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Invisible Long Arm Illusion: Illusory Body Ownership by Synchronous Movement of Hands and Feet

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Abstract

We feel as if a fake body is our own body by synchronicity between the fake body and the actual body (illusory body ownership) even if the body has a different shape. In our previous study, we showed that illusory body ownership can be induced to an invisible body through the synchronous movement of just the hands and feet. In this study, we investigated whether illusory body ownership can be induced to the invisible body even when the arm length of the invisible body was different from the usual body. We modified the length of arm of a full body avatar or changed the position of the hand of the invisible body stimulus, and found that the illusory body ownership was induced to the transformed body by synchronous movement. Participants' reaching behavior gradually changed to use the longer arm more during the learning of the transformed body.

CCS Concepts

• ***Human-centered computing*** → ***Virtual reality;***

1. Introduction

1.1. Illusion of ownership to different bodies

We can feel as if a fake body is our own body even if the body has a different shape and color. It is called "illusory body ownership" [KMKS15], and it is induced by presenting tactile stimuli synchronized with visual stimuli [BC98] or presenting visual stimuli synchronized with an observer's movement [GPSS10]. The method for illusory body ownership is categorized as passive method or active method. The rubber hand illusion [BC98] [TH05] is famous as the passive method. Observers feel as if a rubber hand is their own hand. For inducing the illusion, the rubber hand is put next to their actual hand hidden from their view, and both the rubber hand and their hand were stroked by a brush at the same time. The visible rubber hand stroked by the brush is perceived as their own hand. In the active method, observers feel as if an avatar reflected in the mirror is their own body when the avatar moves synchronously with the observers' movement [GPSS10].

Several studies have reported that the illusory body ownership can be induced to various body shapes and colors. For example, the illusory ownership can be induced to elongated hands [AR03] [KNSS12], six finger hands [HANL16], large belly body [NGSS11], child body [BGS13] [TBBS17], a very small body or large body [VGE11] [VE16].

1.2. Illusion of ownership to transformed hands and arms

Arms and hands are important body parts because we often use them to interact with others and objects. Their tactile sensation is particularly sensitive and their motor control is very fine [Wei68]. Thus, researchers were motivated to focus on the illusory ownership of hands and arms.

Armel and Ramachandran [AR03] showed that the illusory body ownership can be induced to a rubber hand with a longer arm by stroking the observers' hand and the rubber hand at the same time using the subjective ratings of questionnaire and the skin conductance response (SCR) to a threat to the rubber hand.

Kilteni et al [KNSS12] showed that the illusory body ownership for the virtual long arm using the combination of active and passive methods. In their experiment, the virtual arm was presented through a head-mounted display (HMD), and it was elongated gradually. The virtual long arm was synchronized with the observers' movement. Moreover, observers kept touching a virtual table that was located in synchronicity with an actual table so that observers could experience a tactile sensation (touch) with the table. It enhanced illusory ownership of the virtual hand. Their results suggest that illusory body ownership occurred up to three times of the observers' actual arm length. o sum up, illusory body ownership can be induced in both cases that the arm is long from the outset [AR03] and that the arm is gradually elongated [KNSS12].

Metamorphosis hand [OBS*16] is a work where humans play a virtual piano with a dynamically transforming computer-graphics

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hand. A sensor (Leap motion) detected the observer's hand and presented computer rendered graphics of a hand that was metamorphosed and synchronized with the observer's movement on the piano. They can play the piano even if the hand possesses ten fingers or if the fingers become elongated.

Levin and colleagues have published art works called Augmented Hand Series [LSM18]. This work transforms the image of the observer's hand using a camera in real time, and there are various types of the transformation such as increasing and decreasing the number of fingers, and attaching a small hand to a fingertip.

These studies tell us that we can have an illusory ownership of a virtual hand and arm and it can be transformed. Even in the field of art, transformation of the hand and arm is getting popular. We aimed to investigate if we can have an illusory ownership to an elongated arm using the "invisible body" paradigm, that is described in the following section.

1.3. Illusory ownership to invisible body

It is reported that the illusory body ownership could be induced to an invisible body using active method or passive method [GGE13] [GAE15] [VE16] [KSM*18]. In the passive method, illusory body ownership can be induced to an empty space by stroking an observer's body hidden from view and in an empty visual space at the same time [GGE13] [GAE15] [VE16]. Illusory ownership is also induced to smaller and larger invisible bodies [VE16].

Illusory ownership of an invisible body can be induced by synchronous movement of just the hands and feet, and observers perceive the whole body by complementing between hands and feet [KSM*18]. This active method is more freely able to move the body than the passive method. The illusory body ownership is stronger in the active method than the passive method [KS14].

1.4. Purpose

We aimed to investigate whether we can have an illusory ownership to the invisible body with an elongated arm by presenting only hands and feet with modifying the position of the hands. We employed a task of proprioceptive-pointing with the distant hand and measured body sway as potential measurements in addition to the subjective ratings using a standard questionnaire.

In Experiment 1, we measured illusory body ownership of a visible whole body with a long arm using the subjective ratings, and measured body sway after experiencing illusory body ownership. We hypothesized that illusory body ownership is induced to the long-arm body when the hands and feet moved synchronously with the subject's movements, and their body tilts toward the normal arm to maintain body posture. In Experiment 2, we investigated whether the illusory body ownership can be induced to the invisible long arm body by presenting only hands and feet using the subjective ratings. We measured proprioceptive pointing of the hand of elongated arm. In Experiment 3, to see the learning process of the elongated-arm body, we investigated the illusory body ownership for the invisible long arm body through measuring reaching behaviors and body sway in time series as well as the subjective ratings.

2. Experiment 1

2.1. Methods

2.1.1. Participants

Eight volunteers (all male, mean age 22.125 years old ±2.23 standard deviation (SD), mean height 168.43cm±4.83SD, all right-handed) participated in Experiment 1. They had healthy vision and physical ability. All participants gave written informed consent before the experiment. All of the experiments were approved by the Ethical Committee for Human-Subject Research at Toyohashi University of Technology, and all experiments were performed in accordance with the committee's guidelines and regulations.

2.1.2. Apparatus

A computer (OS: Windows 10, RAM: 16 GB, CPU: Intel Core i5-6400, GPU: GeForce GTX 1080) controlled a head-mounted display (Oculus Rift DK2, each eye 960x1080 pixel, 90 x 110 deg, refresh rate 75 Hz). A motion capture system (Microsoft Kinect v2, Sampling rate 30 Hz) acquired participants' movements and imported the data to the computer. The delay was within 80 ms and the measurement error was within 10 cm. A force plate (NEC Medical Systems EB1101) acquired the participants' center of gravity and sent the data to the computer via Arduino (sampling rate 75 Hz).

2.1.3. Stimuli and Conditions

We presented a white full-body avatar from the first-person perspective and a virtual room created by Unity. The length of the arm of the avatar was one of three types: standard (78 cm), a longer left arm (128 cm), and a longer right arm (128 cm). In long arm conditions, both upper and lower arms were stretched 25 cm while the elbow joint bent at the same angle as participants. The avatar was originally 195-cm tall, and fitted (shortened) to the participants' actual height while maintaining its aspect ratio. The avatar moved synchronously (or asynchronously) with participants' movements captured by Kinect. In the asynchronous condition, the avatar moved based on pre-recorded motion data. A mirror reflected the avatar in front of the avatar/participant (Figure 1).

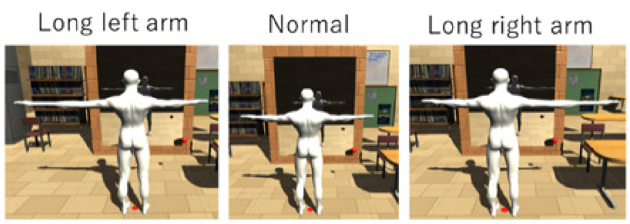

Figure 1: ***White full-body avatar.*** *These images were from the third-person view as schematic. However, actually participants viewed the stimuli from the first-person view of the avatar in front of a mirror.*

2.1.4. Procedure

Participants wearing the HMD stood at the center of the force plate located 2.75 m away from Kinect. They observed stimuli through

the HMD with both eyes. The reaching phase (5 min) was followed by the posture phase (1 min). They observed a whole-body avatar from the first-person view and a red ball, and were asked to reach for the ball. We did not ask them to use either right or left hand, nor to do it as quickly as possible. Balls were made to appear randomly in the range of 60 cm (right: 30 cm, left: 30 cm) from the viewpoint, 1.3-1.6 m height from the floor, and 50-60 cm ahead. Another ball appeared 2s after reaching until the end of phase (5 min). Then, the screen of HMD was blacked out and they stood naturally with their arms by their side for 1 min while their center of gravity was measured. Finally, they were asked to rate eight items in 7-level Likert scale -3 (not feeling at all) to 3 (very strongly felt). 1. It felt as if the white body I saw when looking down was my body.
2. It felt as if the white body in the mirror was my body.
3. It felt as if my right arm became longer.
4. It felt as if my left arm became longer.
5. It felt like the movement of the white body was my movement.
6. It felt like the movement of the white body was another's movement.
7. It felt like my body posture tilted more than usual.
8. It felt as if my body became a floor.
Each participant performed 12 trials in a random order of combinations of the three body conditions (standard, long left arm, long right arm), the two synchronization conditions (synchronous, asynchronous) and two repetitions.

2.2. Results

One participant was excluded from the analysis because he stopped the experiment due to a physical trouble of the legs.

2.2.1. Subjective Ratings

Two-way repeated measure analysis of variance (ANOVA) was performed for each question (Body: normal, long left, long right; Synchronicity: synchronous, asynchronous). Averaged data were shown in Figure 2 as separated graphs of three body conditions. The avatar was felt as their own body in the synchronous than the asynchronous condition irrespective of arm length (Main effect of synchronicity: Q1 F (1,6)=16.11, p=.007, η_p^2 =0.73; Q2 F (1,6)=17.77, p=.006, η_p^2 =0.75 ; No interaction or main effect of body). Own arm was felt as if it was elongated only when the corresponding avatar's arm was elongated and synchronously moved with the participant (Interaction: Q3 F (2,12)=6.46, p=.012, η_p^2 =0.52; Q4 F(2,12)=22.79, p=.0001, η_p^2 =0.79; Multiple comparisons with Shaffer's method: ps<.05). The participants felt as if the avatar was moved by their selves in the synchronous condition, and moved by another in the asynchronous condition, irrespective of arm length (Main effect of synchronicity: Q5 F (1, 6) = 45.12, p = .0005, η_p^2 = 0.88; Q6 F (1, 6) = 58.71, p = .0003, η_p^2 = 0.91; No interaction or main effect of body). They felt as if their posture did not tilt (stable) in the normal arm rather than the longer left/right arm conditions irrespective of synchronicity (Main effect of body: Q7 F(2,12)=5.07, p=.0253, η_p^2 =0.46, though no significance in multiple comparisons; No interaction or main effect of synchronicity). Q8 was a control question to check participants attitude to the questionnaire, and the answers were valid (all were -3).

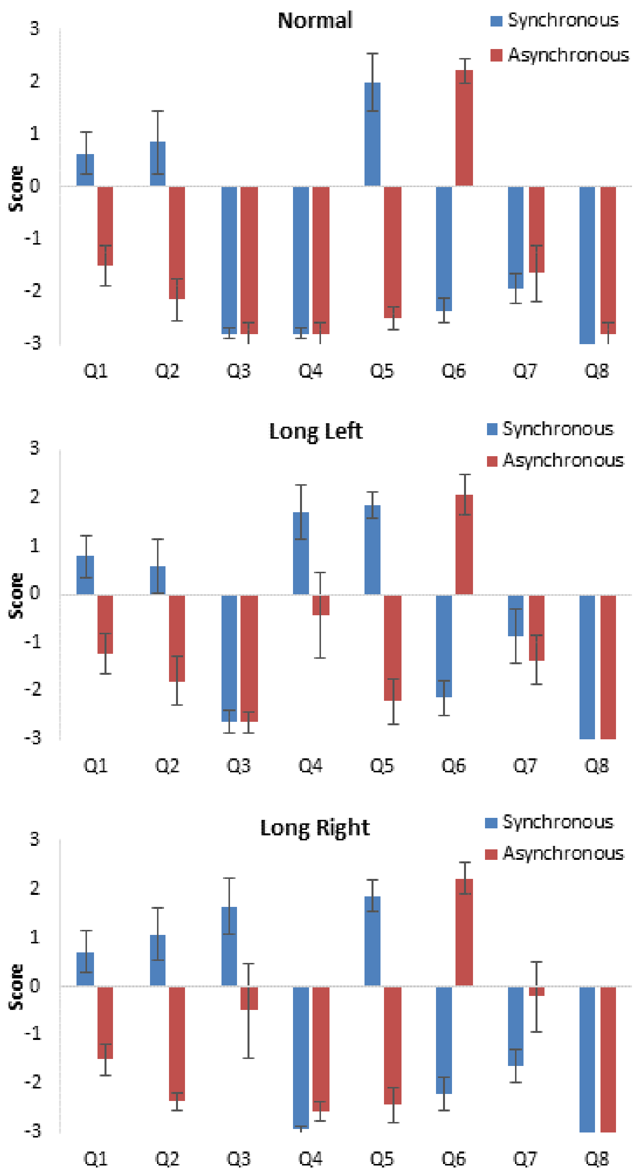

Figure 2: ***Results of subjective ratings in Experiment 1.***

2.2.2. Body Sway

Body sway was relatively larger in the first 10s, then getting stable. Thus, we extracted the average center of gravity of the first 10s after baseline processing using the final 10s data. Two-way repeated measures ANOVA showed that the center of gravity shifted rightward in the synchronous condition irrespective of the arm length (Figure 3; Main effect of synchronicity: F(1,6)=8.32, p=.0279, η_p^2 = 0.58; No interaction or main effect of body).

We also calculated total path length of 60s and applied Two-way ANOVA, but did not find any significant effect.

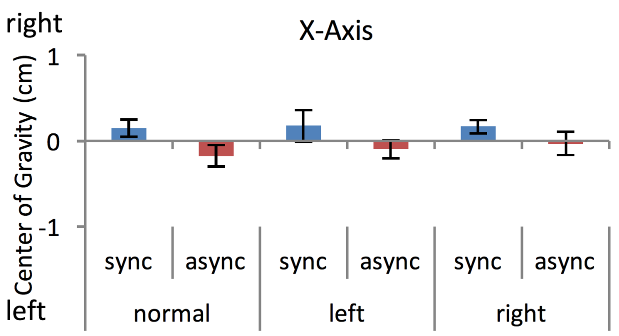

Figure 3: *Center of gravity (x) in Experiment 1*

2.3. Discussion

The subjective rating results suggest that the illusory body ownership can be induced to the whole body even with a longer left or right arm by synchronous movement with observers. The results of body sway were inconsistent with our prediction, and were not affected by the virtual arm length.

3. Experiment 2

We investigated whether the illusory body ownership could be induced to the invisible body complementing hands and feet with a longer arm by changing the position of the left or right glove.

3.1. Methods

Seven volunteers (all male, mean age 22.14 years old ±1.574 SD, 173.79cm ±6.864 SD, 6 right-handed, 1 left-handed) participated in Experiment 2. One of them had participated in Experiment 1. The apparatus was similar to Experiment 1 except that participants actually wore gloves and socks. The body condition and the synchronicity condition were similar to Experiment 1.

Participants stood 2.75 m away from Kinect, and observed the white gloves and socks in HMD from the first-person view (Figure 4). They performed the reaching task similar to Experiment 1 for 10 min (learning block). Then, the gloves and socks disappeared, and a red ball was presented in the virtual room after 10s of darkness. Participants were asked to point to the ball with their hand. Since there was no visually corresponding hands or gloves, they must point at it by using only proprioception. The ball was presented at 50, 52, 54, or 56 cm ahead of the participant in a random order. Participants were asked to reach it by using both the left and right hand for each one. Thus, eight pointing tasks were performed in each trial.

At the end of each trial, participants rated the 9-item questionnaire in 7 levels.
1. It felt as if the invisible body on the socks I saw when looking down was my body.
2. It felt as if the invisible body between the socks and gloves in the mirror was my body.
3. It felt as if my right arm became longer.
4. It felt as if my left arm became longer.
5. It seemed as if there is a whole body between the socks and gloves in the mirror.
6. It felt like the movement of the white socks and gloves were my movement.
7. It felt like the movement of white socks and gloves was another's movement.
8. It felt like my body posture tilted more than usual.
9. It felt as if my body became a floor.

Each participant performed a total of eight trials of a combination of two body conditions (normal same-length arms, left/right longer arm), two synchronicity conditions (synchronous, asynchronous) and two repetitions in random orders. Before and after the experiment, only the proprioceptive pointing task was performed as a control trial for calibration.

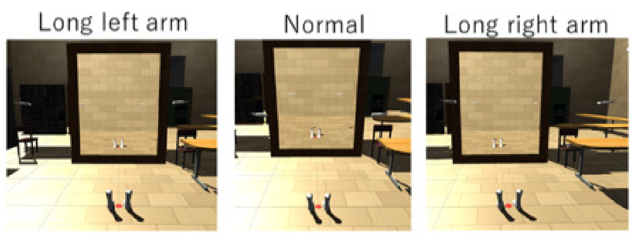

Figure 4: ***Invisible body of socks and gloves.*** *These images were from the third-person view as schematic. However, actually participants viewed the stimuli from the first-person view in front of a mirror.*

3.2. Results

3.2.1. Subjective Ratings

Two-way repeated measures ANOVA (Body: normal, long; Synchronicity: synchronous, asynchronous) was performed for each question. Averaged data were shown in Figure 5 as separated graphs of two body conditions. The invisible body between socks and gloves was felt as their own body in the synchronous than the asynchronous condition irrespective of arm length (Main effect of synchronicity: Q1 F(1,6)=22.00, p=.0034, η_p^2 = 0.79; Q2 F(1,6)=22.57, p=.0032, η_p^2 =0.79; No interaction or main effect of body). Own arm was felt as if it was elongated only when the corresponding arm of the invisible body was elongated and synchronously moved with the participant (Interaction: Q3&Q4 F(1,12)=21.46, p=.0036, η_p^2 =0.78). Whole body between the socks and gloves was perceived when the body with normal arms moved synchronously rather than asynchronously (Interaction: Q5 F(1, 6)=3.93, p=.0948, η_p^2 =0.40; Simple effect of synchronicity in the normal body condition: F (1,6)=8.00, p=.03, η_p^2 =.57; No other simple effect). The participants felt as if the white socks and gloves were moved by their selves in the synchronous condition, and moved by others in the asynchronous condition, irrespective of arm length (Main effect of synchronicity: Q6 F (1,6)=29.98, p = .0016, η_p^2 =0.83; Q7 (F(1,6)=18.63, p=.005, η_p^2 = 0.76; No interaction or main effect of body). They did not feel their posture tilt more than usual in any conditions (Q8: all were approximately 0). Q9 was a control question to check participants attitude to the questionnaire, and the answers were valid (all were -3).

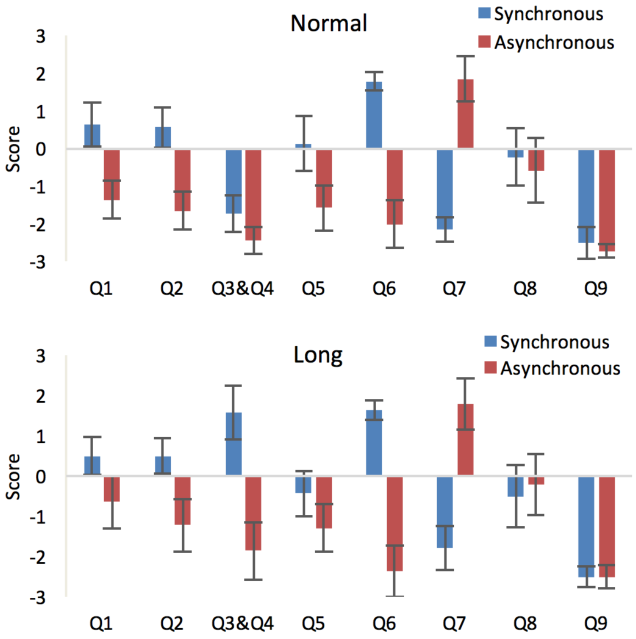

Figure 5: ***Results of subjective ratings in Experiment 2***

3.2.2. Proprioceptive pointing bias

We predicted that participants point at a nearer point after experiencing the long arm than the normal or short arm. We separated the data into normal, long and short arm conditions; all data in the normal arm condition (normal arm condition), the data of the pointing hand that corresponded to the virtual longer/elongated arm (longer arm condition), and the data of the pointing hand that corresponded to the shorter arm in the long arm condition (short arm condition).

The difference between the hand position and the ball position was calculated for horizontal (x), vertical (y), and depth (z) directions. We calibrated the data by subtracting the average data of control trials. In the x axis, left was plus and right was minus, in the y-axis, up was plus and down was minus, and in the z-axis, near was plus and far was minus while the ball was at (0, 0, 0).

Two-way repeated measures ANOVA (Body: normal, long, short; Synchronicity: synchronous, asynchronous) was performed for each of x, y and z-axis. The pointed position was biased leftward in the long arm condition than the other conditions irrespective of synchronicity (Figure 6; Main effect of body: $F(2,12)=7.0481$, $p=.0095$, $\eta_p^2=.54$, No interaction or main effect of synchronicity). There was no significant effect in the y or z-axis.

3.3. Discussion

The results of subjective rating indicate that illusory body ownership is induced to the invisible body with an elongated arm by synchronizing visual gloves and socks with participant's movements. The results of proprioceptive pointing were inconsistent with our prediction, and the hand position was biased leftward when the pointing was performed with the arm that corresponded to the longer arm regardless of synchronous condition.

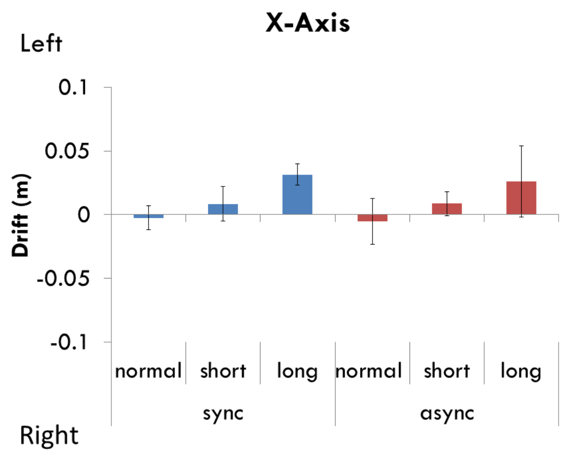

Figure 6: ***Results of proprioceptive pointing bias (x) in Experiment 2***

3.4. Methods

We aimed to investigate the learning process of the novel elongated-arm body. We predicted that participants would use the longer arm more gradually than the shorter (normal) arm as they were getting to use the novel elongated-arm body continuously. In Experiment 3, we investigated changes in the frequency of use of the longer arm when participants reach their hand to touch balls in a 3D space.

Ten volunteers (all male, mean age 22 years old ±1.633 SD, mean height 170.66 cm±7.85 SD, 6 right-handed, 1 left-handed) participated. Four of them had participated in Experiment 2. The apparatus was the same as Experiment 1. The body condition was the same as Experiment 2 and only the synchronous movement was applied.

Participants observed stimuli through the HMD and stood on the center of the force plate. The experiment consisted of two type of blocks: a learning block and 10 test blocks. In the learning block, participants were asked to touch a red ball at their own pace for 10 min similarly to Experiment 2. In the test blocks, they were asked to touch the ball as quickly as possible. Another ball appeared 5s after the current ball was touched. Fifteen balls appeared in one test block for 1 min. The body sway was measured for 15s without vision after every test block. Participants kept both their arms open horizontally while measuring body sway. Posture was changed from Experiment 1 to increase body sway potentially affected by the elongated arm. One session consisted of one learning block and 10 test blocks. Each participant performed four sessions in a random order of combinations of the two body conditions (normal, long arm) and two repetitions. Long arm was either left or right in random orders. Participants were asked to rate the questionnaire at the end of each session. The questionnaire was the same as in Experiment 2.

3.5. Results

One participant who fell off the force plate, and one who was continuously out of tracking with Kinect were excluded from the analysis.

3.5.1. Subjective Ratings

Wilcoxon signed-rank test was used for each question. The participants felt as if their own arm was elongated when the corresponding arm of the invisible body was elongated (z(1,7)=-2.54, p=.0078; Figure 7). There was no significant difference in the other questions.

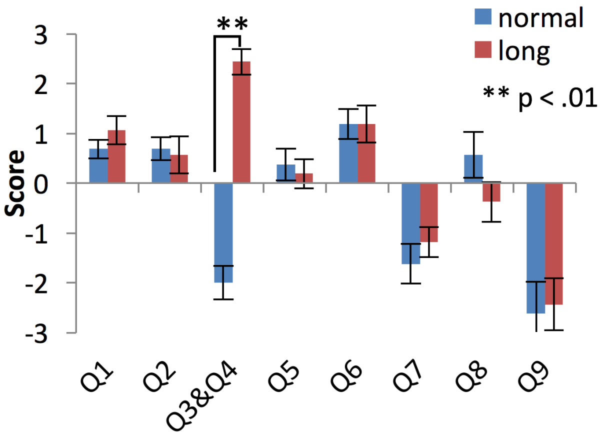

Figure 7: ***Results of subjective ratings in Experiment 3***

3.5.2. Reaching Task

The ratios of touching the ball with the right/left hand in the learning block and test blocks were calculated for each condition. The learning block was divided into four periods in time series. We calculated the total number of balls that participants touched in the learning block (10 min), and divided it into four as each period had the same number of balls. Thus, each period was approximately 2.5 min. The test blocks were 10 (1min each). Three participants who touched all balls with only one hand during all trials were excluded from the analysis. Thus, the data of five participants were analyzed in the reaching task.

The ratios of touching the ball with the right hand were plotted against time (serial blocks) in Figure 8. We performed two-way repeated measures ANOVA (Body: normal (left=right) arms, longer right arm, and longer left arm; Time series: 1st-4th periods). The right (left) hand was used more when the virtual right (left) arm was longer than the normal arms (Figure 8; Main effect of body F(2,8)=15.18, p=.002, η_p^2 =0.79; Multiple comparisons with Shaffer's method: ps<.05). The main effect of time series and the interaction were not significant, but marginal (Main effect of time F(3,12)=2.76, p=.0882, η_p^2 =0.41; Interaction F(6,24)=2.41, p=.0579, η_p^2 =0.38). The effect of the size of arm length gradually increased as time series up to 4th period (Simple effect of the body at 1st (F(2,8)=8.37, p=.0109, η_p^2 =0.68), 2nd (F(2,8)=8.81, p=.0095, η_p^2 =0.69, 3rd (F(2,8)=16.81, p=.0014, η_p^2 =0.81), 4th (F(2,8)=11.97, p=.0039, η_p^2 =0.75) periods).

Two-way repeated measures ANOVA (Body: normal, longer right, and longer left arm; Time series: 1st -10th block) was performed for the test blocks similarly to the previous analysis. Similarly to the learning block, the right (left) hand was used more when the virtual right (left) arm was longer than the normal arms (Main effect of body F(2,8)=13.85, p=.0025, η_p^2 =0.78; Multiple comparisons with Shaffer's method: ps<.05). However, the main effect of the time series and the interaction were never significant (Main effect of time F(9,36)=0.70, p=.71, η_p^2 =0.15; Interaction F(18,72)=1.30, p=.2168, η_p^2 =0.24).

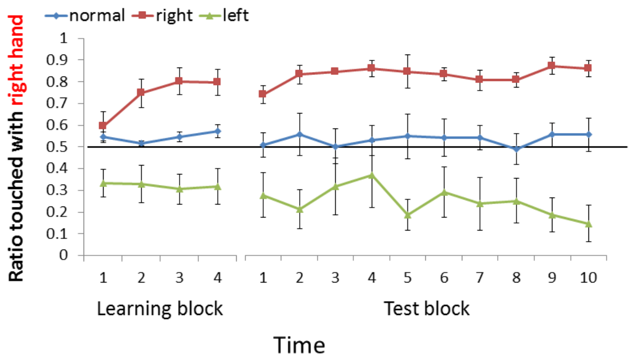

Figure 8: ***Time series data of ratio touched with right hand in learning block and test blocks in Experiment 3***

3.5.3. Body sway

Two-way repeated measures ANOVA (Body: normal, longer left, and longer right arms; Time series: 1st âĂŞ 10th periods) was performed for the center of gravity averaged for 15s. We did not find any significant effects (Main effect of body F(2,14)=1.48, p=.2617, η_p^2 =0.17; Main effect of time F(9,63)=0.44, p=.9100, η_p^2 =0.06; Interaction F(18,72)=0.54, p=.9347, η_p^2 =0.07).

We performed the same analysis using the total-path length, and found that the total-path length gradually increased as the time series (Figure 9; Main effect of time F(9,63)=2.24, p=.0308, η_p^2 =0.24). However, the main effect of the time series and the interaction were never significant (Main effect of body F(2,14)=1.57, p=.2432, η_p^2 =0.18; Interaction F (18, 126) = 0.64, p = .8623, η_p^2 =0.08).

3.6. Discussion

We found that the arm that was virtually longer than the other arm was utilized to touch balls in 3D space more frequently than the normal arm. This tendency gradually increased in the learning block for 10 min, but remained constant in the test blocks following the learning block. These results suggest that the learning is quick and 10 min is enough for the reaching behavior.

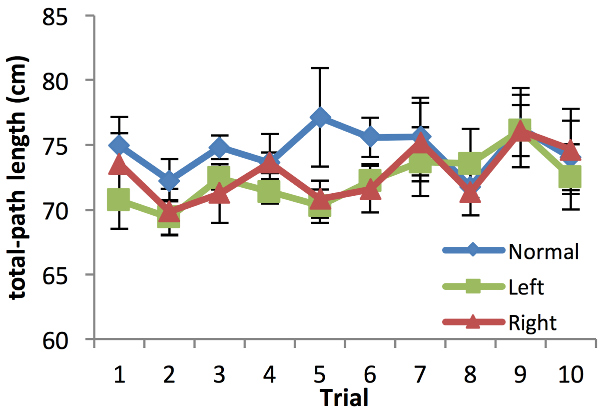

Figure 9: ***Time series data of total-path length in Experiment 3***

For the results of body sway, there was no significant difference in the body condition. The total-path length increased gradually in the test blocks. We speculated that physical fatigue caused the unstable posture in the later blocks. Imaizumi et al [IAK16] reports that participants who frequently use an artificial limb show less body sway while their artificial limb was attached than while it was excluded. Thus, stabilization of posture was expected as the learning advanced. However, our results did not support it. We speculate that the learning of the longer arm body was already completed in the learning block, so that there was no effect in the test blocks.

4. General Discussion

We found that the illusory body ownership could be induced to the whole visible body that had a long left/right arm and a normal right/left arm when the avatar was synchronized with participants' movement (Experiment 1). The similar illusory body ownership to the body with a long arm was induced to an invisible body by synchronizing only gloves and socks with participants' movement (Experiment 2). The behaviors of using the long arm and the normal arm to touch an object changed gradually as learning the invisible body up to 7.5 min (Experiment 3). However, the results of postural sway and proprioceptive pointing were not consistent with our prediction (Experiment 1-3).

Subjective ratings showed that participants felt as if their arm was elongated when the virtual long arm was synchronous with their movement, and the degree of ownership to the long-arm body was not significantly different from that to the normal-arm body (Experiment 1 and 2). These results suggest that we can acquire a new body with different-length arms similar to our physical body that usually has two same-length arms.

In the proprioceptive pointing task in Experiment 2, the participants' hand position drifted leftward in the long arm condition. This is not consistent with our prediction, and might be caused by some artifacts. We need to collect measurements using a more accurate motion capture system than Kinect to further investigate this issue.

In Experiment 3, we showed than reaching behaviors gradually changed as the learning advanced up to 7.5 min. After 10 min, the reaching behaviors was constant, and participants used the longer arm more than the shorter or normal arm. This would reflect the acquirement of the new transformed body. However, one may argue that the change of behaviors is just caused by the learning of a new tool like that when using a toy arm grabber. To investigate the relationship between body ownership and tool use, we need a further study to compare them in a future.

Illusory body ownership was induced to the long-arm whole body (Experiment 1) and long-arm invisible body with only hands and feet (Experiment 2). The latter is novel in the research literature of long arm illusions. Moreover, this method of invisible long arm ownership has an advantage that it is easier to be implemented than the visible extended arm. In the case of the extended long arm, there are ambiguities of position and angle of virtual and visible elbow, while in the case of the invisible long arm, humans would implicitly assume one's own appropriate position and angle of the elbow. Humans are usually conscious of position of the hand, but not conscious of angle of the elbow. However, it is unclear whether the degree of body ownership was the same or different between the visible body and the invisible body. It is necessary to compare them in the future.

The center of gravity was biased rightward in the synchronous condition than the asynchronous condition regardless of the length of the arm (Experiment 1). It is inconsistent with our prediction, and might be caused by the participants' laterality bias that all participants were right-handed. There was no effect of body transformation on the postural sway in either Experiment 1 and 3. We predicted that participants who have a transformed body with a longer arm and a normal (shorter) arm would tilt toward the normal arm to maintain body posture. However, if the participants have already acquired the transformed body as their own body and felt ownership of it, the posture should be rather stabilized with referring an artificial-limb study [IAK16]. In our experiments, the measurements of postural sway were conducted after learning to the transformed body for 5 min (Experiment 1) or 10 min (Experiment 3). Thus, we need to study the postural sway during learning the transformed body in a future study.

5. Conclusion

Illusory body ownership was induced to both the long arm fully visible body and the long arm invisible body, and the length of the arm of participants felt changed. Participants' behavior gradually changed to use the longer arm more during the learning of the transformed body.

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