the training approach could be effective in a larger population of developmental prosopagnosics. A full-scale study investigating the actual effect of the training mode needs to be performed on prosopagnosia patients. The face-naming ability of developmental prosopagnosics needs to be assessed before and after training using the system.

### B. Electroencephalography (EEG) Signals as Feedback

Brain activities in the face-selective region associated with face recognition can be measured from event-related brain potentials [34], [35]. We plan to incorporate EEG measure as a form of feedback in the training mode for the users to more precisely measure their improvement on face memory and recognition abilities.

### C. Face Flashback Training

One of the current rehabilitation studies involves fast face-name flashback with rotated faces [11]. Our next step is to add this feature into the training mode. we will repeatedly present the new contact's picture in an exponentially increasing time (i.e. $1\,\mathrm{min}$, $2\,\mathrm{min}$, $4\,\mathrm{min}$, $8\,\mathrm{min}$). This periodical flashback aims to improve the user's ability to remember new contacts.

## VIII. Acknowledgements

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