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# I'm Transforming! Effects of Visual Transitions to Change of Avatar on the Sense of Embodiment in AR

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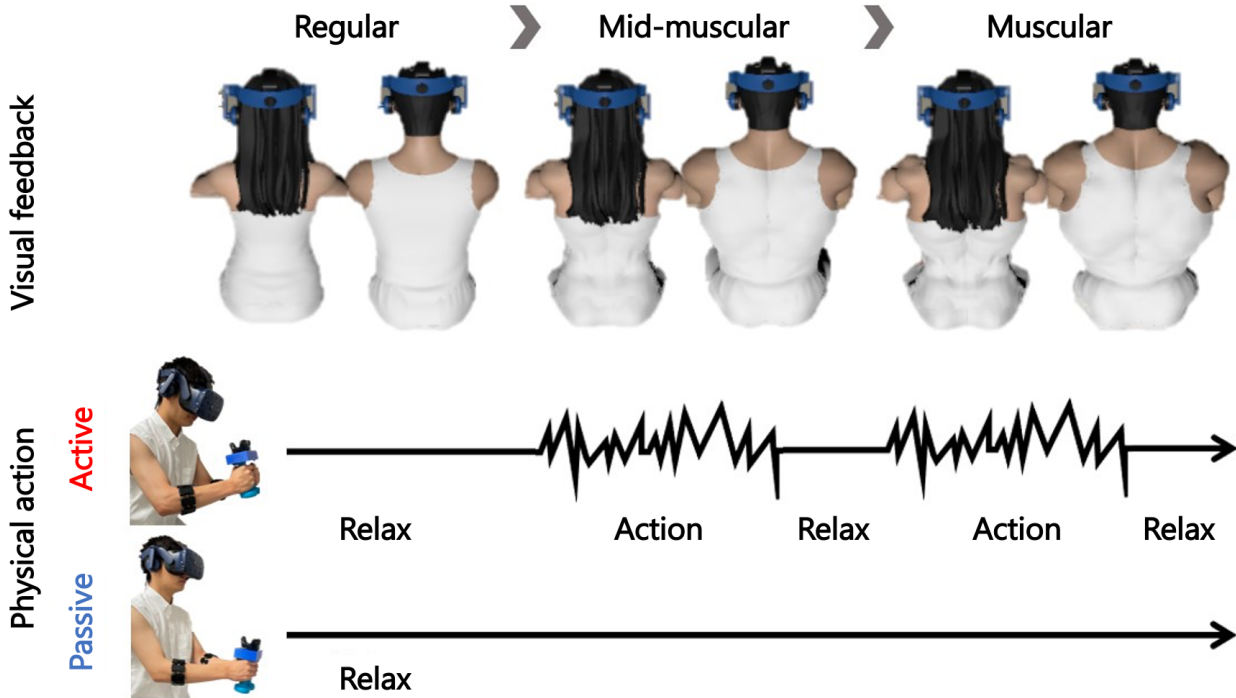


Fig. 1. Illustration of the visual transitions we implemented to change the appearance of one's avatar. *Visual feedback*: during the transition, the user can see their avatar transforming progressively from a regular-shaped body to a muscular-shaped one. *Physical action*: to be experienced, this transition can be either triggered by the user through physical action (active) or launched automatically (passive).

**Abstract**— Virtual avatars are more and more often featured in Virtual Reality (VR) and Augmented Reality (AR) applications. When embodying a virtual avatar, one may desire to change of appearance over the course of the embodiment. However, switching suddenly from one appearance to another can break the continuity of the user experience and potentially impact the sense of embodiment (SoE), especially when the new appearance is very different. In this paper, we explore how applying smooth visual transitions at the moment of the change can help to maintain the SoE and benefit the general user experience. To address this, we implemented an AR system allowing users to embody a regular-shaped avatar that can be transformed into a muscular one through a visual effect. The avatar's transformation can be triggered either by the user through physical action ("active" transition), or automatically launched by the system ("passive" transition). We conducted a user study to evaluate the effects of these two types of transformations on the SoE by comparing them to control conditions where there was no visual feedback of the transformation. Our results show that changing the appearance of one's avatar with an active transition (with visual feedback), compared to a passive transition, helps to maintain the user's sense of agency, a component of the SoE. They also partially suggest that the Proteus effects experienced during the embodiment were enhanced by these transitions. Therefore, we conclude that visual effects controlled by the user when changing their avatar's appearance can benefit their experience by preserving the SoE and intensifying the Proteus effects.

**Index Terms**—Avatar, transition, embodiment, physiological activity, augmented reality

## 1 INTRODUCTION

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Virtual avatars are more and more often featured in Virtual Reality (VR) and Augmented Reality (AR) applications. Their growing presence increases the importance of making users feel comfortable within their virtual bodies by ensuring a strong sense of embodiment (SoE). When users have the sensation that their avatars have become their real bodies, they sometimes experience a phenomenon called the Proteus effect characterized by changes in the user's behaviour and self-perception. This effect can benefit the user's abilities even after the end of the avatar's embodiment [67].

Research has shown that Proteus effects are tightly linked to the implicit stereotypes carried by the avatar's appearance. For example, embodying a taller avatar was shown to lead users to behave more confidently during a negotiation task [67]. Embodying a muscular-shaped avatar was found to improve the user's physical performance [42]. In order to benefit from these diverse enhancements in the real world, one could imagine using an AR embodiment system enabling the switch between these different avatars at will.

However, abruptly switching avatars may disrupt the continuity of the embodiment experience and impact the SoE. In addition to this, it is not guaranteed that the new avatar will be able to evoke an as strong SoE. Indeed, previous work has often shown that this ability varies highly depending on users and avatars [7]. Although how the avatar's appearance impacts the SoE is still not completely clear, more and more work suggests that this might be linked to the avatar's appearance as those that differ a lot from their users tended to produce weaker embodiment illusions [8, 19, 40, 66].

In this paper, we propose to address these issues by implementing visual transitions at the moment of the avatar's change. We designed a system letting users smoothly transition from one avatar to another through visual effects. Our approach relies on AR to display the avatar in the third-person perspective so that the user can fully witness the transformation within a real-world context. In order to launch the transformation, we explored two approaches: one where the user is in charge of triggering the transition through a specific action (referred to as an "active" transition), and one where the user sees the avatar change automatically ("passive" transition).

To evaluate the effects of these transitions on how the SoE evolves when switching avatars, we ran a user study where the user goes from an avatar with a body similar to their own to a highly muscular-shaped avatar. According to previous work [42], the muscular-shaped avatar could be expected to evoke a lower SoE than the regular-shaped one due to its diverging appearance, but to still induce Proteus effects in the form of increased physical strength during a physical task. We hypothesized that applying a smooth transition through our system would allow maintaining the SoE at the level of the regular-shaped avatar when switching to the muscular-shaped avatar. As a consequence, we imagined that the resulting Proteus effects could be enhanced compared to a control condition where visual transitions were not applied.

Our results suggest that applying active visual transitions, compared to passive ones, can benefit the stability of the SoE when switching avatars. They also partially support that Proteus effects induced by a muscular-shaped avatar were enhanced thanks to this transition. In particular, our contributions can be summarized as follows:

- We present a novel AR system providing an end-to-end embodiment experience starting from being in one's real body to embodying different types of avatars in the third-person perspective before returning to one's real body.
- We present a user study investigating the effects of applying visual transitions when changing one's avatar on the evolution of the SoE and Proteus effects.

## 2 RELATED WORK

This section details the previous work on visual transitions, embodiment, and the Proteus effect that inspired our work. We also describe how AR and VR have been employed to improve user physical performance through avatars.

### 2.1 Visual transitions

Several types of transitions for avatars have been investigated in the past. In VR research, transitions were previously designed to provide a smooth experience when entering an immersive virtual environment [20, 56]. For example, Sproll et al. (2013) created a transition method staged in five steps for the user to switch from their own body in the real environment to being inside an avatar's body within a virtual environment [56]. Previous studies that tested transitions between a virtual replica of the real environment and a virtual world showed improved subjective user experience and sense of presence [55, 57, 58].

Transitions were also previously implemented to switch from one virtual body to another [18, 59]. Dynamic morphing can be used to apply changes to virtual content over time in a smooth way. When slow enough, the changes can even go unnoticed by the user. This is of particular interest when trying to maintain a continuous, coherent experience of avatar embodiment, as shown by Jung et al. (2020) [18].

Lastly, previous research explored the use of transitions to change the user's visualization perspective from the first-person perspective (1PP) to the third-person perspective (3PP). Such kind of change is valued in applications like video games to extend the user's spatial awareness of their surroundings. In VR games, the 1PP helps players to focus on in-game action and enhances involvement, whereas the 3PP shifts their focus to the player character and game interaction [9]. Transitioning between these two perspectives allows users to benefit from both points of view without being disoriented [5, 11, 17]. Debarba et al. (2017) tested three approaches using different types of camera movements and found that very fast linear translation of the camera with a slightly blurred vision was optimal in terms of user experience and cybersickness [11]. However, none of the transitions mentioned above was evaluated within an AR context and little is known about their effects on the SoE.

In this research, we combine several types of transitions and evaluate the effects of using them to switch of avatar on the SoE in AR for the first time.

### 2.2 Sense of embodiment

Extensive previous work has shown that it is possible to experience an SoE toward another body than our own, referred to as a body ownership illusion. The most famous example illustrating this is perhaps the rubber hand illusion, during which a rubber hand is perceived as one's real hand thanks to synchronous visuotactile stimulation [2, 30, 64, 65]. This illusion was shown to work in VR environments using VR hands [48, 53, 61–63, 68], and eventually with full-bodied avatars [4, 23, 32, 46].

Many studies have attempted to improve the understanding of how these illusions work through the assessment of the SoE [10, 13, 14, 22, 39]. They generally focused on three sub-components of this sense: (1) the sense of agency, (2) the sense of ownership, and (3) the sense of self-location [22]. These studies revealed that multiple inter-dependent factors could impact these individual senses including the avatar's appearance, degree of control, and embodiment point of view [10]. In particular, some studies on the avatar's appearance have found that it was preferable to use cartoonish or non-human avatars compared to realistic human ones due to the Uncanny Valley effects that they cause [31]. However, several recent papers contrast with these results and suggest a more intricate relationship with the SoE: in these studies, avatars that differ a lot from the appearance of their users tended to result in weaker body ownership illusions [8, 19, 40, 66].

Regarding the impact of the user's point of view, many VR researchers feel that the 1PP is superior to the 3PP in inducing the SoE [15, 17, 32–34, 45, 52, 54]. However, multiple VR studies showed that using a 3PP can also provide strong body ownership illusions [6, 11, 13, 14, 27, 28, 47]. Gorisse et al. (2017) notably found that the 3PP can provide the same amount of agency as the 1PP [13]. Other studies also found that the senses of ownership and self-location could be improved by the 3PP under multi-sensory congruence conditions where the user feels haptic feedback synchronized with a VR scene [27, 28, 47]. However, little research exists to confirm these results in AR.

The recent review of Genay et al. (2021) highlighted that using AR for body ownership illusions presents specific challenges that make the induction of the SoE within it particularly difficult [12]. These challenges include having to deal with the user’s real body visibility, the contrasting rendering of real and virtual things, and the tracking errors and latency that are easier to notice than in VR, especially in the 1PP. As integrating the avatar into the real world cannot be done perfectly with current technologies yet, we had the feeling that AR setups might have even further interest in having visual transitions to mitigate the potential effects of discrepancies resulting from current system limits. This participated to our decision of focusing on AR.

### 2.3 The Proteus effect of muscular avatars

The Proteus effect describes a phenomenon where users “conform to the behaviour that they believe others would expect them to have” while embodying an avatar [67]. This effect has been intensively studied in VR since Yee and Bailenson coined the term in 2007. A meta-analysis of the Proteus effect found that it occurs at different levels [50] and that self-similarity increases the effect [43]. On the other hand, it was rarely studied in AR due to the technical challenges mentioned previously.

Several VR papers have investigated using the Proteus effect to increase the user’s physical strength [24]. Kocur et al. (2020) found that participants embodying muscular-shaped avatars had a lower perceived exertion during an isometric force task [25]. They also found that such avatars could influence the user’s heart rate [24]. Osimo et al. (2015) showed that the Proteus effect led to cognitive changes by using an avatar that looks like Sigmund Freud [41]. Lin et al. (2021) further found that such effects can be obtained during actual physical exercises even after the embodiment of the muscular-shaped avatar ended [29]. The effect of embodiment time on the impact of the Proteus effect was also proposed by hypothesising that the longer users embody an elderly avatar, the slower they will walk in VR [26]. The study of Otono et al. (2022) is the only one to have investigated these Proteus effects in AR. They found that similar results could be replicated in 3PP AR as their results show the user’s physical performance was improved during and after embodying a muscular-shaped avatar [42].

The present research replicates previous work demonstrating that a muscular-shaped avatar can improve physical performance. We use this paradigm to test if this improvement can be further increased when using visual transitions to embody a muscular-shaped avatar.

## 3 TRANSITION SYSTEM

In the study, we aimed to address our research question of how visual transitions impact a user’s SoE and the Proteus effect through end-to-end avatar embodiment experience in AR. To do that, we created a 3PP AR embodiment system that combines several types of transitions at different stages of the embodiment. First, as suddenly seeing the world from a 3PP can be unsettling, we implemented a visual transition allowing users to switch perspectives with a fast camera translation. We refer to these as perspective transitions. Second, instead of directly displaying the user’s avatar in front of them, we propose to let them first see the 3D mesh of their real bodies before gradually fading into the avatar (regular-shaped). Next, the user may switch from this avatar to another one (muscular-shaped) through a visual transition that gains an avatar’s muscle. Finally, users are able to return to their real bodies through the same process the other way around. Figure 5 shows a detailed timeline of these different phases.

To trigger the transitions between two virtual avatars, we explored two approaches :

- **Active transitions:** in this approach, the user may trigger the change of appearance by performing a physical action (squeezing dumbbells). They control the progress of the transformation thanks to visual feedback synchronized with their action.
- **Passive transitions:** the change of avatar is performed automatically by the system and the user witnesses its progress without controlling it.

Both of these approaches can be interesting depending on the targeted embodiment experience or context. For instance, when designing a game that involves physical exertion, one could desire to make the user’s avatar appearance evolve based on the physical activity of the player (e.g., in a fitness game like Ring Fit Adventure on Nintendo Switch, it would become more and more athletic). In other situations such as when simply exploring different avatar appearances for personalization done later, passive transitions could be preferred.

### 3.1 Implementation

The system we present was implemented using Unity (2019.3.11f) and ran on a Windows 10 computer equipped with an NVIDIA GeForce GTX 1080 Ti graphics card. We used an HTC VIVE Pro Eye<sup>1</sup> head-mounted display (HMD) to display the avatars and visual transitions.

**Avatars.** The 3D mesh of the user’s real body is captured with the help of an RGB-D camera (Microsoft Azure Kinect<sup>2</sup>) and overlaid onto the 360 videos. The Azure Kinect DK was positioned right next to the RICOH THETA V. The 3D models we used to test visual transitions between avatars were regular-shaped female and male avatars and their muscular-shaped versions (Fig. 2). They were designed based on the average Japanese body size using Daz3D<sup>3</sup>, from the characters “Genesis 8 Female” and “Genesis 8 Male”.

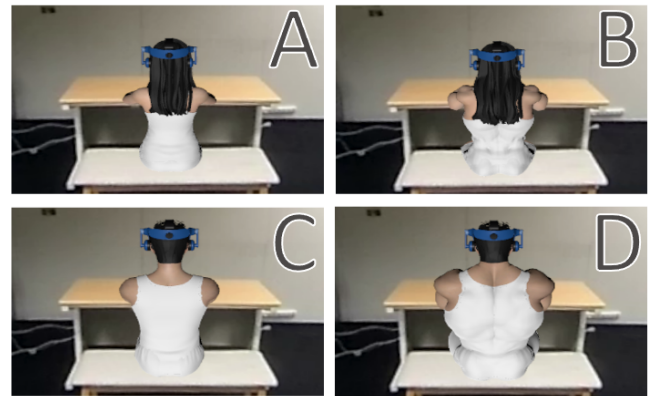


Fig. 2. The upper left (A) and right (B) are female regular- and muscular-shaped avatars, respectively. The bottom left (C) and right (D) are male regular- and muscular-shaped avatars, respectively.

**Arm tracking.** To track the user’s arm movements, users were asked to hold onto an object equipped with an HTC VIVE tracker (3.0)<sup>4</sup>. This object joined two 1-kg weights together with a plastic piece so that the user had to grasp both weights to lift it (see Fig. 4).

**Active transition trigger.** Users were required to wear Myo armbands (Thalmic Labs), a wearable electronic device that detects a user’s hand gestures through sEMG [1, 35, 36, 60]. These sensors were worn on their forearms and captured real-time sEMG values from the extensor carpi ulnaris (ECU) muscle at 50 Hz through Bluetooth. The user’s squeezing action could then be detected based on the real-time sEMG values.

In addition to these Myo armbands, we used a Shimmer3 EMG unit<sup>5</sup> for offline analysis of the sEMG magnitude at 512 Hz through Bluetooth.

**AR visualisation.** While wearing the HMD, users could observe the real world around them in the 1PP through a stereo camera attached to the HMD (ZED Mini<sup>6</sup>). The 3PP, on the other hand, was provided

<sup>1</sup><https://www.vive.com/nz/product/vive-pro-eye/overview/>

<sup>2</sup><https://azure.microsoft.com/en-us/products/kinect-dk/>

<sup>3</sup><https://www.daz3d.com/>

<sup>4</sup><https://www.vive.com/nz/accessory/tracker3/>

<sup>5</sup><https://shimmersensing.com/product/shimmer3-emg-unit/>

<sup>6</sup><https://www.stereolabs.com/zed-mini/>

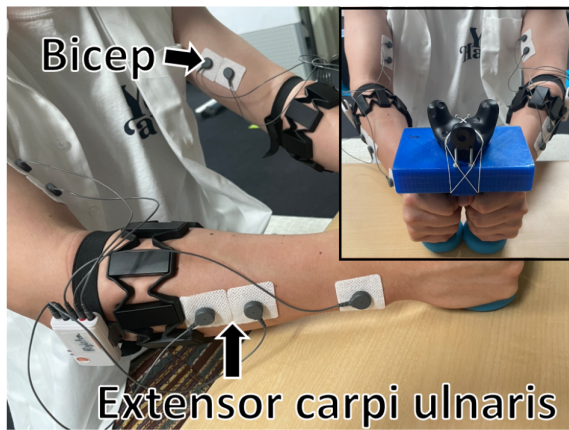


Fig. 4. The sEMG sensor electrodes were attached to the user's ECUs and biceps. Participants held the dumbbells with both hands. The tracker was mounted on the dumbbell pair to track the user's arm movement.

thanks to real-time 360 videos captured by a RICOH THETA V camera<sup>7</sup> positioned 1.5 meters above the ground and about two meters behind users.

### 3.2 Perspective transitions

The transition between the 1PP and the 3PP was achieved by moving the virtual camera from the user's 3D mesh head position to the centre of a virtual sphere onto which the real-time 360 videos of the environment were rendered (see Fig. 3).

When going from the 1PP to the 3PP, the real-time video of the stereo camera zooms out first. Then, the virtual camera moves back to the centre of the virtual sphere rendering the real-time 360 videos. When going from the 3PP to the 1PP, the virtual camera moves forward from the centre of the virtual sphere to the avatar's head first. Then, the real-time video of the stereo camera zooms in. Each perspective transition takes 10 seconds to be achieved.

### 3.3 Transitions from a user mesh to a regular-shaped avatar

Once in the 3PP, users can view the 3D mesh of their real bodies and see it change into a regular-shaped avatar through the 360 real-time videos. The 3D mesh is generated from depth data retrieved with the Azure Kinect development kit, as done in previous work [38]. The transition to the regular-shaped avatar is done by gradually lowering the number of vertices in the mesh to display a "dissolving" effect. At the same time, the regular-shaped avatar is gradually made visible, from fully transparent to fully opaque.

<sup>7</sup><https://theta360.com/en/about/theta/v.html>

Lastly, to avoid the user's actual body image being caught by the 360 camera, a portion of the 360 images was substituted with a static image taken beforehand. Regarding the 3D mesh, using depth-based background subtraction, only the user's actual body is rendered on the 360 video.

### 3.4 Transitions from a regular- to a muscular-shaped avatar

We change the regular-shaped avatars into muscular ones by adjusting morph targets<sup>8</sup>. The avatar's body weights (ABW) of the female and male regular-shaped avatars are estimated using the formula of Buckley et al. (2010) [3]. For the regular-shaped avatar, the height and weight are 160.1 cm and 53.8 kg for a female, and 173.5 cm and 71.6 kg for a male. For the muscular-shaped avatar, the weight is 77.4 kg for a female and 97.8 kg for a male (the height remained the same). As a result, the muscular-shaped avatars are approximately 40% heavier than the regular-shaped ones.

**Active transitions.** To make their avatar become muscular, users have to repeat the physical actions of firmly squeezing the dumbbell pair and then relaxing while still holding it. While doing this, the avatar appears to become more muscular every time they squeeze. This is referred to as the "visual feedback" of the transformation. The avatar's muscularity increased by 20% when the sEMG values exceeded the 1.5 times users' average values, which are measured beforehand. After the users flex their muscles up to five times, the avatar's body reaches its maximum muscle mass.

**Passive transitions.** In this case, the users could see their avatar's body becoming more muscular without any action on their part. Their avatar gained 20% of muscle mass every five seconds and reached its maximum muscle mass after 30 seconds, which was about the same time required by an active transition.

## 4 USER STUDY

Through this user study, we investigated the effects of using visual transitions when changing from a regular- to a muscular-shaped avatar on the SoE and potential Proteus effects.

### 4.1 Experimental design

To check the effects of such transitions on the SoE, we needed at least 2 conditions: a control condition without any transition, and a test condition where a visual transition was applied. As we were interested in comparing the effects of both active and passive transitions, we decided to split our test condition into two separate ones ("physical action" factor).

Additionally, it appeared to us that we would need to investigate how visual feedback, which allows a user to observe their regular-shaped

<sup>8</sup><https://www.daz3d.com/massive-morphs-for-genesis-8-male>,  
<https://www.daz3d.com/massive-morphs-for-genesis-8-female-s>

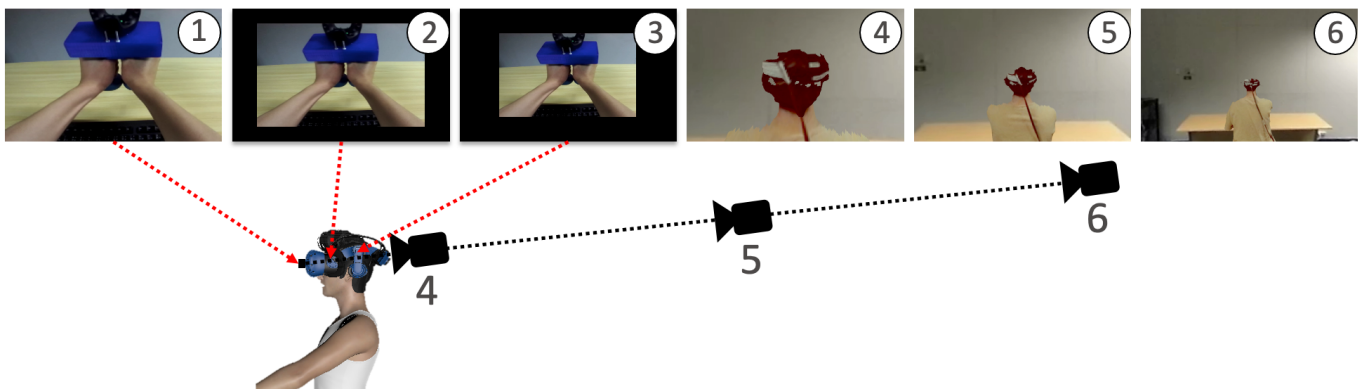


Fig. 3. The path of a virtual camera looking at the avatar and the corresponding view. The user is in the 1PP at the beginning (1 to 3), then in the 3PP (4 to 6) in transitions from the 1PP to the 3PP. The user gets through the reverse path in transitions from the 3PP to the 1PP.

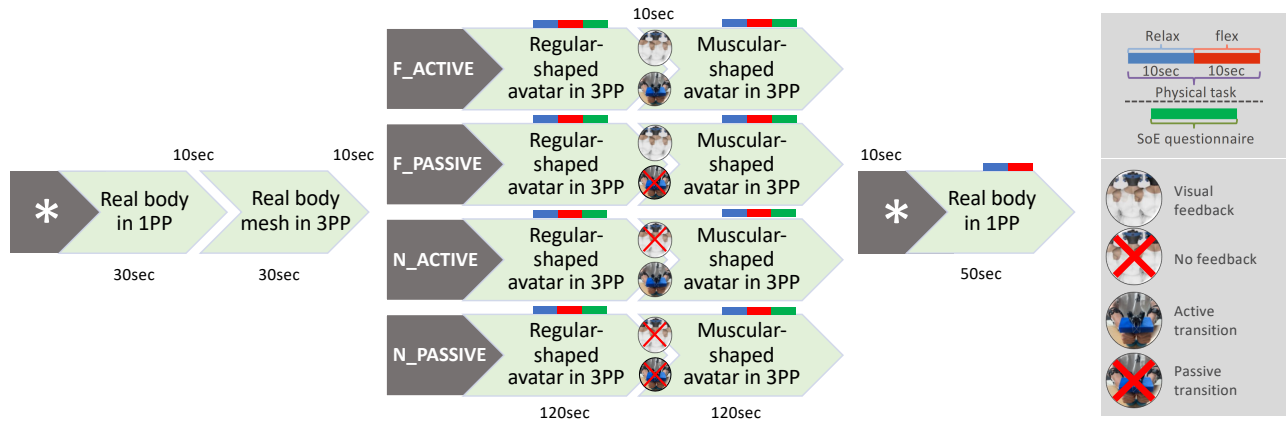


Fig. 5. The experimental procedure. This figure details the timing of tasks in each condition, including the users’ viewpoint, self-report, and sEMG magnitude measurements.

avatar appearance gradually change to the muscular-shaped one, impacts the difference in the SoE and the intensity of the Proteus effect. Therefore, it seemed that the presence/absence of visual feedback during an avatar’s appearance change could be one variable to include in our experiment (“visual feedback” factor).

Consequently, we performed a cross-evaluation of  $2 \times 2$  (visual feedback vs. no feedback  $\times$  active transition vs. passive transition). To do so, we designed four conditions applied in a within-subjects design:

- **Condition F\_ACTIVE**: with visual feedback and an active transition. The user observes their avatar’s appearance progressively become more muscular through their actions.
- **Condition F\_PASSIVE**: with visual feedback and a passive transition. The appearance of the user’s avatar automatically gains muscle without any physical effort from the user.
- **Condition N\_ACTIVE**: with no visual feedback and an active transition. The user repeats the physical action, yet their view is masked by a black screen until the end of the transformation.
- **Condition N\_PASSIVE**: with no visual feedback and a passive transition. The user’s view is masked by a black screen and they wait for 30 seconds without doing anything to see their new avatar.

All subjects experienced all of four conditions, but the order of the conditions was counterbalanced with a Latin-squares design to remove any order effects.

## 4.2 Measures

We used self-report questionnaires to gauge the SoE across avatars and conditions. We also evaluated potential Proteus effects by measuring the magnitude of the sEMG.

### 4.2.1 Sense of embodiment

The participants were asked to answer six questions on a 7-point Likert scale, relating to different components of the SoE (see Table 1). The questions were taken from a study investigating 3PP avatar embodiment and allowed computing scores for the sense of agency, body ownership, and self-location [11]. To measure the difference in the SoE between regular- and muscular-shaped avatars, we needed the participants to answer the SoE questionnaire while embodying each avatar (i.e., two times per condition, and eight times in total through one experiment). To do so, we displayed the questionnaire virtually in front of them and used the eye-tracking system embedded in the HMD to allow them to answer the questions without removing their hands from the dumbbells (see Fig. 6). Participants could choose the number best representing their experience using a virtual ray controlled by their eye-gaze. To confirm their answer, they had to keep looking at the same number for 3.0 seconds.

Table 1. The items of SoE self-report based on Debarba et al. (2017) [11]. Answers were on a 7-point Likert scale ranging from 1 (completely disagree) to 7 (completely agree).

Item number	Category	Question
Q1	Agency	It felt like I was in control of the body I was seeing.
Q2	Agency	Whenever I moved my body I expected the virtual body to move in the same way.
Q3	Ownership	I felt as if I was looking to my own body.
Q4	Ownership	It felt that virtual body was my own body.
Q5	Self-location	It felt as if my body was located where I saw the virtual body to be.
Q6	Self-location	It seemed as if I were sensing the movement of my body in the location where the virtual body moved.

As mentioned in Section 2.2, previous research suggests that avatars whose appearance differs a lot from the user tend to induce a weaker SoE [8, 19, 40]. Therefore, we expected that in our control conditions, the SoE would naturally decrease from the moment the user embodied the regular-shaped to the one they embodied the muscular-shaped avatar. Therefore, to verify whether applying transitions could help maintain a constant (or less diverging) SoE, we computed the differences in SoE scores before and after changing the avatar’s appearance for each condition. We subtracted each SoE component score of the regular-shaped avatar from the corresponding score of the muscular one using the following equation:

$$\Delta Q_N = score(Q_N)_{muscular} - score(Q_N)_{regular} \quad (1)$$

$$\Delta_{Agency} = (\Delta Q_1 + \Delta Q_2)/2 \quad (2)$$

$$\Delta_{Ownership} = (\Delta Q_3 + \Delta Q_4)/2 \quad (3)$$

$$\Delta_{Self\_Location} = (\Delta Q_5 + \Delta Q_6)/2 \quad (4)$$

In the above,  $N = 1, 2, \dots, 6$ ,  $score(Q_N)_{muscular}$  is the answer of the  $N$ th question when embodying the muscular-shaped avatar, and  $score(Q_N)_{regular}$  is the same for the regular-shaped avatar.

Participants are most likely to answer the second SoE questionnaire relative to the first one. Therefore, we expected such a measure would be more sensitive to how the SoE varied based on the transition applied. Additionally, we had the intuition that the active transitions would provide a higher sense of agency than the passive condition (as the user controls the transformation), and therefore generate a superior embodiment. Our hypotheses can be summarized as follows:



Fig. 6. The users view while answering the question with eye-gaze interaction.

**H1.1** F\_ACTIVE and F\_PASSIVE will provide a higher  $\Delta_{Agency}$ ,  $\Delta_{Ownership}$ , and  $\Delta_{Self\_Location}$  than N\_ACTIVE and N\_PASSIVE.

**H1.2** F\_ACTIVE will provide a higher increase in  $\Delta_{Agency}$ ,  $\Delta_{Ownership}$ , and  $\Delta_{Self\_Location}$  than F\_PASSIVE.

#### 4.2.2 sEMG magnitude

As suggested by previous work [29, 42], we assumed that embodying a muscular-shaped avatar would lead to Proteus effects consisting of users applying more strength during a physical task. Therefore, we included a physical task in all conditions to monitor the presence of such effects. The task consisted in grabbing the dumbbell pair as tightly as possible for 10 seconds. In each condition, participants were asked to perform this task three times: during the embodiment of the regular-shaped avatar, of the muscular-shaped avatar, and after the embodiment.

We captured the sEMG magnitude during the tasks over Bluetooth (512 Hz) thanks to the sensors attached to the ECU and biceps muscles (see Fig. 4). This allowed us to evaluate the user's physical performance across avatars and conditions. After the experiment, the acquired sEMG values were band-pass filtered from 25 to 200 Hz and the root means square (RMS) was calculated using a sliding window of 100 milliseconds following the methodology used in the study of Perusquía-Hernández et al. (2021) [44].

The period when participants contracted their muscles during the physical task was analyzed using nine-second epochs. The first second after the beep signal indicating when to start squeezing was removed to exclude the transient section of the sEMG for the duration of the beep (1 second). The timing of the beep signal and the Shimmer3 EMG data capture were synchronized using a hardware trigger sent via the serial port from Unity. The average RMS activity was calculated per epoch, and the ratio of the average RMS activity was calculated as the normalized sEMG magnitude. The normalized RMS activity when embodied in a muscular-shaped avatar ( $EVR_{during}$ ), and after embodiment ( $EVR_{after}$ ) was considered using the following equation:

$$EVR_{during} = \frac{EMG_{muscular}}{EMG_{regular}} \quad (5)$$

$$EVR_{after} = \frac{EMG_{after\_embodiment}}{EMG_{regular}} \quad (6)$$

where  $EMG_{regular}$  is the average RMS during embodiment in the regular-shaped avatar,  $EMG_{muscular}$  is the average RMS during embodiment in the muscular-shaped avatar, and  $EMG_{after\_embodiment}$  is the average RMS after embodiment.

The average of the dominant hand's ECU's  $EVR_{during}$  and the bicep's  $EVR_{during}$  was calculated as the dominant hand's  $EVR_{during}$ . The average of the non-dominant hand's ECU's  $EVR_{during}$  and the bicep's  $EVR_{during}$  was used as the non-dominant hand's  $EVR_{during}$ . In the same way, the dominant hand's  $EVR_{after}$  and the non-dominant hand's  $EVR_{after}$  were calculated using the  $EVR_{after}$  of dominant hand's ECU

and bicep, and the  $EVR_{after}$  of non-dominant hand's ECU and bicep respectively.

We hypothesized that using transitions with visual feedback from a regular- to a muscular-shaped avatar would enhance the potential Proteus effect as the SoE is assumed to be increased. Thus, the user's physical performance would be higher during the embodiment of the muscular-shaped avatar compared to the control conditions at equivalent moments. We also hypothesized that applying transitions with visual feedback would allow prolonging the Proteus effect after embodiment ended, as shown possible in prior research [29, 42]. Lastly, we expected that visual feedback synchronized with an active transition would boost the impact of the Proteus effect more than with a passive transition. The hypotheses about the sEMG magnitude measures can be summarized as follows:

**H2.1** F\_ACTIVE and F\_PASSIVE will result in increases of  $EVR_{during}$  for both dominant and non-dominant hands.

**H2.2** F\_ACTIVE will further enhance both dominant and non-dominant hands'  $EVR_{during}$  than F\_PASSIVE.

**H3.1** F\_ACTIVE and F\_PASSIVE will result in increases of  $EVR_{after}$  for both dominant and non-dominant hands.

**H3.2** F\_ACTIVE will further enhance both dominant and non-dominant hands'  $EVR_{after}$  than F\_PASSIVE.

#### 4.3 Procedure

The experiment started by collecting the informed consent form signed by the participant. They were then asked to complete a demographics questionnaire retrieving data on their body weight and previous VR experience. To match the avatar's clothing, the participants were then instructed to wear a white sleeveless shirt. Participants were then equipped with a Shimmer3 EMG sensor and a Myo sensor on each of their arms (see Fig. 4). After that, the experimenter gave a brief introduction to the goal of the experiment and their task. We highlighted that the participants could withdraw from the experiment at any time without penalty or losing their monetary reward.

Next, we collected baseline Myo sensors values to allow comparing the sEMG data while embodying the avatar in the analysis. To do so, participants were instructed to sit in the centre of the bench and hold the dumbbell pair for 10 seconds twice. In the first measurement, participants were asked to relax while holding the dumbbells for 30 seconds, while in the second measurement, they were asked to hold the dumbbells as tightly as possible for 30 seconds. After that, eye-tracking calibration was carried out and participants took a break for two minutes. Then, the experimenter launched the experimental software on the HMD in video see-through 1PP mode (i.e., using the Zed Mini cameras) and asked the participant to wear it. At this point, the user could see an AR view of the experimental room. They were asked to look around while passively holding the dumbbell pair.

The main part of the experiment started from here, following the steps described in Fig. 3. After 30 seconds in the 1PP, the perspective transition was triggered to switch to the 3PP. Participants could then observe their real bodies as a 3D mesh in front of them. They were asked to look around again and catch the experimenter waving at them on the right to further show that the scene was live.

After 30 seconds in the 3PP, the real-body mesh dissolved to transition to a generic regular-shaped avatar matching the participant's gender. The participant was instructed to look around and lift the dumbbell pair up and down twice. This allowed the participants to confirm that their avatars moved synchronously with them. Then, the participant went through a physical task during which they had to contract their muscles upon hearing three "beep" sounds, separated by 10 seconds. The first beep sound indicated that the participant should get ready while relaxing their arms. After the second beep sound, they had to hold the dumbbells as tightly as possible until the third beep sound occurred. Following this, participants could relax again and were asked to answer the SoE questionnaire displayed in front of them using eye-gaze interaction (see Fig. 5).

Depending on the condition, the participant then saw (or not) their regular-shaped avatar morph into a muscular one, either through an active transition or a passive one as described in Section 3.4. Participants performed the physical task again and completed the SoE questionnaire once more while observing their muscular-shaped avatar. After that, participants returned to the IPP through a perspective transition, looked around, and went through the same physical task again. They could then remove the HMD and had a two-minute break to rest before starting all over for the next condition. Once all conditions were finished, participants provided feedback and received their reward.

#### 4.4 Participants

A total of 32 volunteers (16 females) were recruited via university mailing lists. Participants aged between 21 and 35 years old ( $M = 24.94$ ,  $SD = 3.40$ ) took part in this study. All but three of the participants were right-handed, and 22 participants had experienced VR at least once. Each participant was paid 1000 JPY as a reward.

### 5 RESULTS

Our analysis covered the parameters summarized in Table 2. Shapiro-Wilk tests showed that the (subtracted) SoE scores and sEMG data deviated from the normal distribution. Therefore, all of the parameters were analysed using Friedman tests followed by Wilcoxon signed-rank posthoc tests. A  $p$ -value less than 0.05 was considered statistically significant. Fig.7 provides descriptive information on these parameters.

Table 2. The list of parameters' definitions.

Parameter	Definition
$\Delta_{Agency}$	How much sense of agency for avatar is maintained.
$\Delta_{Ownership}$	How much sense of ownership for avatar is maintained.
$\Delta_{Self\_Location}$	How much sense of self-location for avatar is maintained.
$EVR_{during}$	Normalized sEMG magnitude during embodiment.
$EVR_{after}$	Normalized sEMG magnitude after embodiment.

#### 5.1 Assumption checks

We expected that the muscular-shaped avatar would induce a lower SoE based on previous studies [8, 19, 31, 40, 66]. To verify this, we compared its absolute SoE scores with that of the regular-shaped avatar in the control condition (N\_PASSIVE). A Wilcoxon signed-rank test showed that the ownership score for a muscular-shaped avatar was indeed significantly lower than for a regular-shaped one ( $p < .05$ ), while other scores were not significantly different (agency:  $p = .50$ , self-location:  $p = .20$ ).

From previous work [25, 29, 42], we also assumed that the muscular-shaped avatar would induce a Proteus effect characterized by users employing greater force during physical tasks. To check whether this was the case, we compared the absolute sEMG values collected during and after the embodiment of the muscular-shaped avatar to during the embodiment of the regular-shaped one. As a result, we found that the EMG magnitude of right bicep muscle was significantly higher when users embodied in the muscular-shaped avatar than during the embodiment toward the regular-shaped one ( $p < .05$ ). Therefore, our assumption that the Proteus effect of the muscular-shaped avatar was partially supported. However, we could not find significant difference in the sEMG values between the regular avatar and after embodiment.

#### 5.2 Sense of embodiment

The Friedman test revealed the existence of significant differences in  $\Delta_{Agency}$  ( $\chi^2(3, n = 32) = 29.27, p < .001$ ). A Wilcoxon signed-rank test showed that these significant differences were between F\_ACTIVE and F\_PASSIVE ( $p < .05$ ) and F\_ACTIVE and N\_ACTIVE ( $p < .001$ ), with F\_ACTIVE providing a superior sense of agency. Differences were also found between N\_ACTIVE and N\_PASSIVE ( $p < .001$ ), with N\_PASSIVE providing a superior agency (see Fig. 7, left).

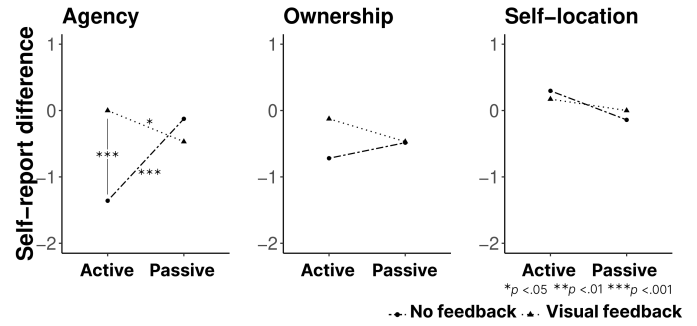


Fig. 7. From left to right, the results of agency difference ( $\Delta_{Agency}$ ), the difference of ownership ( $\Delta_{Ownership}$ ), and the difference of self-location ( $\Delta_{Self\_Location}$ ). The result of ( $\Delta_{Agency}$ ) (Left) shows that visual feedback helped keep the sense of agency when an active transition was applied and an active transition with visual feedback retained the sense of agency more than a passive one with visual feedback.

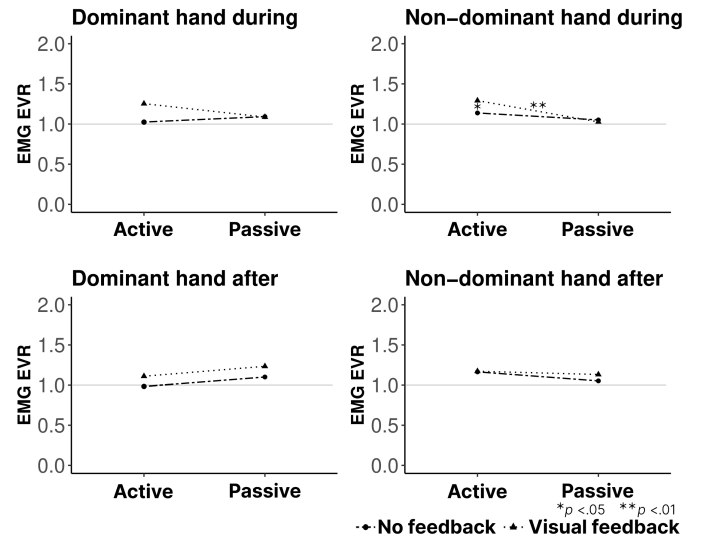


Fig. 8. Upper plots depict the measurements during the embodiment. Lower plots depict the activity after the embodiment. Dominant and non-dominant hands' results are presented separately. The result of the non-dominant hand during (upper right) shows that visual feedback enhanced the sEMG magnitude and an active transition with visual feedback had a more positive impact on the sEMG during embodiment than a passive transition with visual feedback.

On the other hand, the Friedman test did not show significant differences in terms of body ownership and self-location (ownership:  $p = .18$ , self-location:  $p = .14$ ).

These results show that the presence of visual feedback (allowing one to see the avatar progressively transform) has a positive impact on the maintaining of the sense of agency when an active transition is employed. This partially supports hypothesis **H1.1**. Compared to passive transitions with visual feedback, we also found that active transitions with visual feedback provided better help to maintain the sense of agency when switching from the regular- to the muscular-shaped avatar. This partially supports hypothesis **H1.2**.

#### 5.3 sEMG magnitude with the muscular-shaped avatar

The Friedman test revealed significant differences between  $EVR_{during}$  of the non-dominant hand across conditions ( $\chi^2(3, n = 32) = 9.15, p < .05$ ). The Wilcoxon signed-rank test showed that their origin was between F\_ACTIVE and F\_PASSIVE ( $p < .01$ ) and F\_ACTIVE and N\_ACTIVE ( $p < .05$ ), with F\_ACTIVE providing superior sEMG values (see Fig. 8, top).

On the other hand, the Friedman test did not show significant differ-



ences in the  $EVR_{during}$  of the dominant hand ( $p = .14$ ).

These results show that the usage of active transitions with visual feedback of the transformation has a positive impact on the non-dominant hand's sEMG magnitude during the muscular-shaped avatar's embodiment. This partially supports **H2.1**. This positive was found superior to that of the passive transition with visual feedback. Therefore, this partially supports **H2.2**.

#### 5.4 sEMG magnitude after embodiment

The Friedman test could not reveal significant differences in  $EVR_{after}$  for either hand across conditions (dominant:  $p = .27$ , non-dominant:  $p = .83$ ). Therefore, we could not confirm hypothesis **H3.1** and **H3.2**.

Looking at the values of the  $EVR_{after}$ , it seems likely that either visual transition did not have any effect on the Proteus effects once the embodiment ended (see Fig. 8, bottom).

### 6 DISCUSSION

In this paper, we explored the use of visual effects to smooth the transition between the different stages of embodiment experiences in AR. This section summarizes and discusses our contributions to reaching this goal.

#### 6.1 Transition system

We presented a proof-of-concept system applying visual effects when changing of embodiment perspective (1PP/3PP), when changing from one's real body to a generic avatar (3D mesh/regular-shaped avatar), when changing from this avatar's appearance to another one (regular/muscular), and the other way around. Using various techniques, these transitions were designed to allow for a more continuous embodiment experience than when abruptly switching perspectives or bodies, from one frame to another. Additionally, we explored two approaches to trigger transitions from one avatar to another: active transitions which are launched and synchronized with the user's action, and passive transitions which are applied automatically by the system and observed passively.

Although the transition system we present is new in its design, it was strongly inspired by previous work implementing embodiment systems in the 3PP. Like the system of Rosa et al. (2019), our setup allows seeing a remote avatar in the real world thanks to cameras embedded in the headset providing video see-through vision [51]. The main difference with their system is that, complementarily, we also use real-time 360 videos captured with another external camera to provide an "out-of-body" point-of-view where the real body is erased. This point of view is similar to what was done by Leggenhagger et al. (2007) [28]. Lastly, the 3D mesh capture of the user's real body was previously implemented by Nimchareon et al. (2018) who used a Microsoft Kinect to display the user's image in front of them in the real world, as we did [38]. Our system can be seen as an assemblage of these different setups, combining their features and allowing them to transition from one to another. Therefore, it contributes to demonstrating how existing techniques can be merged into an encompassing system, allowing users to flexibly adapt the embodiment experience.

We believe all of these transitions can benefit various kinds of embodiment setups, including VR ones. Contrary to VR where everything is virtual, AR embodiment requires integrating the avatar into the real environment with accuracy and coherence. As this cannot be done perfectly with current technologies yet, we feel that AR embodiment systems might have even further interest in having such transitions to mitigate the potential effects of discrepancies resulting from current system limits.

#### 6.2 User study

To start evaluating the transition system we propose, we investigated the effects of one of its transitions on the SoE: the visual transitions applied between the embodiment of two avatars. We were interested in checking whether applying such transitions would allow for maintaining a stable SoE, even when the new avatar is more difficult to embody. To do so, we used our prototype system to assess such effects when switching from a regular-shaped avatar to a muscular one, inducing a

lower SoE. We hypothesised that visual feedback showing the avatar's appearance progressively changing would help prevent the user's SoE from decreasing because the avatar's appearance gradually becomes different from the user's body. Further, we expected that visual feedback triggered by and synchronized with the user's physical action (F\_ACTIVE) better help to retain the SoE than when visual feedback is presented automatically, without involving the user (F\_PASSIVE).

Our results showed that applying active transitions with visual feedback synchronized with the user's actions helps to maintain the sense of agency. In contrast, applying an active transition without such visual feedback (N\_ACTIVE) had the opposite effect as it reduced the sense of agency. We believe that users in the condition F\_ACTIVE might not have felt in control of their avatar's transformation because they could not see how much their actions impacted it. This feeling of not controlling the transformation's progress may have in turn reduced the feeling of controlling the avatar itself. Therefore, when applying an active transition, visual feedback on the avatar's appearance change seems to be of primary importance to let the user feel in control of the transformation and ensure a positive effect of the transition. In line with this finding, some participants commented that they felt that they were controlling their avatars when they saw the avatar change synchronously with their squeezing actions.

Secondly, we were interested in verifying whether Proteus effect could benefit from visual transitions as a consequence of the higher stability of the SoE. We hypothesized that transitions with visual feedback would improve the intensity of the Proteus effect when and after embodying the muscular-shaped avatar, especially in the case of active transitions. Our results showed that an active transition combined with visual feedback partly led to stronger intensity of the Proteus effect during the embodiment (users applied more strength when squeezing the dumbbells). As the Proteus effect is linked to the strength of the SoE [21], this further supports the idea that condition F\_ACTIVE was able to maintain a superior SoE than the other conditions. On the other hand, we could not observe a difference in the induced Proteus effect between our conditions after the end of the embodiment. Therefore, the impacts we observed on the Proteus Effect may have some limits: they might occur only during the embodiment and probably have short resilience over time. Further investigation is necessary to confirm this, but also to determine whether this is specific to our experiment and whether these effects can be reproduced with other kinds of avatars.

Enhanced impacts of Proteus effects influencing the user's physical performance can benefit various real-world tasks. For instance, in a hypothetical situation where a builder wears an AR headset while carrying heavy objects, transitioning from their real selves to a muscular avatar could provide them with stronger Proteus effects than when directly embodying this avatar. In addition, when people wish to do some exercise in the real world (e.g., in a park surrounded by magnificent nature), they can smoothly embody a muscular avatar standing in this physical location, thereby increasing their exercise performance through the intensified Proteus effect.

#### 6.3 Limitations and future work

Although these results are interesting, they come with limitations that encourage follow-up research. First, we made the choice to use the 3PP to let users embody their avatars due to the difficulty of implementing the 1PP in AR. This gave us the opportunity to explore perspective transitions which we thought could highly benefit the continuity of the embodiment experience. However, previous research suggests that the 3PP tends to provide a weaker SoE than the 1PP [15, 17, 32–34, 45, 52, 54]. Therefore, there is a possibility that the effects we observed on the Proteus effects might have been more pronounced with this perspective.

To investigate the effects of visual transitions in the 1PP, future work will need to investigate how to achieve precise full-body tracking and alignment of the avatar on the user's body, but also ways to increase the vertical field of view of AR HMDs to allow seeing the avatar's body when looking down, as done with VR HMDs by Nakano et al. (2021) [37].

Secondly, although we present multiple types of transitions in our proof-of-concept system, our user study only evaluated active and

passive transitions when changing from one avatar to another. The other transitions we provide (perspective transitions and switching from the real body mesh to the avatar) were experienced across all conditions and did not vary to avoid having too many variables to test. To investigate how they benefit the user experience and SoE, we encourage future work to evaluate their effects in dedicated studies.

Lastly, the present study evaluated the user's physical performance based on only one type of task (dumbbell squeezing) and relied on only one type of data (sEMG). Some of our unsupported hypotheses on the Proteus effects might have been supported by other types of physical tasks and measures such as heart rate or skin conductance values [16, 49]. Other limitations include differences by gender and age, which were not investigated. Although we recruited an equal number of male and female participants, we did not analyze the gender differences. In addition, participants were in their 20s and 30s, and we were not able to examine other age groups. In the future, follow-up studies would benefit from a wider demographic diversity.

## 7 CONCLUSIONS

In this paper, we explored how visual transitions can benefit embodiment experiences in AR. We implemented a system allowing users to transition smoothly between embodiment perspectives, between their real body and an avatar, and between several avatars. We then conducted a user study to evaluate the effects of visual transitions when switching from a generic regular-shaped avatar to a muscular one on the SoE and Proteus effects. Two approaches were explored to trigger this transition: active transitions where the user is responsible for transforming their avatars, and passive transitions where the transformation is applied automatically. We also investigated the impact of displaying feedback showing the avatar transforming. To do so, we performed a cross-evaluation of two factors using the transition system we implemented: visual feedback (present/absent) and transition activation (active/passive). Our results partially supported that visual transitions with feedback help maintaining the SoE when switching to an avatar expected to induce a lower SoE (the muscular one). In addition, we discovered that active transitions with visual feedback retained the sense of agency better than passive transitions, but not when removing the visual feedback. Our results also partially supported the expectation that Proteus effects would also benefit from visual transitions during the embodiment of a muscular-shaped avatar, especially when the transition was active. This phenomenon could be exploited in future applications aiming to utilize the Proteus effects to facilitate real-world tasks. Therefore, we encourage future work to study whether these effects can be reproduced with other avatar appearances for different Proteus effects.

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