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Impacts of Handcrafting Tangible Communication Avatars on the Communication Partners and Creative Experiences

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Abstract

Social networking services allow people to feel and remain connected with others. However, fatigue, loneliness, and anxiety are believed to increase as communication becomes increasingly intimate. In our previous study, we developed Palco, a paper-based, handcrafted, and tangible avatar. We demonstrate that abstract and passive communications are effective in maintaining relationships with communication partners. This study focuses on a mechanism to support the creation of avatars by users by adding the ability to identify multiple avatars and project information to each avatar using a single projector to the Palco system. A user study examined the effectiveness of user-generated avatars by comparing avatars with different levels of user involvement in the process from design to use. The findings indicate that user-generated avatars have the potential to function as a communication medium that strengthens emotional bonds between communication partners. Additionally, the experiences in the design and creation of the avatars allowed the users to demonstrate their creativity.

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1. Introduction

The number of users of social networking services (SNSs), such as Facebook, Twitter, and Instagram has grown. SNSs offer the ability to connect easily with many users and share information freely at any time. According to a survey, many people believe that SNS have deepened their connections with others [1]. However, the increased use of SNSs has resulted in mental fatigue. A survey of elementary, junior-high and high-school students, university students, and adults (up to 25 years) suggests that more than half of users feel stressed when using SNSs [2]. In addition, a survey of working adults between the ages of 20 and 40, who had created and used a personal account on Facebook, found that more than 40% of the users felt tired when they used the service [3]. The reasons for this fatigue include being overwhelmed by the information they must check, annoyed by the connections they make with others, and fed up by other people posting about their positive social lives, which suggests that the participants were tired of communicating with each other.

Krasnova et al. suggested that this stress is caused by tiredness from constantly checking other users' updates, loneliness from comparisons with others, and anxiety about what others think of their posts [4]. A study by Relationships Australia [5] also confirms an increase in lonesomeness as people use SNSs and email. In other words, people tend to feel and maintain a sense of connection with others through frequent use of SNSs. However, the closer the communication and stronger the connection, the more fatigue, loneliness, and anxiety are likely to increase.

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We believe that by loosening the communication connection, we can overcome these problems while providing a sense of security in being connected to others; this is known as loose communication. Based on this idea, we propose Palco, a communication support system characterized by abstract one-way information transfer. As shown in Figure 1, Palco is an avatar-type information display system that can be easily created using handcrafted paper, projector, and video camera. It is intended to provide users with a sense of security, while alleviating social networking fatigue by vaguely conveying the emotions, actions, and locations of their communication partners. Paper-based avatar systems are expected to increase attachment and emotional bonds to avatars using various design drawings distributed on the Internet or by designing avatars on paper.

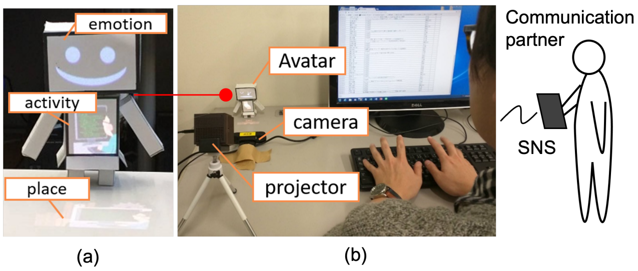


Figure 1. The first prototype of Palco system [6]: (a) a single avatar and (b) a usage scene.

In our previous study [6], we proposed the first prototype of the Palco system (Palco v1), which consisted of a single avatar, to test the effectiveness of tangible avatars and abstract and one-way information presentation for loose communication between people. We confirmed that the system is useful as a communication tool. However, the significance of being printable has not yet been clarified, and the mechanism for handling multiple avatars has not yet been investigated. The enhanced version of the Palco system is called Palco v2, and the concept itself is called Palco. This study makes the following contributions:

- We present a mechanism for handling multiple tangible avatars, wherein a visual marker is used to reliably identify an avatar.
- Through a user study with ten participants, we present the positive impact of user-generated printable avatars on communication partners.
- Creativity in designing and assembling Palco avatars is discussed based on six aspects: collaboration, enjoyment, exploration, expressiveness, results worth the effort, and immersion.

The remainder of this article is organized as follows. Section 2 examines work related to communication support system and handcrafted interactive systems. Section 3 presents Palco v2 system, focusing on the extension from Palco v1. A user study is presented in Section 4, followed by discussions in Section 5. Finally, Section 6 concludes the article.

2. Related work

TOBE [7] is a tangible avatar-based system that aims to externalize the user's inner state such as physiological signals and mental states, to provide users with a out-of-body experience, in which the tangible avatar is created with a three-dimensional (3D) printer and visualizes the user's inner states by projecting them onto the surface of the avatar. Besides, TOBE allows end-users to customize the visual feedback using a multi touch-based editor. The body of the avatar is also customizable using a 3D printer; however, the impact of users' involvement in the design and production process on the perception of avatars has not been clarified.

Sun, et al. investigated the effects of end-users who assembled interaction robots, and found that assembling the robots themselves amplified the sense of ownership and accomplishment, and led to more positive evaluations of the robots such as preferences, credibility, and enjoyment [8]. Costanza, et al. examined the feasibility of a paper-based tangible user interface for musical composition and performance into everyday environments [9]. The users used their own ink-jet printers to print and assemble three-dimensional control objects and a flat surface to interact with the objects. Also, an arm to hold a web camera for identifying markers printed on the object could be printed and assembled. As a result of user study, the users showed very positive impressions, e.g., enjoyment with the Do-It-Yourself (DIY) process. Becker, et al. investigated the Tailored Controls approach that allows end-users to create personalized tangible user interfaces (TUIs) [10], in which the interface elements were made from plain paper while allowing the users to interact with software. The user study showed that the approach offered enjoyable and exciting experiences to the users. These works emphasize the importance of making interactive systems by the users themselves to offer pleasurable experiences to the users; however, feelings such as attachment to the complete object has not been investigated.

Recent advancement of ink-jet printing technologies such as conductive ink and thin-film electroluminescence (TFEL) has made it possible to print electrodes an display elements on a variety of sheet materials using household ink-jet printers. Lee, et al. investigated a method for printed robots [11], in which shape memory arroy (SMA) is added on electrodes printed on a flexible printed circuit board. The contraction force generated by the SMA and the elasticity of the sheet itself allow the robot to changes its shape periodically. PrintScreen [12] is a technology to make customized flexible displays using thin-film electroluminescence, which prints segmented and passive matrix displays in grey scale or multi-color on a wide variety of materials such as paper and leather. Foldio [13] allows designers to model the target object in 3D interactively, including the position of contact-based sensors and visual elements (electroluminescence displays). The tool generates a print-and-fold pattern and circuit pattern based on the 3D design, and prints out conductive ink pattern on paper. Such printing and integrated development environments may allow users to make a tangible avatar augmented with TFEL display and SMA-based shape change; however, the users still need to attach micro controller and electonic parts on the printed material. By contrast, Palco is completely paper-based, and the users do not need to assemble electronic parts at all. Instead, a low-cost laser projector and a web camera, as well as a PC and a printer (or even without a printer, i.e., drawing development diagram by hand) are required, which we expect realizes DIY-based communication support system.

3. Palco v2 System

3.1. Background: Key concepts of Palco system

Palco v2 enhances Palco v1 [6] by adding functionalities of identifying multiple tangible avatars and deploying user designed avatars by the user him/herself. This section presents the key concepts of the original Palco system as basic knowledge to understand the Palco v2.

Tangible avatar-based communication. In Palco, information about the communication partner is communicated via a tangible (physical) avatar, in which we took advantage of the effects contributed by both physical and anthropomorphic aspects of a tangible avatar. Physical contact with objects can provide users with a substantive experience, and can have the effect of influencing people's materialism. Also, anthropomorphic objects affect user performance and subjective responses. In particular, it is thought to have the effect of supporting familiar interaction scenarios, such as the expression of individuality and emotions, with [14, 15]. Non-verbal behaviors such as body language signals and facial expressions have been found to give users positive impressions [16], and it has been suggested that anthropomorphic characters are effective in aiding long-term interaction. In summary, the physicality and anthropomorphic appearance of tangible avatars are expected to amplify the sense that the output from the system is connected to real-world information and the psychological closeness to avatars. Therefore, we apply the features of the tangibles avatar to remote communication.

Loose communication. We define the following features as the components of loose connections and achieve communication that satisfies these two features to provide users with a sense of security while avoiding existing problems.

- Abstract presentation: Non-explicit information presentation that is not too fine grained
- One-way communication: Non-active information transfer with just receiving information

The strong connections found in conventional media, such as SNSs, are either explicitly through words, texts, and photos, or actively engaged in contact. However, an explicit provision of the partner's information can cause envy and loneliness to the user. We consider that the partner's information should be made abstract so that the user can imagine the situation of the partner by themselves. In Palco, the state of the communication partner is represented without a textual expression, such that the avatar talks to the user, but with still or animated images through an appropriate abstractness level conversion.. Also, interactivity in conventional services such as "Like!" in Facebook and Twitter enables active involvement with the partner's information; however, this may trigger fatigue and annoyance on the part of the user. We consider that passive involvement realized by one-way communication plays a role in relaxing the pressure of response. In Palco, the user just watches the partner's information.

Handcrafted tangible avatar. Palco employs the concept of handcrafted, in which the body of the avatar is made of paper and the information of communication partners is projected onto the surface of the avatar through a video projector. The paper-based tangible avatars allow users to download internet-distributed avatar templates of various appearances, print them out on a home printer, or customize the appearance of the avatars by themselves. It is expected to amplify the coupling between the communication partner and the avatar by reflecting the characteristics of the communication partner in the appearance of the avatar. The paper-based avatar also has the advantage of being able to easily scale up regarding the number of avatars and changes in appearance once the projectors, cameras, and control system are prepared. This article particularly focuses on the effect of end-user avatar design and creation.

Presented information. People desire to be with others, and this can be accomplished artificially through the sharing of their current states. The states communicated through Palco are the activity, the location, and the emotional state at a particular moment, which we consider to be the contextual information of the person. We expect that the user may feel at ease by sharing the contextual information that characterizes the person. These elements of the partner's information are projected by taking into account the intuitiveness of the relationship. This means that the location, the activity, and the emotional states are projected at the foot, on the body, and on the head of the avatar, respectively (see Figure 1 (a)). The information about the location and activity is represented through illustrations that can abstract such information, rather than with textual description or pictures. The emotional states are presented with facial expressions. Additionally, for the purpose of increasing the rapport with the avatar as well as its charm, the emotional states are rendered with animations such as blinking, laughing, and so on.

3.2. System configuration and core components of Palco v2 system

Figure 2 illustrates an overview of Palco v2, which were designed to realize the concepts presented above. The Palco v2 system consists of multiple paper-based avatars that correspond to communication partners, a projector for information projection, and a video camera for avatar identification and projection area detection, and is intended for use on a desktop. Although a user can design the avatar based on his/her preferences, a constraint is that rectangles are drawn for the head and body to track the position and for distortion correction, as well as for camera–projector calibration. Major functional components include 1) avatar identification and association with projection regions, 2) partner's state acquisition from SNS, i.e., Twitter, 3) projection image generation based on acquired information, and 4) projection image correction. Among the functional components, the functionalities of avatar identification and association with projection regions are unique to Palco v2.

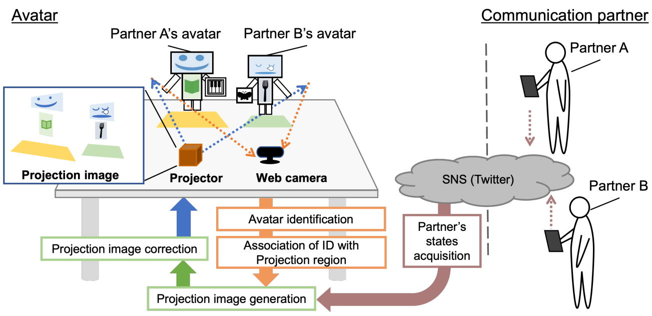


Figure 2. Overview of Palco v2 system with major system components

Avatar identification and association with projection regions. The identifiers (IDs) of avatars, i.e., the IDs of communication partners, are constantly recognized by visual marker detection once the avatars are set in the camera's angle of view. Simultaneously, the projection regions for each avatar are detected, in which the rectangular regions that correspond to the head and the body of an avatar are detected using a rectangle detection method. In Palco v1, only projection area detection was needed to deal with one avatar; however, since Palco v2 targets multiple avatars, the identification functionalities was introduced. Recent advancement of computer vision technologies such as YOLO [17] may enable marker-less object identification; however, incorporating a new target, i.e., an avatar for a new communication partner, requires the user to collect and register hundreds of its images. Furthermore, since the appearance of an avatar varies by the projected information, the object identification task should be much harder. Thus, we took an approach of visual marker-based object identification, in which the users design the markers, and we provide a tool for the users to associate new maker patterns with their IDs.

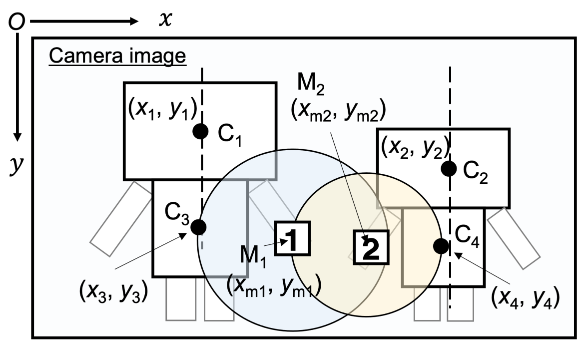


Figure 3. Association of avatar's ID with projection regions

Information from a particular communication partner should be projected on the corresponding avatar; however, given that N avatars exist in the camera's angle of view, N head and N torso regions for projection are detected, the ID, the head region, and the torso region are not associated each other. Therefore, appropriate head and torso regions must be identified to represent a single avatar, and the corresponding ID should be assigned to the regions. Figure 3 illustrates an example where two avatar IDs, i.e., "1" and "2", four rectangles with certain area are detected. The centers of four rectangles are represented as $C_{i\in\{1,2,3,4\}}$, and x- and y-coordinate as x_i and y_i, respectively. The centers of the visual markers are represented as $M_{j\in\{1,2\}}$. First, the head and the torso regions are associated by finding two regions with the smallest distance between the x-coordinates of the centers of the rectangles because we assume that the head is located almost directly above the torso. Thus, in Figure 3, C_1 and C_3 are regarded to belong to the same avatar and to represent the head and the torso, respectively.

A similar approach is applied in the association between the marker ID and the body of an avatar, in which the distances between the center of a particular marker and all the centers of rectangles are calculated, and the ID is associated with the avatar with the closest distance. In Figure 3, the distance between M_1 and C_3 ($\overline{M_1C_3}$) is shorter than the other three pairs, which assigns the ID "1" to the avatar on the left. Similarly, ID "2" is assigned to the avatar on the right because $\overline{M_2C_4}$ is the shortest in the four pairs. If two avatars are placed very close together, it may happen that a marker attached to one avatar is associated with the other. In such a case, the projection will fail; however, we expect that the user can adjust the position by him/herself to avoid such mis-association.

The number of avatars detected by one camera depends on the diagonal field of view of a camera (θ), the distance between the camera and the shooting plane (d), and the width of the circumscribed rectangle of the avatar (s). Figure 4 illustrates the positional relation, in which the aspect ratio of the camera is $a_v : a_h$ and we assume that the center of the camera is on the same straight line as the center of the shooting area. The maximum width of the shooting area (w) is defined by Equation (1). Given that s is equivalent to all avatars and no overlap of avatars is allowed, the maximum number of avatars (n) is represented by Equation (2), where $\lfloor x \rfloor$ gives the greatest integer less than or equal to x.

$$w = 2 \cdot \frac{a_h}{\sqrt{a_v^2 + a_h^2}} \cdot d \cdot tan\frac{\theta}{2} \quad (1)$$

$$n = \lfloor \frac{w}{s} \rfloor \quad (2)$$

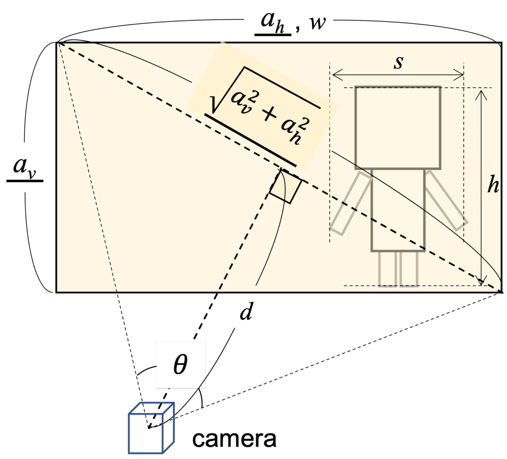


Figure 4. Relationship in the diagonal field of view of a camera (θ), the vertical distance between camera and the plane containing avatars (d), and the physical width of shooting area (w). The variables with underline indicate the dimensionless quantity representing the aspect ratio.

Furthermore, the "detectability" of the projection regions in the shooting area depends on the area of the background. If the distance is too far, the camera captures unrelated objects or patterns that may cause mis-detection of rectangular as the projection regions. Also, since the true projection regions are detected as small regions, they could be filtered out by a threshold of the area of the rectangular for projection region detection. In Section 3.4, the upper limit of the number of avatars for a particular setting is evaluated.

Acquisition of the communication partner's states. The system acquires the states of communication partners whose avatars are identified. In Palco, Twitter was used as an SNS and infrastructure of communication. The tweets are fetched and analyzed to acquire the state information, i.e., the emotion, the activity, and the place. Ideally, the communication partners should be able to tweet without the awareness of Palco, meaning that they can tweet in natural language and attach photos and videos, and that Palco system should extract the information. The information of activity and place could be obtained by the analysis of sensors on the smartphone such as a Global Positioning System (GPS), wireless signal strength, and accelerometer. Additionally, the emotional state can be recognized by emotion recognition technologies using text, video, speech, etc. data [18–20]. However, in this study, we developed a dedicated Twitter client application; the users specify their current emotional state, activities, and places by selecting the most appropriate ones from the lists of candidates, which is to focus on the evaluation on the recipient sides.

Projection image generation and correction for projection. The projection to the avatar consists of three parts: head (face), torso, and the ground, corresponding to emotion, activity, and place, respectively. Appropriate illustration is chosen for the new state from a number of possible states in daily life. When an avatar ID is detected for the first time or the partner's state is updated, the projection image also needs to be updated with the chosen illustrations. Furthermore, even if the partner's state does not change, the projected position needs to be updated each time the user moves the avatar.

Since the avatar's head and torso are recognized as rectangles, the four vertex coordinates of these rectangles are acquired from the projection region on the camera image. By applying the camera–projector perspective transformation matrix to each coordinate of the rectangles, the projection regions on the projection image are calculated. Additionally, the projection area at the feet of the avatar is calculated relative to the head and torso coordinates of the projection image. The four vertex coordinates of the projected images corresponding to the partner's states are perspectively transformed to match with these calculated coordinates. A single image for projection is finally generated. Note that the perspective transformation matrix is obtained by the calibration to match the coordinates of the camera and projector, in which a user performs the calibration through the guide from the system every time the spatial relationship between the camera and the projector changes.

3.3. Run-time environment

A Logicool HD Pro web camera (C920; diagonal field of view $(\theta) = 78^\circ$ and aspect ratio $(a_h : a_v) = 16 : 9$) and a SK Telecom Smart Beam Laser (LB-UH6CB) were used as a image capture device and projection device, respectively. The projector is a laser projector, which is focus-free and preferable for Palco because the distance between the projector and the avatar may vary depending on the user's preference or deploying environment. The visual marker identification was implemented by using ARToolkit 2.72.1 [21], while the rectangular detection and projection image generation and correction were realized with OpenCV 3.1.0. The system was implemented using C++, except for Java in the tweets fetch functionality realized with Twitter API (Twitter4J 4.0.4). The software ran on a PC (OS: Windows 7, CPU: Intel Core i5-3470 3.20 GHz).

3.4. Basic performance in avatar detection

The detectability of avatar was evaluated by changing the distance (d in Equation (1)) and the width of the circumscribed rectangle of the avatar (s in Equation (2)). The detectability of a single avatar (det_1) is defined by the ratio of the sum of detected rectangles ($r_{k \in \{1,f\}}$) to the sum of rectangles to be detected in f frames in 30 sec (Equation (3)). Since one avatar was used in the experiment, the number of rectangles to be detected in a frame was two: the head and the torso. The detectability of n avatars is obtained as the joint probability of det_1 as shown in Equation (4).

$$det_1 = \frac{\sum_{k=1}^{f} r_k}{2 \cdot f} \quad (3)$$

$$det_n = (det_1)^n \quad (4)$$

We used two types of avatars with different body size: large ($s = 8.75$ cm) and small ($s = 7.5$ cm), and changed the distance d from 14 cm to 36 cm by 2 cm. The relationship between s, det_1, and det_n for each of the two types is summarized in Table 1, which also contains the calculated value of w, n, and det_n. Note that the subscripts L and S indicate types of large and small, respectively. We can see that more avatar with small size can be used at the same distance compared with large one with lower detectability and that four avatars can be used at the same time with detectability above 0.900 when the camera is placed 22 to 28 cm away from the avatars. We consider that this is sufficient for use among very close friends. Note that the camera with wider diagonal field of view (θ) may allow the user to handle more avatars in a more stable manner.

The frame rate to update the state of one avatar and that of two avatars were about 2 fps and 1 fps, respectively. The frame rate decrease as the number of avatars increase because of the increase in the processing of partner's information and projection image generation that took about 0.20 sec and 0.14 sec per avatar, respectively. Nevertheless, we consider that the frame rate is acceptable because the update of the partner's state occurs in an asynchronous manner, i.e., it may happen when the user is not watching an avatar, and the user might not move an avatar so often and quickly even if he/she changes its position.

4. User study

We validate the concept of a communication support system using paper-based avatars, assuming that the users themselves create avatars corresponding to their communication partners and use the completed avatars. The study was approved by the Institutional Review Board of Tokyo University of Agriculture and Technology (No. 30-55, January 10 2019).

4.1. Methodology

Overview. To understand the significance of creating avatars by the subjects themselves, four types of avatars that have different degree of subject's involvement in the design, creation, and use were introduced. Figure 5 summarizes the differences in the roles of the subject and the experimenter. In Type 1, the subjects perform all processes of avatar creation except for making unfolded patterns of an avatar for printing; the subjects design avatar (Figure 6 (a)), cut out unfolded parts of an avatar from printed sheet (Figure 6 (b)), and assemble the cut-out parts (Figure 6 (d)). Therefore, Type 1 represents the most active involvement with the avatar. The avatars of Type 2 are slightly different from the ones of Type 1 in the absence of the process of cutting out printed parts. The cut-out parts are also folded by the experimenter so that the subjects can simply assembling by taping and gluing them (Figure 6 (c)). In Type 3, the subjects can only choose preferred avatars from the ones already completed by the experimenter. Thus, the experiences in the design and the creation of avatars are missing, as well as the reflection of the subject's preferences is limited. Finally, the avatars of Type 4 are randomly chosen by the experimenter, and the subjects simply use them. Note that the unfolded patterns were drawn by the experimenter from the sketches of the subjects in Type 1, as well as other types, to focus on the evaluation of different degrees of the

Table 1. The relationship between the distance between the camera and the shooting plane (d), detectability (det), and the upper limit of avatars in the shooting plane (n).

d [cm]	14	16	18	20	22	24	26	28	30	32	34	36
$det_{1,L}$	1.000	1.000	1.000	0.995	1.000	0.990	0.998	0.988	0.962	0.943	0.900	0.844
$det_{1,S}$	1.000	1.000	0.987	0.953	0.978	0.946	0.788	0.729	0.830	0.906	0.900	0.854
w [cm]	19.8	22.6	25.4	28.2	31.1	33.9	36.7	39.5	42.3	45.2	48	50.9
n_L	2	2	2	3	3	3	4	4	4	5	5	5
n_S	2	3	3	3	4	4	4	5	5	6	6	6
$det_{n_L,L}$	1.000	1.000	1.000	0.985	1.000	0.970	0.992	0.953	0.856	0.746	0.537	0.428
$det_{n_S,S}$	1.000	1.000	0.962	0.866	0.915	0.801	0.386	0.206	0.394	0.553	0.402	0.388

user involvement in the avatar. In practice, a software tool that generates unfolded patterns from the user's sketch should be incorporated into the Palco system to reduce the burden of the user, or the users utilize external software for this purpose such as PePaKuRa Designer [22].

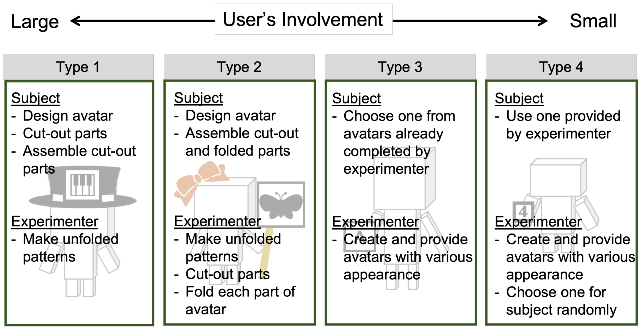


Figure 5. Avatars with different degree of subject involvement toward use.

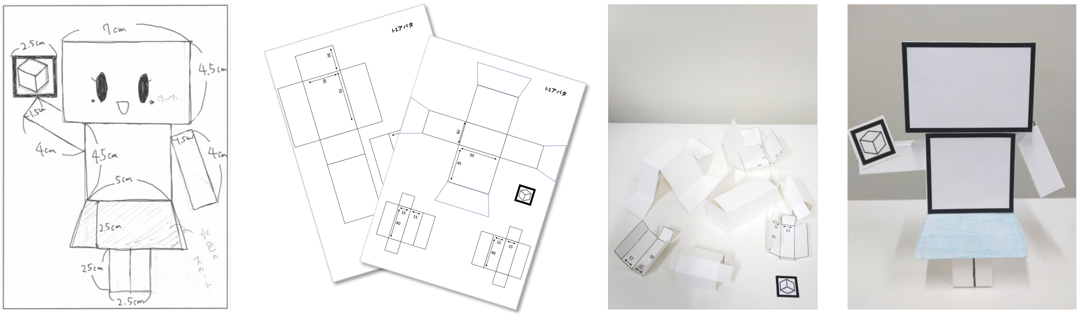
A group of 10 undergraduate and graduate students who know each other participated in the experiment. The experiment took three days. The first day was for the design of avatars of Type 1 and Type 2; the second day was for creation of these avatars; and the third day was for use of all four types of avatars. Each of the four avatars is associated with a specific communication partner who is assigned by the experimenter in the subject group. The partners transmit their own states, i.e., emotion, activity, and place, via a dedicated application during the experiment. The partners choose one for each type from a drop down list in the smartphone application. After each step of design, creation, and use of avatars, a semi-structured interview about impressions of the system is carried out. Video recordings of the system usage process and interview responses are analyzed. More specific descriptions of the three steps are presented below.

Designing avatars. According to a preliminary study on the potential users' preferences regarding the design of an avatar, the design spaces of the appearance of Type 1 and Type 2 avatars are 1) the size of the head and body and their proportions, 2) the height, 3) the length and thickness of limbs, 4) accessories if any and 5) the size and the pattern of visual markers.

Each subject was provided with A4-size sheets of paper to use as a design area for two avatars at actual size. The back of the paper contained design examples and notes. The notes were used for reliable system operation, such as projecting information to the correct location and accurately identifying specific avatars for information update. The notes acted as constraints in the design for the subjects and listed below:

- The head and body of the avatar should always be composed of squares.
- Due to the angle of view of the camera, the maximum length of the avatar (including accessories) should be 18 cm.
- In case of large avatars, only two or three avatars can be used at the same time due to the camera's angle of view. To use four avatars, up to 8 cm in width including hands and accessories is acceptable.
- If the head and body are too small, it may not be able to project stably; the 3×2.5 cm model behaves slightly unstable, while the 4×3.5 cm model improves the stability.
- A rectangle is drawn for the outline of the head and body of the avatar, but accessories and visual markers cannot cover the rectangular area.
- Visual markers should be square and at least 8 mm on all sides.
- Visual markers should be attached to accessories or to the limbs of the avatar. They should not be attached to the head or body, but can be put on the head, for example, on a hat.

In order to investigate the validity of the avatar design with these constraints, we examine the degree of satisfaction and the perceived degree of freedom by 5-points Likert scales. We will discuss the factors



(a) Appearance design (b) Unfolded parts printed on cardboard (c) Cut-out parts (d) Completed avatar

Figure 6. The outcomes of appearance design (left), unfolded parts of an avatar printed on cardboard (center), and an assembled avatar (right).

that are important to connect the avatar with the communication partner based on the appearance of the avatars drawn by the subjects and the feedback from the subjects. An example of an appearance design is presented in the left part of Figure 6.

Creating avatars. As described above, the unfolded parts of avatars were drawn by the experimenter (Figure 6 center), and the subjects were provided with a sheet of printed unfolded parts for Type 1 avatar. The subject completed the avatar by cutting the printed unfolded parts using scissors and assembling the cut-out parts using glue and tape. The parts that correspond to the limbs of the avatars could be freely colored with colored pencils (Figure 6 left), and the parts corresponding to the hair could be attached with yarn as well as the design constraints were kept. In Type 2, the parts were cut out and folded by the experimenter in advance, and the subjects just assemble the avatar. The enjoyment and the burden of making avatars as well as the satisfaction with the completed avatars were investigated to understand the impression that the experience of making avatars offered to the subjects, in which Type 1 and Type 2 of avatars that had different level of difficulties in creation were compared.

Using avatars. In this phase, the Palco v2 system was used with a total of four avatars, i.e., from Type 1 to Type 4; however, the number of avatars and the combination actually used was up to the subjects. The system was placed on a tabletop in the subject's field of view so that they could glance at the avatars. The subjects were asked to use the system for one day (about 6 hours), where the timing of viewing the avatars was left to the subjects. The subjects were free to work on the tabletop or leave the room. In addition, the subjects were allowed to freely interact with the avatars, such as moving or touching them.

The communication partners sent their current emotional states, activities, and location information to the system using a dedicated Twitter client application when there was a change in any of the three pieces of information. The information was transformed into images and superimposed on the head, body, and the ground beneath the feet of the avatars.

The usage pattern and the impressions of the four avatars were investigated through the statistics of usage obtained from video analysis and the feedback from the subjects, which includes the ratio of time each avatar was used, the way of using avatars, impressions and interest scores for each type of avatar in a 5-point Likert scale, the amount of change in emotion on the communication partners compared to before use, and the frequency with which the subjects suddenly thought about the communication partners. The results were used to explore the significance of handcrafted avatars as a communication medium and the influence on the emotional states on users.

4.2. Result

Designing avatars. A summary of the major features that were considered in designing the avatar are summarized below, which is based on the subjects' responses. The numbers in the parentheses represents the number of subjects.

- Body length and the proportion of body parts (7)
- Accessories representing the hobbies, preferences, and group affiliations of the communication partners (5)
- Clothes (4)
- Hair styles (3)

Additionally, the features that were considered in designing the visual marker to be attached to the avatar are summarized below:

- Hobbies and preferences (6)
- The initials and nicknames (3)
- Club activities belonging to (2)
- Impressive shared memories (2)

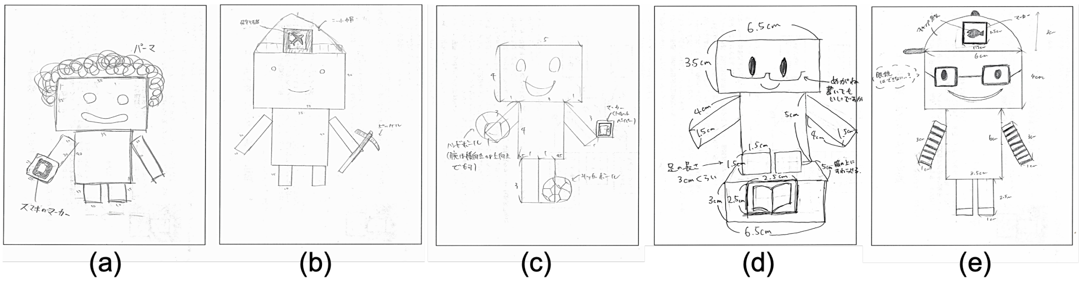


Figure 7. Examples of the design sketches by subjects.

These design choices are found in Figure 7 that shows examples of appearances of avatars including visual markers. Various features that characterise the communication partners were sketched, e.g., the hair style ((a) and (b)), the objects related to their hobbies ((b), (c), and (d)), body length (e), and clothes (e). The positions of the visual markers were also unique and show natural appearances, e.g., on the hand ((a) and (c)), on the head ((b) and (e)), and at the foot (d).

The degree of satisfaction was assessed for each trial of Type 1 and Type 2 avatar design on a 5-point Likert scale (1: strongly dissatisfied, 2: dissatisfied, 3: neither, 4: satisfied, and 5: strongly satisfied) with a mean of 3.85 and a median of 4. Only one subject gave a score of 2, and others rated more than three among which three subjects rated 5, which shows that the subjects were generally satisfied. The main opinions obtained as reasons for (dis)satisfaction with the design are listed below. Note that the number in parentheses represents the average satisfaction of the two trials.

- $\mathbf{O_{D,1}}$: I did not have the design skills to reflect my ideas. It would have been nice to have templates for parts. (3.0)
- $\mathbf{O_{D,2}}$: I couldn't think of elements to include or characteristics of the communication partner, so I couldn't reflect them in the design. (2.5)
- $\mathbf{O_{D,3}}$: It is satisfying to be able to reflect the features well. (4.5)
- $\mathbf{O_{D,4}}$: I think I could reflect the characteristics that identify the communication partner, such as appearance and hobbies. (4.5)
- $\mathbf{O_{D,5}}$: The appearance of the avatar is easy to distinguish the communication partner at a glance although it was troublesome to come up with distinctive elements to include. (3.0)
- $\mathbf{O_{D,6}}$: I think I could successfully incorporate the characteristics of my opponent into the design of the avatar. (5.0)

Throughout the design of avatars including the visual marker, the following opinion was obtained.

- $\mathbf{O_{D,7}}$: Designing the avatars was fun. It gave me a chance to think about the communication partners, such as what characteristics they have and what they like (2).

The perceived degree of freedom in designing avatars under the constraints shown in Section 4.1 were also asked by 5-points Likert scale (1: felt strongly restrictive, 2: felt restrictive, 3: neither, 4: felt free, and 5: felt strongly free). The scores were either 3 or 4, and the mean and the median were 3.7 and 4, respectively. The fact that there was no subject who gave 5 implies that the design that the subjects had initially envisioned could not be fully reflected due to the constraints although there had been rather a lot of freedom in design. The major reasons for giving that score are as follows. The number in parentheses represents the score.

- $\mathbf{O_{D,8}}$: I found that there were some elements that could not be included due to the restriction that the rectangle could not be covered with anything. But, it was nice to have the freedom to design the visual markers. (4)
- $\mathbf{O_{D,9}}$: I wanted to design it (the avatar) a little smaller, but I couldn't because there was a minimum size limit. But, I liked that the design of the markers and accessories had a lot of flexibility in the design. (3)
- $\mathbf{O_{D,10}}$: I wanted to make it smaller (but couldn't due to the constraint). But, I think it is good because the constraints make the design process simple and consistent. (4)
- $\mathbf{O_{D,11}}$: The constraints made it easier for me to think about the design. (4)

Creating avatars. Figure 8 shows examples of avatars that were actually created by subjects from the unfolded parts created by the sketches in Figure 7. The satisfaction scores of the avatars were asked with a 5-point Likert scale (1: strongly dissatisfied, 2: dissatisfied, 3: neither, 4: satisfied, and 5: strongly satisfied). The results showed that the mean and median satisfaction scores were 4.45 and 4.50, respectively. The following are the main opinions obtained as reasons for the level of satisfaction with the avatars, where the number in parentheses represents the average satisfaction of the two trials.

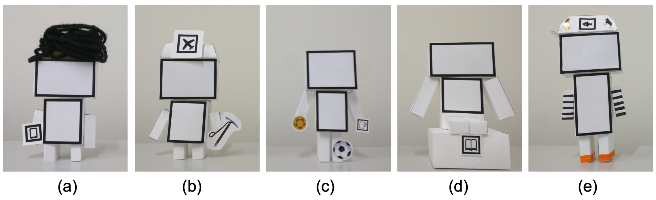


Figure 8. Examples of the completed avatars by subjects, which corresponds to the sketches in Figure 7

- $\mathbf{O_{C,1}}$: The design was poor, but the actual product was well made. (5.0)
- $\mathbf{O_{C,2}}$: I was satisfied with the way I could to make it as I had expected. (5.0)
- $\mathbf{O_{C,3}}$: I could make the design into a three-dimensional object as I had imagined. (5.0)
- $\mathbf{O_{C,4}}$: I felt cuteness and attachment on the avatars by making them. (5.0)
- $\mathbf{O_{C,5}}$: I was too clumsy to complete the avatars. (4.0)
- $\mathbf{O_{C,6}}$: I messed up on the cutout, so the finished product were not as complete as I would have liked. (4.5)
- $\mathbf{O_{C,7}}$: I could express myself in the way I wanted by painting, but if I couldn't paint well, I think the level of completeness would be lower. (4.0)

Next, we asked the subjects about their enjoyment of the creation process. The main results and their breakdown are summarized below, which indicates that all subjects gave a positive opinion about the enjoyment of the creation process. Note that the number in parentheses indicates the number of subjects who mentioned the point.

- $\mathbf{O_{C,8}}$: I felt a sense of enjoyment and accomplishment in the process of creating the decorations and the gradual assembly of the parts. (5)
- $\mathbf{O_{C,9}}$: I enjoyed creating it because I felt a sense of accomplishment and having made it by myself after completing it. (4)
- $\mathbf{O_{C,10}}$: I enjoyed and was happy in seeing my own design reflected in the resultant avatar. (1)

Nine subjects existed who felt burdensome in the creation process; six of nine subjects felt it difficult to cut out the parts from the printed unfolded parts, while five of nine subjects felt the difficulty in folding the cut-out parts. On the other hand, only one subject felt that it was burdensome to perform the final assembly using the pre-folded parts.

Using avatars. Figure 9 shows a scene of using three avatars on the tabletop. The percentage of time spent to use each of the four avatars is shown in Figure 10, which is obtained from the video recordings of the system usage process. Significant differences ($p < 0.05$) were found between Type 1 and Type 3, Type 1 and Type 4, Type 2 and Type 3, and Type 2 and Type 4, in the percentages of time spent to use each avatar. This means the subjects spent more time with avatars they created (Type 1 and Type 2) than the ones just chose from finished products (Type 3) and provided by the experimenter (Type 4).

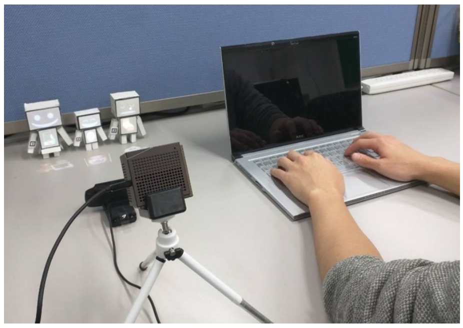


Figure 9. A scene of using three avatars in Palco v2 system

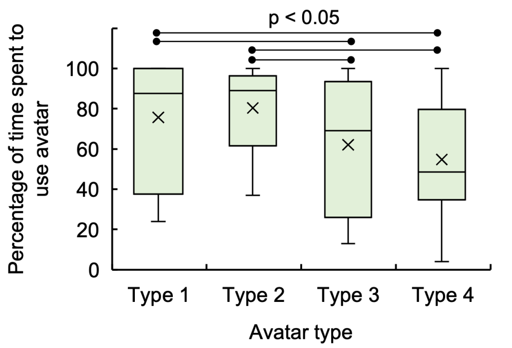


Figure 10. Percentage of time spent to use each avatar.

The subjects were asked to indicate their impressions of or interest in each avatar on a 5-point Likert scale (1: not impressive/interesting at all, 2: little impressive/interesting, 3: neither, 4: impressive/interesting, 5: very impressive/interesting). Figure 11 shows the result. The result of multiple comparisons using Ryan's method with Wilcoxon's signed rank sum test showed significant difference ($p < 0.05$) between Type 1 and Type 4, Type 2 and Type 4, and Type 3 and Type 4, which indicates that the impression and interest were significantly lower for the avatars specified by the experimenter.

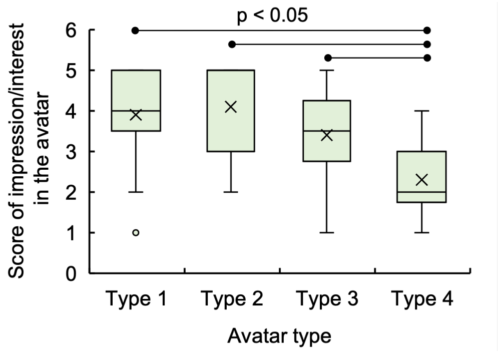


Figure 11. Scores of impression to/interest in the avatar.

The main opinions are summarized below. The number in parentheses indicates the number of subjects who mentioned the point with duplicated answer.

- $\mathbf{O_{U,1}}$: I think the frequency of updates is related to the strength of interest and impression regardless of whether I made the avatars or not. (6)
- $\mathbf{O_{U,2}}$: I would like to watch the avatars I made because of attachment to them. (5)
- $\mathbf{O_{U,3}}$: I would like to use avatars that match the appearance of communication partners. On the other hand, it was difficult to use avatars that did not match the partners' appearances. (3)
- $\mathbf{O_{U,4}}$: I would like to use avatars with the favorite appearances and interesting shapes regardless of whether I made the avatars or not. (2)

Furthermore, the subjects were asked to rate the perceived change of frequency of recalling the communication partner compared to before the experiment on a 11-point scale from -5 to 5, in which positive and negative values indicate that the subjects perceive the frequency to have increased and decreased, respectively, while zero indicates no change. The result is shown in Figure 12, in which the subjects seemed to perceive that the frequency of recalling the communication partners increased from before the start of the experiment, regardless of the type of avatar used. Significant difference ($p < 0.05$) was only confirmed between Type 2 and Type 4 as a result of multiple comparisons using Ryan's method with Wilcoxon's signed rank sum test. The major opinions from the subjects are as follows.

- $\mathbf{O_{U,5}}$: Due to my attachment to and interest in my own work, I found myself looking at the avatar and imagining the communication partner at a moment's notice.
- $\mathbf{O_{U,6}}$: The avatars that I made myself could be easily recognized by a quick glance. However, for the other types of avatars, i.e., Type 3 and Type 4, it was difficult to remember the association between the avatar and the communication partner.
- $\mathbf{O_{U,7}}$: I frequently looked at the avatars I was interested in, and I thought of the communication partners.

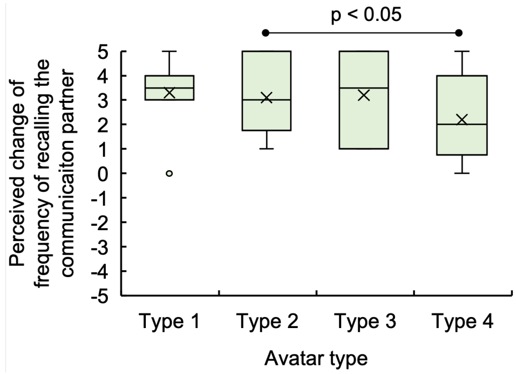


Figure 12. Perceived change of frequency of recalling the communication partner.

5. Discussion

5.1. Representing personality of communication partners by end-user design

By analyzing the reasons for the rating on satisfaction ($O_{D,1}$ to $O_{D,6}$), the failure to reflect the features of the communication partner in the design decreased the score representing the satisfaction level as shown in $O_{D,1}$ and $O_{D,2}$. On the other hand, the score was increased by successful reflection of the features of the communication partner in the design, as shown in $O_{D,3}$, $O_{D,4}$, and $O_{D,6}$. In addition, the opinions $O_{D,4}$ and $O_{D,5}$ indicate that the avatars were designed to reflect the characteristics of their communication partners so that the subjects could distinguish them at a glance. Furthermore, $O_{D,1}$ suggests that providing templates or pre-designed parts is effective in supporting the design.

The survey of the features considered in the design of avatars and fiducial markers showed that the size and the proportion of the parts of the avatars were the most preferred features to differentiate the physique and gender of the communication partners. We further confirmed that the accessories attached to the avatars express the hobbies and preferences of the communication partners and their group affiliations. In addition, gender and personality of the communication partners were expressed by clothes and hairstyle. Similar tendency could be found in the design of visual markers; the markers were designed to symbolize the hobbies, preferences, and club activities to which the avatars belonged. Furthermore, the markers were designed to represent the past conversations and events that were impressive for the subjects. These results suggest that there is a tendency for avatars and visual markers to be designed in a way that expresses personality and identifies the communicating partners, which could strengthen the connection between the communication partner and the avatar.

5.2. Impact of the design constraints

The opinion $O_{D,8}$ suggests that the constraint that the rectangular areas of the head and the body of an avatar should not be covered with accessories and visual marker inhibited more freedom in design. Another constraint claimed by the subjects was the size of the head and the body of the avatar ($O_{D,9}$). Visual markers that depict items usually used in the hand were attached to the hand of the avatar, while the items that were too unnatural to be held in the hand were attached to accessories so that they could be seen as patterns. This indicates that the subjects did their best to create a natural appearance within the constraints of the design, and they seem to be satisfied with the high degree of freedom in the design of the accessories and the visual markers so that they could represent the personality of communication partners and identify the partners. The benefit of the constraints can be seen in $O_{D,10}$ and $O_{D,11}$ that may contribute to reduce design parameters that the subjects need to consider.

5.3. Importance of ease of creation on the satisfaction with completed avatars

Section 4.2 showed that the level of satisfaction with the completed avatars was high, i.e., 4.45 (mean) and 4.5 (median). The opinions $O_{C,1}$ to $O_{C,3}$ imply that the level increased when the subjects thought that the completed avatar looked fine or that the subjects could create avatars as they imagined. This indicates, on the contrary, that the low level of completeness of the avatars leads to a decrease in satisfaction as indicated in $O_{C,5}$ to $O_{C,7}$. Cutting-out and/or folding the parts of an avatar was found to be a great burden by nine of ten subjects. In addition, the difficulty associated with these phases also affected the low level of completion perceived by the subjects. By contrast, only one subject felt the effort to assemble the folded parts. Since all subjects provided positive opinions in the creation process, we consider that it is necessary to support cutting-out and folding the parts to eliminate the degradation of the level of completeness, such as showing tips for cutting and assembly. Otherwise, the cutting-out phase could be automated if laser cutters become as common in our homes as printers.

As shown in Section 4.2, no significant difference was found in the evaluation of the user experience between Type 1 and Type 2. Thus, mere assembly of cut-out and folded parts seems effective for those who are not good at cutting out and folding parts. Furthermore, in this experiment, the unfolded diagrams were provided by the experimenter on behalf of the subjects to focus on the comparison of different degrees of the user involvement in the avatar; however, this task should also be burdensome and be automated in a way similar to computer-aided design (CAD). When deployed as a real service, a service that supports the user at various phases, i.e., designing avatars, generating unfolded parts diagrams, cutting out the parts, and folding the cut-outs, may highly satisfy the user with various levels of interest in handcraft and creating skills. Some users may just use the service to generate a unfolded parts diagram and print it out by a printer in their home, and other users may just assembly the cut out and folded parts sent by the service provider.

5.4. Impact of user involvement in the design and creation on the usage of avatars

As Figure 10 suggests, the percentage of time spent to use the avatar increased as the degree of involvement increased. The attachment to the avatar made by the user could emerge ($O_{C,4}$), and the user's preferences to the appearance of the avatar are likely to be reflected ($O_{D,3}$, $O_{D,4}$, and $O_{D,6}$), which could facilitate the subjects to use the avatar due to positive impressions to and interests in the avatars as reported in $O_{U,2}$. We can consider that making one's own avatar facilitates the subjects to look at the avatars and thus to recall the communication partners if we interpret the opinions $O_{U,5}$ and $O_{U,7}$ in light of these ideas,

Although the opinions $O_{U,3}$ and $O_{U,4}$ show a possibility that the subjects may use avatars that they did not make if they liked the appearances, the significant difference between Type 3 and Type 4 in the score of impression/interest in the avatars (Figure 11) emphasizes the importance of user's involvement, which is to choose the most appropriate avatar for specific communication partner in this case. As described above, designing the avatar may increase the possibility of meeting the user's preference in the appearance. Furthermore, the possibility of meeting "matched" ones increases when the user designs and creates them by him/herself. It should also be noted that, as $O_{U,1}$ suggests, frequent update of the communication partner's information is important from an application's perspective, regardless of whether the avatar was made by the subjects or not.

5.5. Demonstrating creativity

Palco has an aspect of creativity in that it offers the freedom of designing the appearance of avatars and assembling the parts into concrete avatars. The Creativity Support Index (CSI) [23] proposed six dimensions of creativity: collaboration, enjoyment, exploration, expressiveness, results worth effort, and immersion. We review the results from these six aspects.

In terms of *collaboration*, although we did not assumed in the design of the Palco system and did not evaluate such a case, we consider that the design and the creation can be done by multiple persons. In a family use scenario, a child and the parents can work together to design and create avatars representing their grandparents. There were mentions about the *enjoyment* in the feedback from the subjects. They felt a sense of enjoyment when thinking about the communication partners in the design ($O_{D,7}$) and when assembling the cut-out parts resulting in making them feel accomplished ($D_{C,8}$ to $D_{C,10}$). Regarding the *exploration*, the subjects tried to incorporate the characteristics such as appearances and hobbies within the design constraints ($O_{D,3}$ to $D_{D,6}$). *Expressiveness* was also confirmed as discussed in Sections 5.1 and 5.2, in which the subjects designed avatars with wide variety of appearances under the design constraints for the system so that they could reflect the communication partner as much as possible. Interestingly, not only standing avatars, but also a sitting avatar was designed ((d) in Figures 7 and 8). In terms of the aspect of *results worth effort*, the level of satisfaction with the design outcomes and the completed avatars was high, i.e., medians of 4.0 and 4.5, respectively. Although some subjects indicated the difficulty in drawing the avatar appearance ($O_{D,1}$ and $O_{C,7}$) as well as in cutting out, folding, and assembling the parts of an avatar to complete ($O_{C,5}$ and $O_{C,6}$), we consider that they were satisfied the results and felt their efforts had been rewarded. Meanwhile, no responses was obtained that indicated *immersion*; however, the fact that nine out of ten subjects felt burdensome in the creation process implies the presence of a factor that could inhibit immersion. As suggested in Section 5.3, a service that supports the user at various phases may highly satisfy the user with various levels of hand-creating skills. Overall, we consider that the design and creation processes in Palco system allowed the subjects to demonstrate their creativity, in which three dimensions from CSI, i.e., *enjoyment*, *expressiveness*, and *results worth effort*, were confirmed, while *immersion* could be enhanced by providing various levels of crafting support depending on the skills of handcrafts.

6. Conclusion

In this article, we carried out a user study to investigate the effect of user-generated printable avatars for loose communication with remote partners, which was conducted by augmenting the Palco v1 system with multi-avatar identification and information projection. In the user study, the subjects used avatars with different degree of involvement ranging from sketching the appearance, cutting out parts, assembling the cut-outs, and using the completed ones to just using ones specified by the experimenter.

As a result, the subjects could reflect the personalities and the characteristics of the communication partner in the appearance of the avatar. The process of creating the designed avatars allowed the subjects to have a sense of accomplishment and attachment to the avatars. We found that attachment to the avatar, the degree of matching between the avatar's appearance and the partner's characteristics, and the design preference had an effect on increasing the time spent to use the avatar and the impression of/interest in the avatar. Furthermore, more frequently used and more interesting avatars tended to produce more favorable effects on the partner, such as recalling the partner's current state. We believe that the handcrafted avatar has a potential to serve as a communication medium that increase the emotional bonding between the communication partner. In addition, the experiences in the design and creation of Palco avatars allowed the users to demonstrate their creativity.

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