Morphing Identity: Exploring Self-Other Identity Continuum through Interpersonal Facial Morphing Experience

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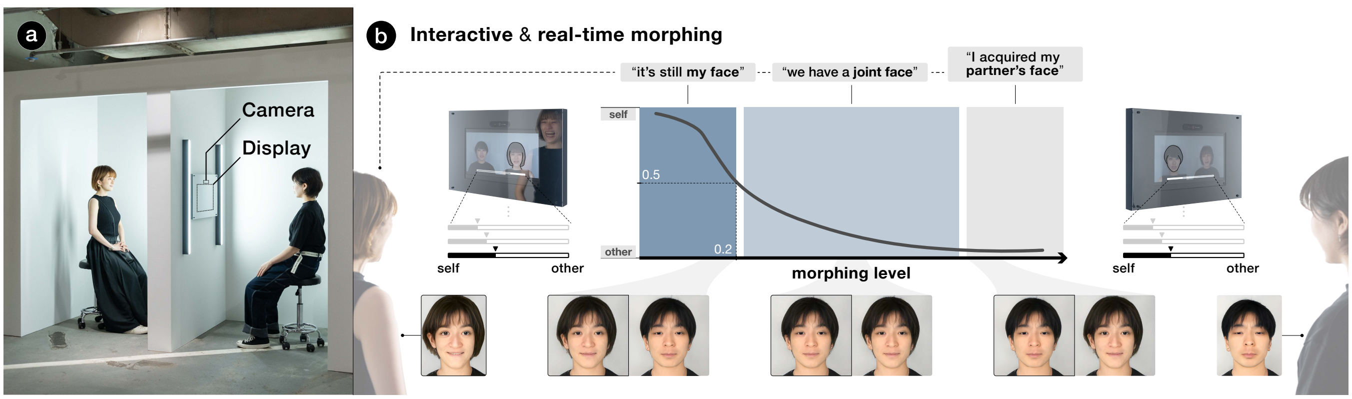

Figure 1: (a) We developed Morphing Identity, an interactive system that blends facial images of two users in real-time. Users' facial images are gradually blended from image of self to that of partner, while both users can see and interact with each other. (b) We installed this system in several exhibitions to conduct a qualitative study to explore interpersonal experiences and quantitative analysis to provide further insights into the boundary between self and others.

ABSTRACT

We explored continuous changes in self-other identity by designing an interpersonal facial morphing experience where the facial images of two users are blended and then swapped over time. Both users' facial images are displayed side by side, with each user controlling their own morphing facial images, allowing us to create and investigate a multifaceted interpersonal experience. To explore this with diverse social relationships, we conducted qualitative and quantitative investigations through public exhibitions. We found that there is a window of self-identification as well as a variety of interpersonal experiences in the facial morphing process. From these insights, we synthesized a Self-Other Continuum represented by a sense of agency and facial identity. This continuum has implications in terms of the social and subjective aspects of interpersonal communication, which enables further scenario design and could complement findings from research on interactive devices for remote communication.

CHI '23, April 23–28, 2023, Hamburg, Germany

ACM ISBN 978-1-4503-9421-5/23/04…$15.00
https://doi.org/10.1145/3544548.3580853

CCS CONCEPTS

• **Human-centered computing** → *Interaction devices*; *Interaction paradigms*.

KEYWORDS

face, morphing, enfacement illusion, self-other identity

ACM Reference Format:
Kye Shimizu, Santa Naruse, Jun Nishida, and Shunichi Kasahara. 2023. Morphing Identity: Exploring Self-Other Identity Continuum through Interpersonal Facial Morphing Experience. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23), April 23–28, 2023, Hamburg, Germany*. ACM, New York, NY, USA, 15 pages. https://doi.org/10.1145/3544548.3580853

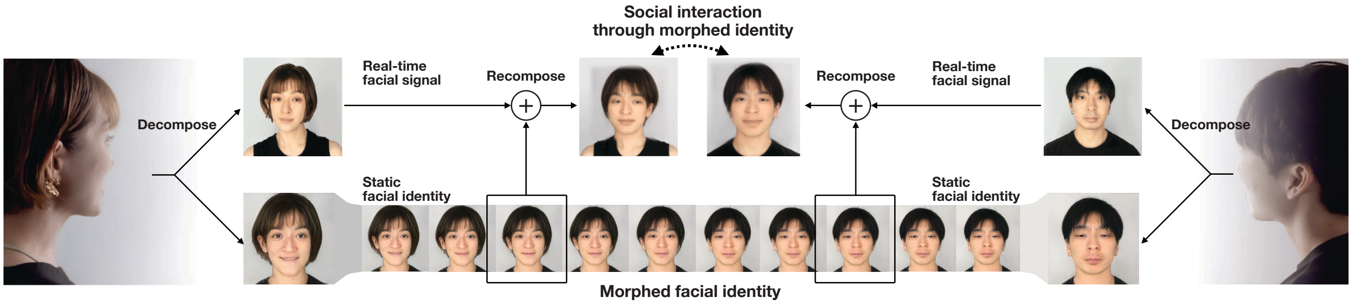

Figure 2: Our system achieves facial identity morphing by decomposing facial signals and facial identity from the user's face and then recomposing them, allowing for social interactions through morphed identities.

1 INTRODUCTION

With recent advancements in wearables, haptics, and virtual reality techniques, developing interactive systems that can share or blend human embodied experiences across multiple users has become an increasingly emerging research interest in the HCI community. These allow a user to embody a partner's physical attributes in real-time (e.g. swap visual perspectives [44], copy muscle activities [68], and blend body movements [31] between users). It is also known that embodying different physical attributes can change the user's bodily sensations, such as the perception of size or distance and even self-identification (e.g., [7, 30, 53, 90]).

Recently, another bodily attribute important in shaping our social interaction has also been explored, that is **facial signals**, the changeable aspects of faces such as facial expressions, gaze, mouth movements, and so on [9, 36, 39, 69, 112]. These play a significant role in shaping our emotional states [26, 27]; thus, HCI researchers have employed these findings into interaction design that can be applied in daily life, such as for regulating one's emotional states using a digital mirror [101, 111] and enhancing relationships during video communication [51, 76, 89] by manipulating facial expressions.

In addition to these facial signals, faces also contain a **facial identity**, an important aspect that defines the boundary between self and other. The psychology community has previously explored this identity boundary by transferring the sense of ownership to a different person's face by means of a visual and tactile stimulation technique, where a user sees an image of someone's face on a screen while receiving tactile stimulation that is synchronized to both the user's face and the face appearing on the screen [29, 91].

While the technique has lead to significant findings, such as how a user's implicit bias against a person with a different skin tone can be positively changed by transferring the ownership of the face [29] through the use of visuo-tactile interactions, due to the nature of the technique (i.e., it requires a certain amount of time to induce the transfer of ownership and the user's body must be fixed), these systems do not allow users to have conversations or communicate using non-verbal communication methods (i.e., facial expressions, body actions), which play a critical role in creating a sense of motor agency. While these studies have provided valuable insights through controlled lab studies, taking social context and interaction into account would also be beneficial for providing further interaction design implications for face-changing applications.

2 OUR APPROACH: INTERPERSONAL FACIAL IDENTITY MORPHING IN REAL-TIME

In this research, we focus on building a system that morphs two users' facial identities together in real-time, while preserving their diverse social interactions and contexts through the communication of their facial signals.

To this end, we propose Morphing Identity, an approach that initially decomposes facial signals and identities from facial images, as shown in Figure 2. By generating interpolation between two static facial images and real-time image animation processing, the user moves an interpolated facial image that represents an interpolated facial identity with his/her own facial signals.

With our Morphing Identity system, the user can see his/her own face side by side with their partner's face. The left side of the screen shows the moving face of the user as it gradually morphs into the partner's face. On the right side of the screen, the user can see the partner's face freely moving as it gradually morphs into the user's face. Our system can decompose and recompose the relationship between one's own real-time movements (facial signals) and facial identity. This allows us to create a multifaceted relationship in interpersonal communication where the user is able to become the partner's face and maneuver it, while at the same time, the partner is able to move the user's face.

We carried out both quantitative and qualitative analysis to investigate the changes in interpersonal experience as well as to explore the boundaries of self-other identity, which could be used for further scenario design, described in a later section (Figure 1 - b). Since we are particularly interested in exploring how such a system can change the interaction between two users and its application to actual scenarios, we conducted a field study at public exhibitions where we could invite dozens of people with diverse backgrounds and relationships, such as family, friends, and couples [78]. We found that different interpersonal experiences emerged during the process of interpersonal facial morphing, as well as areas of self-identification across the steps of morphing. From these insights, we synthesized the Self-Other Continuum, which is represented by a sense of agency and facial identity. This paper also presents the technical pipeline involved in the creation of the facial morphing system, which can be installed at exhibitions, and discusses its technical challenges and further opportunities.

Lastly, note that our objective is to explore potential interaction design spaces under an interpersonal facial morphing setting by investigating boundaries (Section 6) and subjective experiences (Section 7) in the interactive and continuous changes of identity. This paper addresses this unexplored setting along with the scenario design for the first time to identify possible factors that can be further examined by the community.

3 RELATED WORK

Our work is built primarily on the areas of computer-mediated communication, enfacement illusion, and facial morphing techniques.

3.1 Interactive systems for sharing/changing experience

A number of interactive systems have been proposed for sharing embodied experiences among users to facilitate motor-skill acquisition as well as embodying different physical attributes. These are often achieved by using a pair of wearable cameras and head-mounted displays (HMD) [19, 44–47, 49, 50], as well as haptic devices that share haptic sensation from the upper-limbs [55, 66, 79], wrist [32, 41, 96, 97], hands [6, 12, 38, 63, 70], muscle activity [38, 67, 68], tactile sensations [21, 61], and whole body sensations [73, 75] from one person to another.

The effect of using these techniques has been also examined in virtual reality (VR) environments to understand the changes in user subjectivity, such as in their sense of agency through having a shared virtual body [31, 98] or size/distance perception and even self-identification by embodying a different person's body (e.g., that of children [7, 53, 90, 102], with a different skin tone [8, 56, 72], or one appearing as a taller [109] or smaller [30] avatar).

It has been shown that these can also enhance interpersonal feelings such as the sense of togetherness, trust, presence, and partner's affect through the sharing/blending of physical experiences [6, 13, 52, 64].

3.2 Face, self-identity, and morphing

In addition to these body components, it is also noted that **our faces** play a critical role in shaping not only interpersonal feelings but also social interaction [9, 39, 69], one's own emotional states [101], relationships [76], and behavior [40], which should also be considered for this type of interactive system.

Researchers have conducted a series of face-changing and face-morphing studies. Canonical examples use the technique of the Rubber Hand Illusion (RHI) [10], in which a user feels that a dummy rubber hand becomes a part of their body by receiving synchronous visual and tactile stimulation to both a dummy and their real body. This has been extended to induce a sense of ownership over a different person's face, which resulted in changing self-facial identity and attribution [71, 82, 99].

HCI researchers have also worked to incorporate these findings into designing interactive devices to support users in regulating affective states in a daily life setting. Examples include a wearable projection mapping onto a user's face [4], a glasses-type device that dispenses teardrops to induce a feeling of sadness [110], a mirror-type face morphing device for emotion regulation [101, 111], and even an avatar with age-progressed renderings of a user's face in VR, fostering saving behavior through showing one's future self [40]. Suzuki et al. developed *FaceShare* [89], which shares facial expressions, such as smiling, from one user to another during a video conference, demonstrating that it enhanced a feeling of closeness and the conversation flow among the users.

These have demonstrated the significant potential of sharing or changing *facial signals* to modify self-perception, subjectivity, and even behavior, and our research extends these findings to explore the role of sharing *facial identities* in an interpersonal setting.

3.3 Interpersonal self-other face boundaries

There have been several attempts to investigate changes in identity in an interpersonal setting in the psychology community, since it is known that how we identify the faces of others is adaptive and highly dependent on our context and experience [62].

For instance, with synchronous visuo-tactile stimulation on the face, participants accepted faces that contained a significantly higher percentage of the other's face when their own face was stimulated [91, 99]. This change in self-other boundaries in the face, called enfacement illusion, has been reported to occur with active touch [93], visuomotor synchronization [28, 81], and synchronization of the heartbeat and vision (Cardio-Visual Integration) [80], and it has been shown to correlate with whole-body embodiment [23], interoceptive sensitivity [94] and interpersonal somatosensory processing [18]. These types of bodily illusions take place based on the mechanisms by which our brains attempt to solve conflicts between sensory and sensorimotor information [5, 100], also based on computational principles of movement [108]. These mutual fusions of self and other face recognition have been reported to correlate with interpersonal relationship factors such as empathic traits, physical attractiveness [82], and positive interpersonal interactions [14].

More importantly, the changes in self-other boundaries are expected to increase the positive chemistry with others by overcoming the boundaries between in-group and out-group categories [29], in fact, the similarity between individuals is considered to be a foundation for social cognition [59]. Under the enfacement experiment paradigm, researchers have reported that the interpersonal enfacement effect resulted in participants judging others to be closer to the self physically and in terms of personality [58], or reported the potential of increasing closeness and attraction towards an opposite-gender other [35, 65, 76]. These prior researches may indicate that a change in self-other boundaries through multisensory integration of face images (though not only face images) can affect interpersonal social cognition [22].

In light of the technological capabilities for facial image intervention in communication spaces including virtual reality and video communication, investigating the impact and possibilities of interpersonal face fusion under various contexts is an important agenda for HCI. To this end, to further elevate the face morphing paradigm, which has previously been seen in laboratory experiments, we built a real-time interactive face morphing system with state-of-the-art video processing to enable exploration within various social contexts.

3.4 Real-time face morphing

In recent years, face morphing methods using machine learning technology have been proposed [103]. Generative adversarial networks (GANs) such as the StyleGAN2 series [43] are able to generate incredibly photo-realistic face images that are represented as a latent vector, and the vector distance relates to how we perceive and recognize generated images [85]. Moreover, not only for generating facial images, GAN projection methods allow us to tie images to latent vectors in latent space [2, 77]. This enables the generation of a series of interpolated images between a source and target image, e.g., between two users.

Although interpolated images can be generated, the images are static without facial signals. To recompose the facial movements in sync with the user's facial movements, a facial reenactment technique is utilized, that is, a technique for transferring the emotion and pose of a source face to a target face while preserving the identity of the target face [33, 86]. Facial reenactment has also been used to reduce the network bandwidth by transmitting only face signals (feature points) and key frame images, and then recomposing a realistic face image [1, 106]. This approach is closest to our proposal in terms of creating realistic face images using one's own face as a key frame. By combining these algorithms, we built a face morphing system that can generate arbitrary interpolation while preserving the facial movements of the users.

4 IMPLEMENTATION

Our system consists of 1) a real-time interpersonal face morphing algorithm, 2) a server-client data streaming network, and 3) user I/O interfaces.

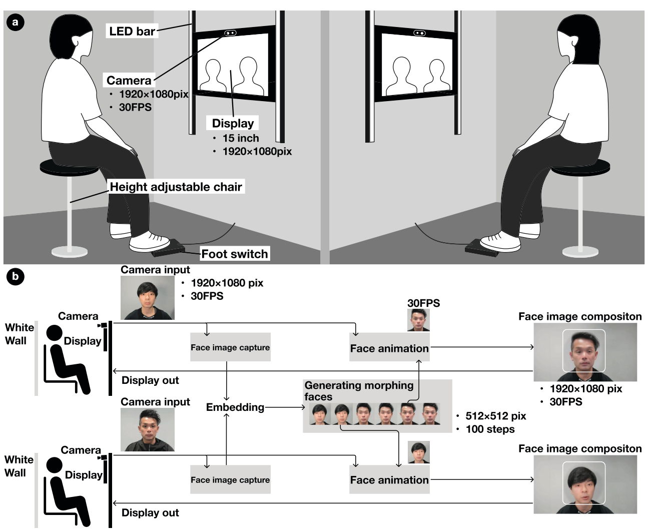

Figure 3: (a) Overview of the device setup, (b) process of generating and animating morphing faces from a facial image of a camera input.

4.1 Real-time interpersonal face morphing

Here, we describe the technical pipeline of the Morphing Identity system. The pipeline consists of 1) projecting the user's face onto the latent space, 2) generating a morphing sequence by interpolating the latent vector from the user's face to the destination face, 3) performing real-time facial reenactment and alignment with the key frame image from the morphing sequence while applying dynamic control to proceed with morphing (Figure 3 - b).

4.1.1 Projecting user's face onto the latent space. We employed a pre-trained model based on StyleGAN2 [43] that was trained with the Flickr-Faces-HQ Dataset (FFHQ) [42]. This model generates realistic face images at a resolution of up to 1024×1024 pixels, which are generated from a latent vector (18×512 matrix of real values, 512-dimensional vectors are input to 18 layers). By manipulating the latent vector, StyleGAN2 can generate a corresponding facial image. For instance, a vector interpolated from two latent vectors can generate an interpolated facial image between two corresponding two facial images. We leverage this principle to generate the face morphing images between two users.

To create a GAN-generated facial image from an actual facial image of a user, a latent vector corresponding to the input facial image of the user is estimated through a projection process, embedding an image into the latent space of a pre-trained GAN model [1]. The quality of the generated image is correlated to the model and GAN utilized for inferencing. Though some architectures of models can infer faster due to their more limited number of parameters and model size, they produce lower-quality images. For feasibility in terms of time and experience at the exhibitions, StyleGAN2 was used for its balance of quality of facial imagery and inference time for the projection process. To make sure that participants recognized a facial image as themselves at the beginning of the experience, the image in the first 10% of the morphing process also included a geometry-matched blended image, combining a generated image and the actual captured facial image.

4.1.2 Generating Morphing Sequence. Face morphing can then be performed by mixing the latent vectors of two face images with $\boldsymbol{W'}_{\mathrm{f}} = \boldsymbol{W}_{\mathrm{f}} + r(\boldsymbol{W}_{\mathrm{t}} - \boldsymbol{W}_{\mathrm{f}})$. Here, $\boldsymbol{W}_{\mathrm{f}}$ and $\boldsymbol{W}_{\mathrm{t}}$ represent the latent vector of the original facial image (from) and the destination facial image (to).
Morphed latent vector $\boldsymbol{W'_{\mathrm{f}}}$ from $\boldsymbol{W}_{\mathrm{f}}$ to $\boldsymbol{W}_{\mathrm{t}}$ can be obtained by changing r. Utilizing the latent vector generated in the first step, the system generates a sequence of smooth morphing images from the face of the user to the destination face with 100 interpolated steps (Figure 4 - 1).

4.1.3 Real-time composition with facial reenactment. To allow interaction between users while the facial morphing proceeds, face reenactment technology was integrated to enable the transfer of a facial expression and head pose of a source input to be transferred to a target face while preserving the target facial identity.

Our system performs real-time composition with a facial reenactment process utilizing the First Order Motion Model [86]. A face image selected from the morphing sequence is animated on the basis of the motion appearing in the real-time video of the user. At the beginning of interpersonal face morphing, the source image for facial reenactment is the user's projected face (Figure 4 - A'), i.e., the user's facial image is animated on the basis of their own facial motion. Then, the source image for facial reenactment

[1]Example: https://github.com/rolux/stylegan2encoder

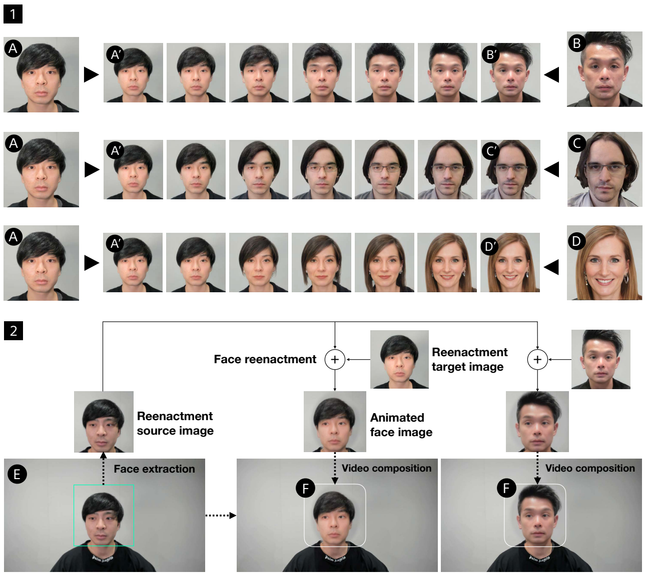

Figure 4: (1) Process of generating morphed static facial identity. (2) Real-time facial signals processed by video composition with real-time facial reenactment.

is gradually morphed towards the destination face (Figure 4 - B' or C' or D'). To enable dynamic movement of the user's face, the system extracts the region for facial reenactment by considering face alignment (Figure 4 - E). The synthesized facial image and corresponding image region are synchronized and composited together for the final display output to the users. (Figure 4 - F). In our implementation, the latency of the real-time composition is approx. 100 ms. All delays caused by the camera capturing, image composition, and display output add up to approx. 300 ms as the end-to-end latency, which was measured using a high-speed video camera. It is noted that previous studies generally agree that a critical range of visual-delay range for preserving the sense of agency is 200–300 ms [60, 84, 105, 107]. Thus, our system provides fast enough video feedback to users.

Throughout the pipeline for interpersonal face morphing, the user's facial image appearing on the display is gradually mixed and then swapped with the other user's face over time, while both users are able to move the facial image in real-time. As the facial image is gradually updated, the visual change can be difficult to be detected since the visual transient is suppressed [87]. This allows us to investigate how users recognize facial identities rather than detecting visual changes.

4.2 System architecture

To facilitate a real-time interactive experience as well as heavy computational processing, we implemented our system with two computers: 1) a main computer to manage the interactive experience including face reenactment rendering and user interface control, and 2) a server computer to organize heavy computational processes, including projecting the user face into the latent space, and creating the GAN generated images. The main computer is equipped with two GPUs (NVIDIA RTX 3090) and an i9-9900K CPU, and the server computer is equipped with one GPU (NVIDIA RTX 3090). The two computers are connected via a 5-Gbps network.

4.3 User input and output

The exhibition consisted of two semi-open white booths that were mirrored against each other, integrated with digital mirror devices, a foot pedal for input in the experiment, an LCD monitor, and a camera attached to the inner wall, allowing a clear view of each individual in front of the monitor from the camera (Figure 3 - a). Instead of showing a single facial image, we opted to use a side-by-side layout, which provided the opportunity for the participant to see both faces at the same time and experience diverse contexts in their agency and identity, allowing us to explore complex interpersonal facial morphing experiences. Because of the semi-open structure of the booths, users were also able to openly communicate with one another while the morphing experience took place.

Both the display and the camera on either side of the booth were connected to the main computer. The camera was used for tracking the facial movements of each user, acquiring facial images for the GAN projection to generate facial morphing images. The display showed the instructions and facial images of the two users side by side for interpersonal face morphing. As the generated GAN image takes background imagery into account when generating imagery, two 4000K LED bars were equipped on either side of the monitor to provide an adequate lighting environment for the camera as well as a uniform lighting background for the user image.This is important for maintaining the quality of the image taken at the very beginning to avoid the artifacts in the generated images. The foot pedal, which worked as keyboard input, was used by the participants to respond to consent questioning as well as to provide input during the facial morphing experience.

5 EXPLORING SELF-OTHER FACIAL IDENTITY THROUGH EXHIBITIONS

Our research objective in the exhibition was twofold; first, to conduct a quantitative investigation regarding how much a person recognizes a facial image as their own, while gradually morphing towards another face, and second, to conduct a qualitative investigation regarding the interpersonal experience during the face morphing process with diverse social relationships and contexts.

5.1 Booth design

The exhibition space was designed with the following three design considerations: 1) allowing interpersonal communication in a public space by designing the installation booth as a half-open box space (Figure 5 - a) to avoid disturbance by social anxiety such as from being observed by outsiders, 2) allowing participants of all ages to experience the exhibition by preparing adjustable seats that fit into the camera frame, video instructions, written explanations as well as having well-trained museum staff on-site and 3) providing expectations of the interpersonal experience from the form factor, which appeared like a photo booth in a symmetrical configuration.

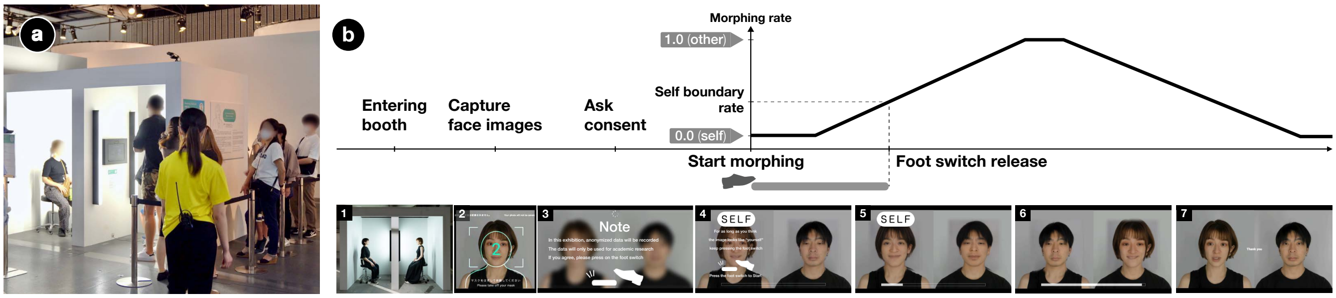

Figure 5: (a) Exhibition setting, showing participants lining up to participate, with the well-trained exhibition staff in yellow overlooking the situation. (b) A sequence of interpersonal face morphing experience.

5.2 Sequence

Two exhibit participants were first instructed to sit in the adjustable seats (Figure 5 - b1). When the system recognized the participant's face, the display showed a mirror image from the camera with an overlay graphic to guide the face to a designated position so as to capture it from the front while it was stable (Figure 5 - b2).

After the participant's face was captured, the system cropped the facial areas from the camera image and utilized the server computer to search for a latent vector corresponding to the facial image by projecting the image into the latent space of the GAN. During the approx. 15 seconds taken for this computation, the system showed a written statement for getting consent, stating, "Taken photos will not be stored; anonymized data will be recorded and used for research purposes only," and then asked the participant to press the foot switch if they agreed to give consent (Figure 5 - b3).

After 100 morphed images were generated, the display showed each participant's real-time moving faces (i.e, 100 percent themselves). The participants were instructed, "For as long as you think that the image looks like "yourself," keep pressing the foot switch," and they were also told to "Press the foot switch to start" to start the sequence (Figure 5 - b4),which was important for ensuring that the participants saw the face image from the beginning of the sequence.

The real-time face morphing started to proceed with a morphing speed of (2%/1 sec). During the face morphing, the display showed both faces of the participants in side by side. Throughout the experience, the participants could freely see their own faces and the other person's face, and also have conversations. The participants were expected to release the foot switch when they no longer recognized that the displayed face as their own face (Figure 5 - b5). The face morphing proceeded until the faces were completely swapped (Figure 5 - b6), and the displayed face then began to return towards the original face in the opposite direction as well. Finally, after the morphing was completed, the faces on the screen had returned to their original form, and the display indicated the end of the experience (Figure 5 - b7). All participants were allowed to use glasses to have corrected vision. Throughout the experience, the two participants engaged in real-time interactive face morphing while having a conversation and viewing realistic facial expressions.

5.3 Data acquisition

In the exhibition experience, we acquired two types of data: 1) the self-face recognition boundary as input using the foot switch, and 2) the metadata recognized from the facial images of both participants. These data were recorded in an anonymized manner and securely managed only for this research purpose only. For analysis of the experiment and to preserve the privacy of the participants, we asked each participant for their consent through an explanation panel and foot switch. Underage participants were asked for parental consent before partaking in the experience.

To analyze the age and gender of each participant, we used the data from commercial facial image recognition software (Azure Face API [2]) as an alternative method to direct input so as to obtain of demographic information from participants and provide a smooth experience for both the active participants and those waiting. It is also noted that there are still limitations regarding the quality of the analysis as well as the risk of bias towards specific demographics [16]. The participant facial-imagery data was stored as a latent vector, in favor of facial imagery, to protect the privacy of the participants. This study was approved by our Institutional Review Board (22-F-0002).

6 QUANTITATIVE ANALYSIS

Our primary interest in this analysis was to measure the boundary of self-face recognition across the steps of morphing toward the other face. We analyzed the participants' responses obtained throughout the exhibition from the foot switch from our collected, 9269 pairs of response data throughout the exhibition. Each piece of collected data included the self-face boundary at a particular morphing rate (0 - 100 %), software-recognized metadata (gender and age range), anonymized ID, and partner's anonymized ID.

As planned, our exhibition was participated by an arbitrary pairs of participants with various social relationships, from pairs of strangers to families. These variations might have also influenced the variance in our analysis. One may consider that the morphing rate (r_m: 0 - 100 %) is a relative metric that could potentially diverge based on how much two faces are visually similar or different. To measure the self-face boundary between arbitrary pairs of faces, instead of the morphing rate r_m, we used the distance of the latent vector (d_w) which can be calculated by multiplying the r_m and the distance between two latent vectors of two faces ($\boldsymbol{W}_{f1}$ and $\boldsymbol{W}_{f2}$). Here, we define the self boundary as $d_w = r_m * |\boldsymbol{W}_{f1} - \boldsymbol{W}_{f2}|$. In the following section, we describe d_w (distance of the latent

[2]Microsoft Azure Face API:https://azure.microsoft.com/products/cognitive-services/face

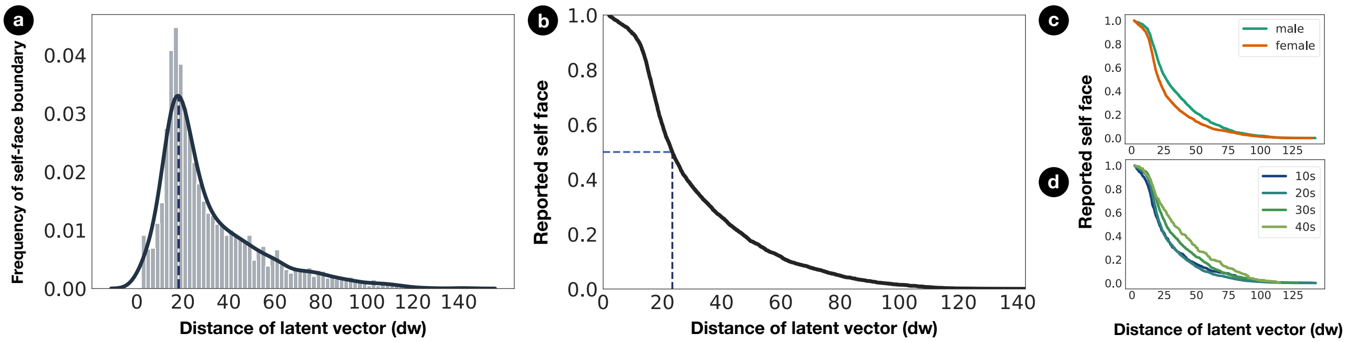

Figure 6: (a) A histogram of the reported boundary value. The solid line depicts the kernel density estimation of the distribution (N = 3411). The dotted line represents the peak in the histogram. (b) Cumulative distribution of reported boundary value. The dotted line represents the point of halfway 50% recognition of the self-face. (c) Cumulative distribution of reported boundary value by recognized gender and (d) the range of age.

vector) as the **self-boundary value**, and r_m (0 - 100 %) as the **self-boundary rate** in the morphing steps. Since both the value range of the distance of the latent vectors and the rate of morphing are indeed similar, we also note that we describe the rate of morphing in terms of morphing level (0 - 100%) in the later part of this paper to facilitate an intuitive understanding.

6.1 Data preparation

Due to the nature of this public exhibition in a public space, it would be difficult to completely guarantee that participants would understand the instructions accurately and respond to the experience as we expected. To analyze data collected in unpredictable situations, we carefully observed the behavior of the participants and defined the criteria for the data exclusion as follows.

- **estimated age < 10**: Younger (kids) participants would not understand the instructions for the foot switch correctly.
- **count of foot switch > 5**: To filter out data from some participants who pressed the foot switch multiple times without any intention.
- **self-face boundary rate > 70%**: The face image on the display was clearly not the user's face, but the foot switch was accidentally pressed.
- **self-face boundary rate < 1%**: The participant did not understand how to use the foot switch.
- **invalid captured face**: For the case where the facial image of the participant was not correctly captured, for example, due to incorrect cropping or obstacles appearing in the frame.

On the basis of these criteria, we excluded 5858 pieces of data (63.2 %) before analyzing the collected data. Even with a higher exclusion rate, this amount of data is sufficient for reflecting on the nature of the public exhibition in public space. Thus, we used 3411 pieces of data for our analysis.

6.2 Result

Figure 6 - (a) shows a histogram of the self-face boundary rate, i.e. when the person recognized that the displayed facial image was no longer his/her face in the face morphing starting from his/her own face and morphing into the partner's face. A kernel density estimation of the histogram is also displayed in Figure 6 - (a) as a solid line. To generalize the data obtained for analysis, we have transformed the obtained histograms into a cumulative distribution function (Fig. 6 - b), calculated as a percentage that aggregated all the collected data. As we can observe, a peak (in Fig. 6 - a) and shape drop (in Fig. 6 - b) in the self-face boundary rate appeared at 18.2 in d_w, the distance of the latent vector. In other words, there was a clear margin for self-face recognition along with the face morphing into the other face. Indeed, the corresponding d_w where the halfway 50% recognition point was 23.4, was at a morphing level of approx. 20 %.

We also found differences in the self-face boundary in terms of gender and age based on the recognized metadata of the participants. Figure 6 - (c, d) shows graphs of the cumulative distribution function with different demographics. Since a violation of normality was found in the self-boundary value across the age group and gender (Shapiro-Wilk Test), we used non-parametric methods to evaluate the significance in statistical comparisons.

For the difference in gender, a Wilcoxon Rank Sum test showed that there was a statistically significant difference between gender (male and female) in self-boundary value in terms of d_w, (W = 9.40, $p < 0.001$). Indeed, the median values were 34.9 for males (N = 1491) and 28.9 for females (N = 1920). For the age range, a Kruskal-Wallis H test showed that there was a statistically significant difference in d_w among the age ranges, H = 77.0, $p < 0.01$, with a mean self boundary value (d_w) of 29.6 for 10s (N = 438), 29.1 for 20s (N = 1839), 34.8 for 30s (N = 852) and 39.9 for 40s (N = 231). A Steel–Dwass posthoc analysis revealed that there were significant differences between 10s-30s, 10s-40s, 20s-30s, and 20s-40s (p=0.001) and a trend of difference between 30s-40 (p=0.054).

Taken together, our main findings from the quantitative analysis on the self-face boundary were that 1) there is a window of self-identification in the face morphing steps and 2) the windows of self-identification would differ with the demographics.

6.3 Discussion

6.3.1 Window of self-identification. The results for the boundary of self-face recognition allowed us to analyze how the participants recognized faces in the images displayed during the experience. In particular, our analysis revealed that when the morphing level was within 20% (with a latent vector distance of 23.4), participants tended to recognize the displayed face as their own, even though morphing changes were applied. On the other hand, if more morphing was applied, the face was not recognized as their own. Furthermore, our analysis may suggest that when the morphing level is 80% or higher, the face displayed on the opposite side should be within the boundary of self-face recognition, where it would be recognized as the participant's own face even if it is moved by the other person. This means that participants would experience that their faces were swapped and that the other person is moving the swapped face and vice versa. This is also mentioned in the qualitative observations in a later section.

6.3.2 Comparison to previous literature. Here we **compare our results with the results from the previous studies on the enfacement illusion** to further understand the potential mechanism of enfacement and identity [3, 15, 92]. Enfacement illusion experiments have reported that the window of self-identification for static facial images can be changed before and after the visuo-tactile stimulation. While many experiments reported a boundary value of around 40-60% in self-other judgments [82, 91, 99] as a morphing percentage, our results indicated different trends compared with these previous reports. Here, we discuss the potential factors that induce these differences.

Firstly, in our morphing identity experience, participants **judged the self-identification on the basis of their real-time facial signals** (facial movements), while the enfacement illusion employed a sense of ownership over the static facial images [28, 81, 82, 91, 99]. While the real-time and congruent visuomotor feedback of the facial movements would preserve a sense of agency that may facilitate self-attribution [36, 37, 48], at the same time, it would also provide more visual cues for discriminating between faces [24]. Thus, the identity recognized through real-time motion could be perceived differently from that recognized by observing a still image. This difference may also provide an interesting experimental setting as a paradigm for investigating the self-boundary.

Secondly, the enfacement illusion experiments used a pair of same-gender faces when morphing [81, 82, 91, 99], whereas **arbitrary gender combinations were provided in our study**. Thus, the window of self-identification found in the previous studies could be larger than that of our results. To overcome measurement consistency, we introduced the GAN latent vector distance [43] as a metric for the self-face boundary. It has been shown that the latent vector distance can be larger between different genders and races than between the same-gender and race [83, 88] and that the vector distance is correlated with the distance required to identify the face of the other [85]. Using this metric would allow us to compare distances between any pair of faces using a common distance scale rather than a relative scale of morphing percentage.

Lastly, **the answering criteria for self-identification** could be a potential factor. In the enfacement illusion experiment, the participants are asked to answer binary categorization questions such as "rather me or other" in Two-alternative forced choice [81, 91], visual analog scale [15, 82], or a key press with "look more like self than other" as comparison manner[28, 99]. In comparison, in our study, the participants were directly asked whether "it is me" (asking about self-attribution), which may have resulted in the criteria being stricter.

Due to these aspects, our results cannot be directly compared with previous enfacement illusion studies; however, our study could suggest new ways to further understand the potential mechanism of enfacement and identity.

6.3.3 Race and gender. As an additional discussion, previous research has also shown that latent vector distances can vary depending on the race and gender of individuals [83, 88]. Our quantitative study specifically focused on the distance between two arbitrary faces, and did not include a comprehensive analysis of racial differences; however, in fact, we statistically confirmed that the average latent distance between two participants was larger for face pairs of different genders than pairs of the same gender. A Mann-Whitney test indicated that the latent distance was greater between different genders (Mdn = 105.84, SD. = 12.80, n = 1358) than between the same gender (Mdn = 93.93, SD. = 14.15, n = 1010), U = 526890, $p < 0.0001$. Note that this latent distance indicates the distance between two faces, which corresponds to a 100% morphing rate. In addition, the categorical perception of gender could also influence the recognition of the self-boundary [17]. Further incorporating these control factors could enhance the feasibility and effect of the interaction design in our scenarios.

7 QUALITATIVE FEEDBACK

To further gain insight into the interpersonal experience between a pair of participants, a series of semi-structured interview sessions were organized on-site. Interviewees were chosen from participants who were able to complete the experience without having any interruptions and failures and were willing to partake in the survey (31 pairs totaling 62 participants; 36 participants reported "family" status, 7 chose "in-a-relationship" status, 14 chose "friends" status, and 5 chose "other" status). As the interview research scope looked into the interpersonal changes, participants who experienced the exhibition alone were excluded from the interview.

7.1 Data preparation

The data corpus consisted of audio recordings of the semi-structured interview sessions, field notes taken by the authors, and surveys on our questionnaire completed by participants. All audio recordings (63 recordings with an avg. of 2.4 minutes) and our field notes were transcribed and analyzed using a deductive thematic analysis focusing on both semantic and latent interpretation [11], which is widely used for deriving key themes across various datasets, and is increasingly used in exhibition settings [20, 54, 74]. Initial coding was carried out by one of the authors, who interviewed and reviewed the data with the other authors to extract themes and structures from the qualitative data. We then integrated the insight from the qualitative data and quantitative data to yield outcomes from our overall experiment.

7.2 Questionnaire and comments

Participants were asked to answer the following 7-point Likert questions after completing the experience (Q_{1-3}; 1: disagree, 7: agree, Q_4; 1: decreased, 4: no change, 7: increased): (Q_1) Did you enjoy partaking in the experience?; (Q_2) Do you think your own face has changed?; (Q_3) Do you think your partner's face has changed?; (Q_4) Was there any change in your interpersonal feelings such as increased closeness with the partner?

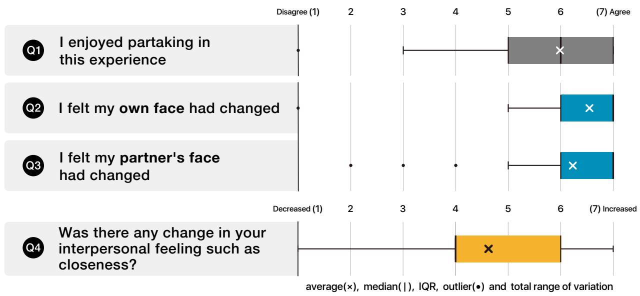

Figure 7: Subjective reporting on (1) the overall experience, (2,3) the changes in self and partner's face, and (4) an interpersonal feeling.

Figure 7 shows the results of the Likert questionnaire. **First**, the participants reported that they generally enjoyed partaking in the experience at the exhibition (range=3-7, median=6), which suggests that the setup was an enjoyable experience for most participants overall. When asked why, the participants mentioned: "the experience was weird but fun"(P38 and P44), "[it was] interesting to see a mixed face"(P43), "it was intriguing to explore the boundary between the sense of my face and the other over time"(P1), and it was "fun to become my son's face"(P17, the mother of P18). They also commented that it reminded them of their family ties, such as "[I] realized that our faces are comprised of that of my parents"(P23, who tried the experience with his sister(P24)) and "I could imagine the face if there had been one more child [brother]"(P11 and his mother(P12)). Similarly, P10, the mother of P9 who was in his teens, stated after the experience, "I was happy to see and have a conversation with my son when he was a bit older looking." The participants also felt entertained when controlling their partners' faces, such as "I see her face every day but never control her face. So it was strange, totally strange and interesting"(P49).

On the contrary, some participants mentioned that the experience was neither convincing nor entertaining. When asked why, they mentioned the difference in race (P39, a white female, who experienced the exhibition with an Asian female(P38)) and in gender (P52, a male, who experienced it with a female(P53)).

Secondly, the participants reported the degree of the change in their *own faces* throughout the experience (median=7, range=5-7) as well as the change in their *partner's faces* (median=7, range=5-7) but with a slightly lower average rating and higher deviation. In fact, some participants clearly mentioned this trend, for instance, "It was actually a bit difficult to notice whether my partner's face had clearly changed"(P3) and "I felt awkward when I realized my face had changed. On the other hand, I did not feel the same way when I saw my partner's face had changed"(P4, who was a total stranger to P3). P45 added, "When I realized, my wife's face had completely changed." At the beginning of the experience (at the low morphing level), many participants mentioned that they were unsure of a change occurring in their own faces; for instance, P55 remarked, "I did not realize there were some changes until the middle [stage of the morphing level]," and both P40 and P57 mentioned, "When I explicitly noticed it, the face already looked like someone other than me, but at the same time, it somehow felt familiar."

Lastly, the participants stated that they felt slightly positive when asked about the changes in their interpersonal feeling (median=4, range=1-7). P38 stated, "It felt entertaining when controlling the head orientation of my face, which is slightly morphed into my partner's face, resulting in an increasing sense of closeness." P60 also added, "It actually increased my awareness towards my husband's face(P61), enhancing my feeling of closeness." P13, who is the mother of P12, stated that "I realized my son's face is very similar to mine, and this finding increased the sense of closeness." P52 and P53, who are in a relationship and reported that their feeling of closeness has increased, commented, "I could see the potential face of our future generation." P42 and P43, who are female friends, also mentioned that their feeling of closeness had increased because they enjoyed the experience together.

The participants, who reported that there was no change, pointed out that it was because they have already established good relationships, such as friends (P54 and P55) or spouses (P48 and P49). P47 (a male friend of P46) and P30 (a male, who is in a relationship with P29) also stated that they felt no change because their partner's faces became their own faces, which was not something expected or pleasant for them.

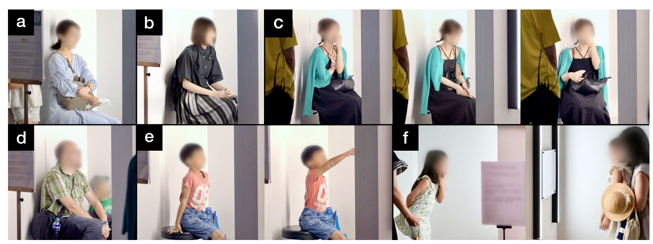

Figure 8: Participants reacted to the interactive morphing experience in various ways.

7.3 Interaction observation

Figure 8 shows the various reactions of the participants captured in the middle of the morphing experience. As shown in Figure 8 - (a, b), one of the most common reactions we observed from participants was their expression indicating a weird and strange feeling. As seen in the comment feedback as well, the participants were very new to this situation where faces were morphed into those of another while they could still control them. As depicted in Figure 8 - (c), many participants were surprised and embarrassed when they realized that their facial image was blended with that of a partner, mentioning that it was worth trying since it provided a feeling of shared attention and became a conversation topic with their partner. In addition, some participants enjoyed controlling their facial images by actively moving their mouths, eyebrows, and heads, as shown in Figure 8 - (d). Interestingly, a participant (female), who was experiencing the exhibition with her son, stated "Stop playing with my face!" when their morphing level was at the highest (almost completely swapped). Several participants also

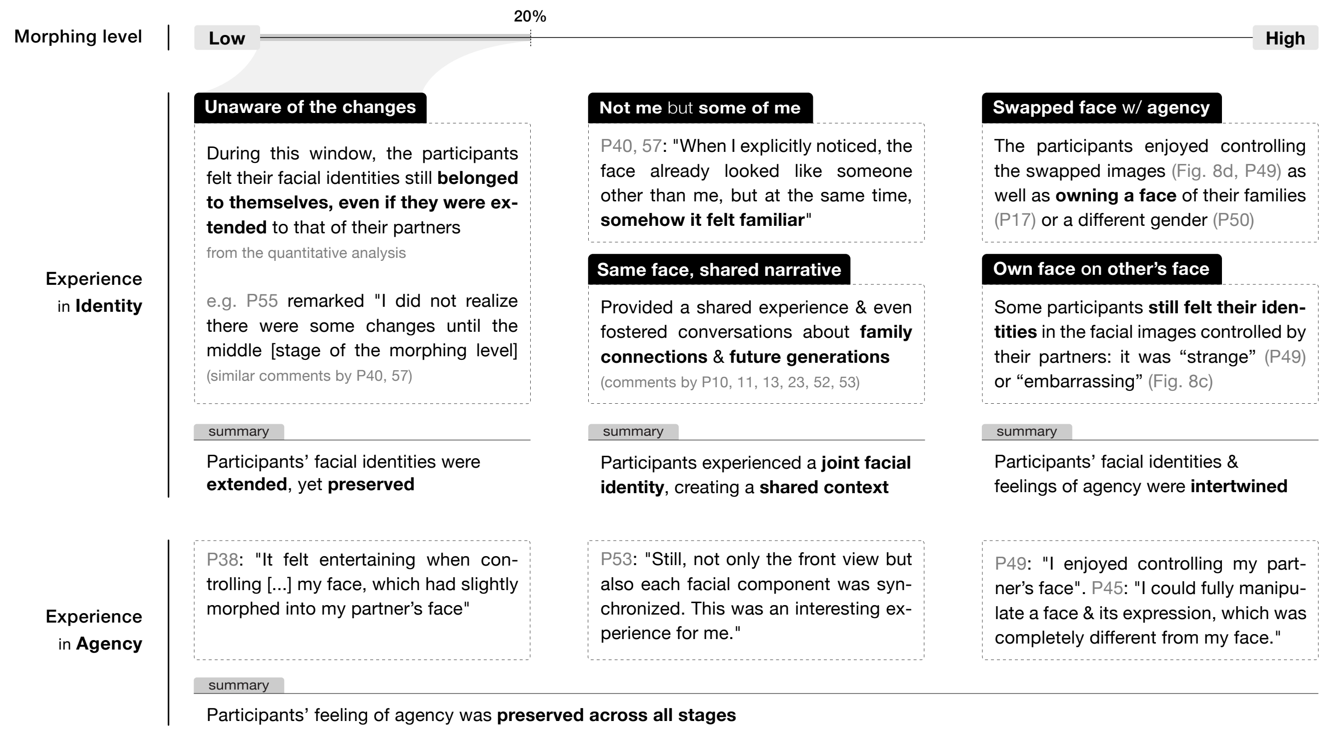

Figure 9: Summary of the experiences in identity and agency plotted based on the morphing level.

tried to identify the differences from the original facial images while conversing with their partners (Figure 8 - e). We also observed that even a pair of children (friends), who had experienced the system, showed strong interest in the morphing images (Figure 8 - f).

8 SYNTHESIS OF OUR FINDINGS: SELF-OTHER CONTINUUM

In this section, we review on our findings, to synthesize a Self-Other Continuum through the interpersonal facial morphing experience.

8.1 Summary of quantitative and qualitative findings

Here, we first summarize the quantitative analysis, comments, and observations from the perspective of participants' facial identity and agency, grouped by reported morphing levels at the time.

As revealed in the quantitative analysis, we found that the participants had a certain window in the morphing level, where **they were unaware of the changes in their facial identity, even if it was morphed to that of their partners**, and they were able to interactively send facial signals to each other. In fact, this was also supported by the comment feedback, as P40, P55, and P57 stated. Regarding their sense of agency, as stated by P38, we observed that the participants felt that they were controlling their own faces.

It was also indicated that when the morphing level progressed beyond the edge of self-identity (20%), the participants started feeling that **there were mixed faces that felt like new but were still comprised of their own facial identities**, which was also clearly mentioned by P40 and P57. It is also worth noting that, at the same time, this created an interesting opportunity for both users to see faces that are similar to each other based on the projections of the two users' facial identities, *creating a shared context* that fostered conversation on the topic of family connections and even their future generations, as P10, P11, P13, P23, P52, and P53 pointed out. Regarding their sense of agency, as noted by P53 when their faces were mixed ("Still, not only the front view but also each facial component was synchronized. This was an interesting experience for me."), they still felt a sense of control over their overall and detailed facial components during this stage.

At the stage of a high morphing level, where their facial components were almost swapped, the participants started mentioning the enjoyment and curiosity that they felt to not only controlling the facial image that had morphed into their partner's face (pointed out by P49 and as depicted in Figure 8 - d) but also embodying a new face such as that of their family (P17) or a different gender (P50) on their own. Interestingly, some participants also stated that they felt weird or embarrassed when they saw that their faces were controlled by their partners, as depicted in Figure 8 - c). Even though the participant had no agency over the facial image, which had morphed into that of the participant but was controlled by the partner, **the participant still felt his/her identity over it and felt disgusted** (P49). Regarding their sense of agency, as quoted by P45 ("I enjoyed controlling my partner's face") and P49 ("I could fully manipulate the face and its expression, which is completely different from my face"), they were still able to feel that they were

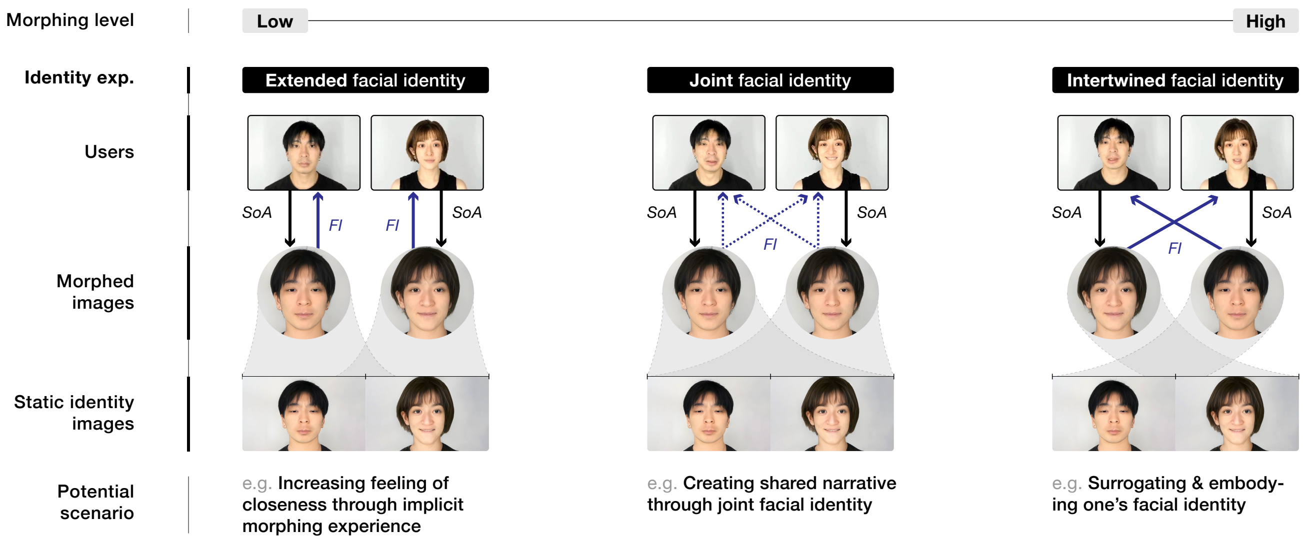

Figure 10: Self-Other Continuum: consists of three concepts of facial identity; 1) Extended Facial Identity: where self-identity is implicitly extended to that of a partner while feeling their own facial identities attached to each user, 2) Joint Facial Identity: where their facial identities are mixed, but each user still feels an essence of each identity, and 3) Intertwined Facial Identity: where their facial identities are swapped, with each user controlling a facial image with the other user's identity morphed into it. (SoA: sense of agency, FI: facial identity)

in control of the facial images that had morphed into those of their partners. We found this an interesting situation in that their sense of agency and identity over the morphed facial images were separated but intertwined with each other.

Throughout the entire exhibition process, it is notable that we did not receive any comments that pointed out a decrease in the feeling of control at any facial identity stage. Overall, while this suggests that the participants felt a sense of agency over the facial images across all different morphing levels, we observed there were **three potential boundaries in the facial identity** during the interpersonal morphing experience when the measured self-identity window, comment feedback, and observations were grouped and plotted based on the reported morphing level, as depicted in Figure 9. We then discuss further implications along with potential scenarios in the next section.

From our findings, we then synthesized a continuum that represents the experiences with interpersonal face morphing, as depicted in Figure 10. It consists of three concepts of facial identity: 1) **extended facial identity**, 2) **joint facial identity**, and 3) **intertwined facial identity**, grouped based on how users recognize the facial identity and the feeling of agency over the facial images. To better illustrate the design implications, we give details on each region in the continuum, along with potential scenarios.

8.2 Extended facial identity

The left region on the Self-Other Continuum depicts the state of "extended facial identity" where **self-identity is implicitly extended to that of a partner while feeling their own facial identity. In addition, users can feel a full sense of agency fully.** With extended self-identity being congruent with the agency, it would be possible to design a scenario where a user can attach an extended facial identity to his/her partner undetected in a daily life setting.

8.2.1 Potential scenario: increasing closeness through implicit morphing experience. As comments from the participants suggested, the morphing experience at this stage increased the feeling of facial similarity (P3, P49, P62), and the participants envisioned more effective changes to interpersonal feelings through more gradual and longer usage of the morphing, rather than having it progress in 100-second intervals as provided in the exhibitions. Previous studies showed that facial resemblance enhances the feelings of trustworthiness, likability, and attraction [35, 65, 76]. Our system might be able to achieve this in a more implicit and interactive manner that can be embedded in daily life settings while retaining the user's facial identity, such as increasing the sense of closeness between friends during a video call or between a store staff member and a customer during online shopping, or decreasing anxiety when a student or a patient are talking to a teacher or a medical doctor during a remote class or a clinical examination.

8.3 Joint facial identity

The middle region on the Self-Other Continuum depicts the joint facial identity, where users feel **their facial identities are mixed, and feel a sense of agency over the intermediate facial identity,** i.e., both users do not fully feel the mixed faces are their own faces. However, as pointed out by the participants through the comments regarding family connections, **they can still feel the**

essence of each facial identity in the joint faces and can initiate and perform social interactions with a complete sense of agency. This would provide an opportunity to have a common experience and narrative by interacting concurrently through a joint facial identity, enhancing the feeling of togetherness among users.

8.3.1 Potential scenario: creating shared narrative through the joint identity. When multiple users are working together as a team and performing joint action [104], it is known that they tend to feel a higher sense of agency in the case that the task outcome is positive (success), providing a stronger feeling of achievement and motivation to individuals, with the same principle applying to the case of a negative outcome (failure) [95]. This principle seen in joint action could also be applied to this joint facial identity setting where two or more users need to work together as one representative virtual avatar (such as [31, 98]), which would allow each user to minimize feelings of social responsibility when the outcome is negative and maximize feelings of success when the outcome is positive since each user still feels a part of the facial identity in the joint face. Scenarios include a situation where a new employee is working together with a senior instructor at a virtual online store so that they are able to share a sense of responsibility as well as achievement at the same time or a situation where only one person is allowed to give a speech from a company while sharing the feeling of representing the company with teammates.

8.4 Intertwined facial identity

Lastly, the right region on the Self-Other Continuum depicts an intertwined facial identity where **the facial identities are swapped, with each user controlling a facial image with the other user's identity morphed onto it,** i.e., each user still feels a sense of agency over the face that belongs to another identity. This intertwined situation causes the attribution of self-control and self-facial identity to become conflicted, which can be described as: "I am moving the partner's face" but "My partner is also moving my face." As seen in our qualitative observation, this could lead to beneficial use cases of embodying or surrogating one's identity when two users have a consensus. On the other hand, these conflicts could lead to violating one's facial identity without consensus, inducing distress.

Our observations suggest that the experience of swapping faces can be highly bipolar, with individuals reporting both enjoyment and disgust. Since we believe that the direction of this polarity is likely influenced by factors such as personality, nonverbal, and non-categorical relationships between individuals, the complexity of these factors makes it difficult to fully analyze using only the qualitative data obtained in our study. As such, we would not assume that there is a one-size-fits-all approach for designing experiences involving facial swapping; instead, we highlight the fact of the bipolar experiences as a design guideline for potential scenarios.

8.4.1 Potential scenario: surrogating identity to a partner user. Previous research has demonstrated that embodying different bodies changes users' implicit attitude and self-identification [57], resulting in better performance in social interactions [109]. This intertwined facial identity experience also has the potential to change our subjectivity through owning a partner's facial identity in daily life. For instance, one user might be able to acquire a trusted partner's facial identity (e.g., such as those with more social authority like business superiors, or those who are more physical facial attractiveness) to have more confidence when speaking to a large audience and to give a better impression and speech performance.

9 FUTURE WORK

9.1 Extended "other"-identity

Under our current scope, we focused on investigating an extended window of self-identity, which provided insight to boundaries of self-identity with the facial morphing experience that enables one to augment their facial identity in order to increase their feelings of closeness. In addition to this, it would also be possible to reveal an extended window of "other-identity" that represents how one user perceives changes in another user's facial identity. The qualitative feedback suggested that there could be a wider window of the "other-identity", as the participants reported a slightly lower score on the degree of facial changes when it comes to their partner's faces. Revealing this factor would append further knowledge to the continuum, allowing us to open up new design spaces in facial communication systems, as well as future applications.

9.2 More factors on self-identity

Though our focus was to explore potential interaction design spaces in an interpersonal facial morphing setting, our approach also suggests new research directions, such as introducing baseline conditions. These include how factors in the facial signal transmission (e.g., video latency, quality of facial signal mapping, morphing speed, manipulation of latent vector values, physical attributes such as age, gender and race, and social relationship statuses) could affect the morphing experience from the perspective of identity and agency. Investigating these factors in a more controlled setting would provide a better understanding of the emergence of self-identity and application scenarios in various facial communication formats, such as video conferencing, virtual reality, or even in-person with augmented reality.

9.3 Face composition technologies

Moreover, moving around with different face postures is an essential part of the experience, as users are able to interact with how their face is being morphed in real-time. However, as there are limitations to how the facial image is generated, only a frontal image was generated, making full head movements and gestures difficult for the system to synchronize. Recent research utilizes GANs to generate facial imagery to be used as UV textures for facial reenactment [25] and 3D face reconstruction and generation [34]. Additionally, the end-to-end latency of our system (300 ms) is right on the upper limit of the critical range for preserving or disrupting agency over movements [60, 84, 105, 107]. A more fully generated image of the head and minimized system latency could provide a more immersive experience to participants communicating through non-verbal head gestures.

10 CONCLUSION

Through the designing of an interpersonal facial morphing experience where the facial images of two users are blended and then swapped over time, we investigated continuous changes in self-other identification, as well as various interpersonal experiences. Through a public exhibition, we conducted a qualitative and quantitative analysis to examine this with diverse social relationships. We revealed that the process of facial morphing includes an extended window of self-identification as well as a variety of interpersonal experiences. We then synthesized a Self-Other Continuum, which is symbolized by a sense of agency and facial identity. This continuum offers implications on social and subjective components of interpersonal communication, enabling additional scenario design and complementing research findings on interactive technologies for remote communication.

ACKNOWLEDGMENTS

This work was supported by the JST Moonshot R&D Program (Grant Number JPMJMS2013). Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of any funding agencies. We are grateful for the feedback from our reviewers. We thank The National Museum of Emerging Science and Innovation in Tokyo, Japan for providing an opportunity for the exhibition.

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