Verification of out of body sensations, attribution and localization by interaction with oneself

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Abstract

To enhance the realistic sensation and the human presence in a telepresence or a telexistence system, it is important not only to match the audio-visual sensation of the operator with the robot but also to match the embodiment of the operator with the robot by reflecting the somatic sensation of the operator. Presently, however, in telexistence, the key factors for matching the embodiment of the operator with the robot are unclear and lack established evaluation methods. In this paper, we experiment with out-of-body sensations in a telexistence system on the basis of the rubber hand illusion. We construct a system to self-interact with and evaluate the stimulation influence of the self-attribution and self-localization of the body.

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities

1 Introduction

We have been researching the body sensation of humans in telexistence or telepresence. Telexistence or telepresence is a technology by which we can experience advanced realistic sensations of being in a remote environment through remote operation and remote communication. In a telexistence or a telepresence system, there is a master-slave relationship between an operator and a remote robot, and information is transmitted from the operator to the remote robot and back. The master-slave system for achieving these objectives is under development [1]. Even though the presence and realistic sensations have improved, in several of the existing master-slave systems, they remain inadequate. Therefore, it is necessary to examine how high presence and realistic sensations can be transferred. In addition, the standard index for measuring these sensations such as presence and existence should be defined. In [2], the author(s) mentioned several factors for the presence; however, it is necessary to reveal the key factors for the applications. In a telexistence master-slave system, the operator must be able to exist in a remote environment through the slave robot. In a remote environment, we need to look at the presence and existence in order to offer to the operator the existence sensation.

We focus on the body sensation of humans as a very important factor for the presence. We think that the presence and existence will be created by building the body sensation of being present. Therefore, it is necessary to establish the localization and attribution of the body in the remote place and to make that body ours without doubt. If there is a method to control the body sensation intentionally, it is possible to enhance the quality of telexistence. In this paper, we look at the presence and existence from the viewpoint of body sensation.

There is research that has succeeded in extracting the body sensation from the body using the out-of-body sensation experience. There is also research on the out-of-body sensation. In [3, 4], it is shown that it is possible to extract the sensation of the body from the physical body. The theory of rubber hand Illusion (RHI) is used in both studies. RHI is a phenomenon when a person feels the rubber hand as his own hand by synchronous stimulation. Researchers of [3, 4] extended this phenomenon to the entire body. On the basis of the concept of RHI, they tried to localize and attribute the body sensation from the physical body to the virtual body by touching both bodies.

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In this paper, we examine whether the localization and attribution of the body sensation accrue in an environment with a robot, on the basis of previous research methods. The main aim of this research is to acquire knowledge in order to reveal the method of controlling the ”body sensation” in humans. First, we experiment with previous research setups under our experimental conditions; we change the actor that holds the two rods. Next, we experiment with the actor changing from a certain actor to oneself in a telexistence environment. Thus, we consider whether past research applies to the telexistence system. In other words, we study where and how the localization and the attribution of body are caused by the presence or absence of stimulation.

2 Related works

In this section, we introduce two related researches.

In the past, [3, 4] experimented with the illusion of the out-of-body sensation to provide and apply to the body the perception of the RHI [5]. In the RHI, the rubber hand, which resembled the human hand, was set in front of the participant and the hand of the participant was hidden. The experimenter touched the rubber hand and the participant's hand (hidden from the participant's view) simultaneously. Then, the participant could see only the rubber hand that was touched by the experimenter. As a result, the participant felt the rubber hand as his own. [3, 4] also extended this perception to the entire body using a part of the body.

In [3], the participants wore a pair of head-mounted displays that were connected to two video cameras placed behind their backs, which enabled them to see their backs. The experimenter stood beside a participant and used two plastic rods to simultaneously touch the participant's actual chest and the chest of the “illusory body” by moving one rod toward a spot just below the cameras in view. After 2 min of stimulation, the participants were asked to respond to a questionnaire (10 statements, 3 illusion statements, and 7 control statements) with a seven-point visual analog scale. The participants reported the experience of sitting behind their physical bodies and looking at them from this spot. To provide an objective evidence for the illusion, they registered the skin conductance response (SCR) as a measure of the emotional response when the illusory body was ”hurt” when it was hit with a hammer after a period of stimulation. They reported significantly greater threat-evoked SCRs after the illusion condition. From these results, they concluded that body localization and attribution are better constructed by multisensory correlation (visual information and tactile information). The author of this research also examined several other phenomena of body sensation [6].

In [4] the author examined whether the body localization and attribution occurred by synchronous/asynchronous stimulation within

60 sunder similar conditions. The difference with [3] is that the stimulation point is the back and not the chest of the participant. In addition, the motion shift of the subject was measured for quantitative verification. Motion shift is the distance between the initial position and the final position of the subject when the subject returns back to his/her initial position after he/she has been moved by the experimenter. They also used a questionnaire of ten statements, and they reported that strong illusion only occurred in the synchronous stimulation mode based on the questionnaire and motion shift results. Furthermore, they examined the difference of a visual body form and suggested that strong illusion occurred when the subjects saw a human-like image.

From these results, it will be possible to control the localization and attribution of the body, between the real and the virtual body, by adding the synchronous/asynchronous stimulation to the visual and auditory senses of a third person under an environment in which one can see himself/herself.

3 Evaluation procedure of embodiment

In this paper, we built upon past research in order to examine whether the localization and attribution of body sensation accrue in an environment with a robot. Thereby, we considered whether the past research results could be applied to the telexistence system. That is, we studied where and how the localization and the attribution of the body are caused by the presence or absence of stimulation. In particular, we focus on the actor who applies the stimulation to the physical body and virtual body and experiment with the condition that the robot replaces the actor as the experimenter. Next, we change from the PAHNToM to oneself in a telexistence environment.

4 Experiments

4.1 Preliminary experiment

In this section, we explain the preliminary experiment on the basis of the past research of the out-of-body experience. From these results, we judge that this phenomenon can apply to telexistence.

One aspect of our experiment is to examine the response of the body when a machine stimulates the participant. In conventional research, the participant can see the experimenter; therefore, the participant feels that the experimenter who is a person touches him/her. However, supposedly in telexistence or telepresence, the operator causes the localization and attribution of the body without any person in the master and slave sides. Moreover, in previous research, the localization and attribution of the body are decided by the synchronous or asynchronous stimulation. Then, we review the effect of the localization and attribution of the body when the actor is not a person or there is no other person except the participant. In addition, we examine the difference between the effect of the synchronous and that of the asynchronous stimulation. In this experiment, we selected the PHANToM Omni as the robot because of its simplicity and functional force feedback.

4.1.1 Experimental environment of preliminary experiment

The arrangement of this experiment is shown in Figure 1. In addition, Figure 2 shows the actual environment.

Two cameras are connected to head-mounted displays (HMDs) with a wide field-of-view and high resolution (resolution = 1024 × 768 pixel, diagonal field of view = 42.0 ° for each eye, and refresh rate = 30 ms). This HMD was developed in our laboratory, and its viewpoint distance adjusts to match the distance between the two cameras; therefore, the participants can feel the remote environment rather naturally. The cameras and the HMDs are placed side-by-side 1.5 m behind each participant's back. The slave robot head of the visual telexistence system, which can express a 6 degrees of freedom motion of the upper body, acts as the stereo camera system.

Two styrene foam rods (participant's side rod: 2 cm in diameter and 40 cm in length; robot's side rod: 2 cm in diameter and 60 cm in length) were used to repeatedly touch the participant's physical chest, which was out-of-view and just below the cameras. The two rods were attached to two haptic PHANToM Omni (SensAble technologies) devices. The two PHANToM devices moved to follow preset motion patterns. The motion command for the two PHANTOM devices was issued from a personal computer to avoid the delay between the master and the slave.

The participants were seated in a relaxed position and were instructed not to move. They wore an HMD that was connected to the stereo cameras behind the participant's back at the same height as the person's eyes. This arrangement meant that the person saw his or her back from the perspective of a person sitting behind him or her with stereoscopic vision and without noticeable delay (depending on the LCD refresh rate of 30 ms). The experimenter stands besides the participant, holds the rod at the participant's side, and operates two rods periodically. As an experimental condition, the rods stimulate the participant's physical and virtual chest constantly. After the participant puts off the HMD, he or she answers ten questions of a prepared list.

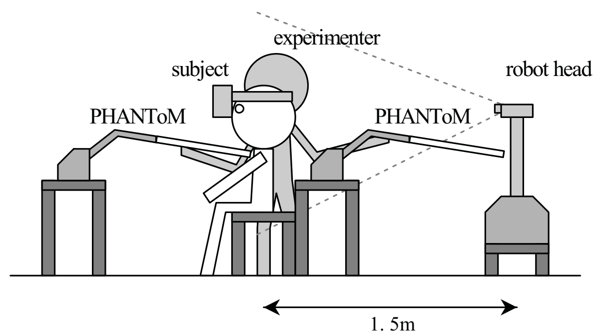

Figure 1: Experimental system environment.

Figure 2: Experimental system environment (actual).

4.1.2 Experimental condition of preliminary experiment

The motion constraints of the rods are categorized to six modes:

- Sync 2 passive rods,

Sync/Async, 2 passive rods | Sync/Async, 1 passive / 1 active rods | Sync/Async, 2 active rods

Figure 3: Experimental modes.

No.	Question
Q1	I experienced that I was located at some distance behind the visual image of myself, almost as if I was looking at someone else.
Q2	I felt as if my head and eyes were located at the same place as the cameras, and my body just below the cameras.
Q3	I experienced that the hand I was seeing approaching the cameras was directly touching my chest (with the rod)

Figure 4: Illusion statement.

No.	Question
Q4	I felt that I had two bodies.
Q5	I experienced that my (felt) body was located at two locations at the same time.
Q6	I experienced a movement-sensation that I was floating from my real body to the location of the cameras.
Q7	I felt as if my head and body was at different location, almost as if I had been decapitated.
Q8	I did not feel the touch on my body but at some distance in space in front of me.
Q9	I could no longer feel my body, it was almost as if it had disappeared.
Q10	The visual image of me started to change appearance so that I became (partly) transparent.

Figure 5: Control statement.

- Async 2 passive rods,
- Sync 1 passive / 1 active rods,
- Async 1 passive / 1 active rods,
- Sync 2 active rods,
- Async 2 acrive rods.

In Sync 2 passive rods and Async 2 passive rods, the experimenter stands beside the participant, holds “two rods” and touches the participant’s physical chest and the virtual chest. In Sync, two rods move synchronously, and in Async, two rods move asynchronously, which generates additional random phase signals to the rod at the robot side. These modes are presuming the same motion as in past research. In Sync 1 passive/1 active rods and Async 1 passive/1 active rods, the experimenter stands beside the participant and holds only ”one rod” at the participant side and touches the participant’s physical chest. Then, the PC-controlled PHANToM automatically moves the rod at the robot side and touches the virtual chest of the participant. The participant can see the rod moving in front of him/her while seeing his/her body touched by the experimenter. Similarly, to above two modes, the rods move synchronously in Sync and asynchronously in Async. In Sync 2 active rods and Async 2 active rods, the experimenter does not stand beside the participant. The PC-controlled PHANToM moves the two rods at the robot and participant side and touches the physical chest and virtual chest. The difference between Sync and Async is the same as above. Figure 3 shows the difference among the above three patterns.

The duration time of the stimulation is 60 s, and the period of the stimulation is 1 Hz in the synchronous mode. In the asynchronous mode, it is 1 Hz with a random phase signal to PHANToM.

The details of the experimental procedure are provided below:

1. The experimenter explains the system configuration to the participant
2. The participant wears the HMD
3. The experimenter gives instructions to the participant to take the same posture as the robot head
4. The experimenter touches the participant’s physical chest and virtual chest, placed just below the cameras, according to the motion of PHANToM (controlled by the PC in response to modes)
5. After 60 s, the participant answers ten questions.

Procedures 2- 6 are executed in each of the 6 modes. Six students participated in this experiment (five males and one female, in their twenties). All participants were healthy.

After a stimulation of 1 min, the participants were required to answer a questionnaire. The ten questions required a rating of the strength of sensation. The questions were presented in a random sequence. The first three questions are illusion statements, which rate high when the participant feels his/her body sensation in the robot. On the other hand, the other seven questions are control statements, which rate low when the participant did not feel his/her body sensation in the robot. These questions are the same as in [3], making it easy to compare the results.

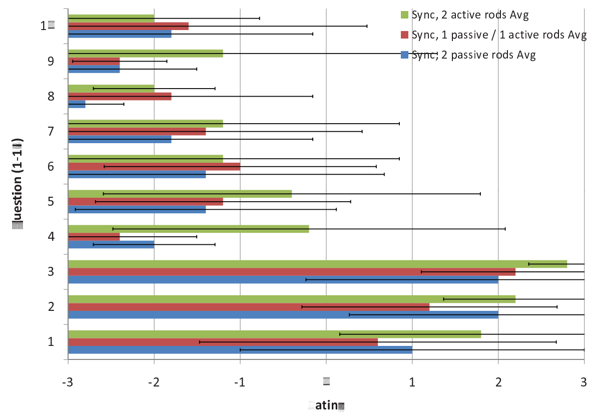

Figure 6: Experimental result of preliminary experiment: Synchronous.

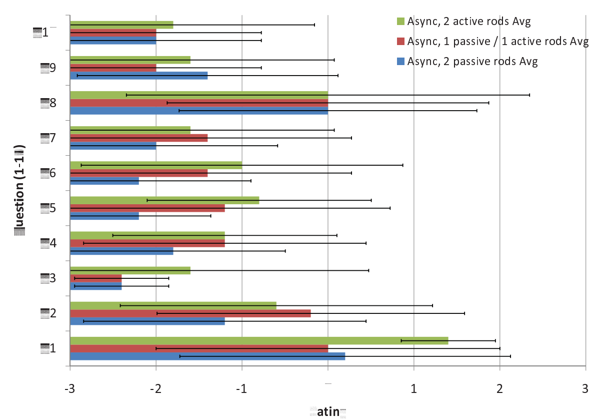

Figure 7: Experimental result of preliminary experiment: Asynchronous.

4.1.3 Results of preliminary experiment

The results of the preliminary experiments are shown in Figures 6 and 7. Figure 6 shows the result of the synchronous stimulation of each mode, and Figure 7 shows the result of the asynchronous stimulation of each mode.

From the results, the rating of questions Q1-Q3 is high and the rating of the other questions (Q4-Q10) is low in synchronous stimulation. In contrast, in the asynchronous stimulation, the rating of all the questions is low. The trend of these results is similar to that observed in the previous research. Moreover, the difference between the ratings of the questions of each mode is not large. Therefore, it shows that the localization and attribution of the body occur regardless of the kind of actor that provides the stimulus.

Next, we look at the individual results. In synchronous stimulation, the score of “Sync, 2 active rods mode” is high all around. This trend is good for the illusion statement; however, it is noteworthy that the score of questions 5 and 6 are also high. These two questions ask whether the person feels his/her body at two places. Therefore, it seems that the person loses sight of the localization and attribution of oneself. In asynchronous stimulation, the scores of question 1, question 2, and question 3 are low; however, the score of question 1 is higher than those of the other two questions. We assume that this result is attributed to the experimental environment. In our environment, the condition of the robot head and HMD is optimized (view angles and distance between eyes are equal in both); therefore, a very natural stereoscopic view is achieved. These results indicate the possibility that a realistic sensation is high, regardless of the synchronous of stimulation. Thus, the score of question 1 could increase by a stereoscopic effect of the image, in spite of the asynchronous stimulation. In addition, the score of question 8 is higher than that of the rest. In the asynchronous stimulation, the rod touches the actual body before the apparent rod touches the apparent body. The timing between the touch of the actual and apparent rod differs; therefore, we assume that the subject feels the stimulation at a point distant from the actual body. On the other hand, in synchronous stimulation, the score of question 8 is low. Therefore, we think that the person will tangibly recognize the apparent rod position.

4.2 Main experiment

From the results of the preliminary experiment, we represent the environment of previous research and find that it does not depend on the actor of the stimulation. Next, we verify this result by probing and looking for the kind of elements that influence the out-of-body sensation.

The feature of our experiment is to use the active tactile stimulation by telexistence, and not the passive stimulation by a third person. By interaction with one’s body, active stimulation is achieved. Thereby, a person can become both a giver and a receiver of tactile stimulation. Therefore, in this section, we evaluate the factors that decide the localization and attribution of the body.

We also use rods for tactile stimulation, and we examine the difference in the presence or absence of the stimulation to the arm and the body.

4.2.1 Experimental environment of main experiment

The arrangement of this experiment is shown in Figure 8. In addition, Figure 9 shows the actual environment. Similar to the preliminary experiment, two cameras are connected to head-mounted displays (HMDs) with wide field-of-view and high resolution (resolution = 1024 × 768 pixel, diagonal field of view = 42.0° for each eye, and refresh rate = 30 ms). This HMD was developed in our laboratory, and its viewpoint distance can adjust to match the distance between two cameras; therefore, the participants can feel the remote environment in a natural way. The cameras and the HMDs are placed side-by-side 1.5 m behind each participant’s back. Similar to the stereo camera system, the slave robot head of the visual telexistence system can perform a 6 degrees of freedom motion of the upper body. As in the preliminary experiment, two styrene foam rods (participant’s side rod: 2 cm in diameter and 40 cm in length; robot’s side rod: 2 cm in diameter and 60 cm in length) were used. The two rods were attached to the two haptic PHANToM Omni (SensAble technologies) devices. The difference with the preliminary experiment is that the direction of the two PHANToM devices with the rod follows the direction of the participant. The two PHANToM devices are in a master-slave relationship, and the control method changes according to the experimental conditions. To avoid delays between the master and the slave, as in the preliminary experiment, a personal computer directs the motion of the two PHANToM devices. Moreover, the hand of the participant was covered to hide its view by the camera. Responding to the experimental conditions, instead of the human’s back, we placed the object in front of the PHANToM at the participant’s side. In this experiment, the advantage of using the PHANToM is the ease in setting up the experimental conditions.

As in the preliminary experiment, the participants are seated in a relaxed position. They wear an HMD that is connected to stereo cameras behind their back. The participants use the PHANToM with the rod at its side and touch their back, which they have in their view. During the experiment, the participant wears a earphone and hears the sound of a metronome. The participant receives at his/her back the stimulation by the rods of the robot side constantly. After the participant puts off the HMD, he or she answers ten questions from a prepared list.

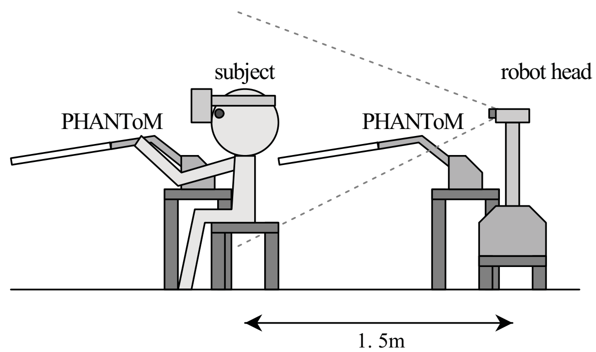

Figure 8: Experimental system environment.

4.2.2 Experimental conditions of main experiment

The motion constraints of the rods are grouped into four modes. We grouped by the existence or nonexistence of the stimulation to the subject’s arm, which has the rod at the subject’s side, and the stimulation to the subject’s back, which is touched by the rod at the robot side.

- Arm + Back
- Arm
- Back
- None

“Arm + Back” refers to the stimulation to the subject’s arm and back. “Arm” refers to the stimulation to the subject’s arm, whereas the stimulation to the subject’s back is nonexistent. “Back” refers to

Figure 9: Experimental system environment.

the nonexistent stimulation to the subject's arm, whereas the stimulation to the subject's back is present. "None" refers to the lack of stimulation to the subject's arm and back. These differences are shown in Figure 10.

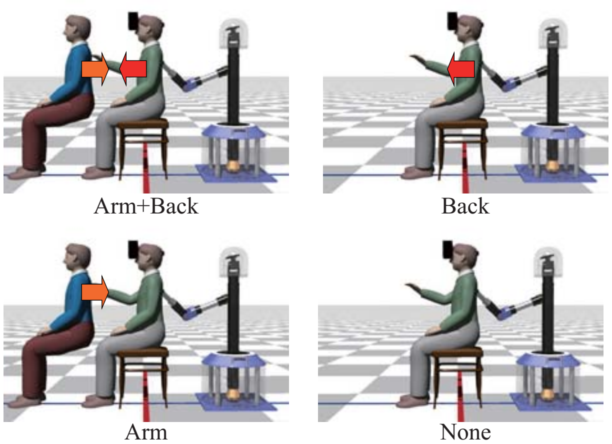

Figure 10: Experimental modes.

After a stimulation period of 1 min, the participants were required to answer a questionnaire comprising eleven questions that rated the strength of the sensation. The questions were presented in a random order. The first three questions were illusion statements, which were rated high when the participant felt his/her own body sensation in the robot. In contrast, the other eight questions were control statements, which were rated low when the participant did not feel his/her own body sensation in the robot.

The duration time of the stimulation is 60 s. The experimenter directs the participant to operate the rod using a period of 1 Hz.

The details of the experimental procedure are provided below:

1. The experimenter explains the system configuration to the participant

2. The participant wears the HMD and earphone

3. The experimenter instructs the participant to take the same posture as the robot head

4. The participant touches the participant's physical back in view

5. After 60 s, the participant answers ten questions.

Procedures 2-6 are executed in each of the four (4) modes. Five male students participated in this experiment (all five were in their twenties). All participants were healthy.

We assume that the stimulation is the key factor. If the stimulation is applied to the arm of the subject, then the subject will feel as if he/she is the actor. If the stimulation is applied to the back of the subject, then the subject will feel as if he/she is the

4.2.3 Results of main experiment

The results of the main experiments are shown in Figure 13.

From the results, we find that the score of question 1 is positive and the scores of questions 7-11 are negative. These trends are similar to the results of the preliminary experiment. Question 3 and question 4 are important statements. They decide where localization and attribution occur in the subject's body. The "Arm" mode is positive for question 3 and negative for question 4. Therefore, when the stimulation to the subject's arm is present, the subject feels as the actor, that is, the subject feels in the robot position. In our expected result, the "Back" mode is positive for question 4 and negative for question 3. However, the actual results show that the "Back" mode is positive for both questions 3 and 4. The score of question 4 is larger than that of question 3, and it is the largest. Therefore, the "Back" mode is the most effective in question 4. Why the score of question 3 is positive? As one reason, we think that the experimental environment is not appropriate. We used PHANToM as the actor to provide stimulation to the subject's back. PHANToM can exert force but its power is small. Therefore, it might not stimulate sufficiently enough. Moreover, PHANToM has three degrees of freedom, which is a large value. For these reasons, we must reconsider the experimental environment. Alternatively, there is a possibility that the score of question 3 increases owing to the activity of the subject's arm. That is, the activity of the person may be dominant in the case of body localization and attribution. Thereby, the subject would feel both as the actor and as the receiver. In fact, because the score of questions 5 and 6 is positive in the "Back" mode, the subject would feel as having two bodies.

We did not obtain the expected results in this case; however, the results show that the existence or nonexistence of stimulation on the subject's arm and back can change the feeling of body. In particular, the activity of the person may be important to body localization and attribution in a remote place. In the next step, we will reconstruct the experimental environment and examine the body sensation in detail.

5 Conclusions

In this paper, we examined whether the localization and attribution of the body sensation accrue in an environment with a robot, on the basis of methods of past research. First, in a preliminary experiment, we examined the out-of-body experience on the basis of past research. From the results, we concluded that this phenomenon could be applicable to telexistence. As a result, the localization and attribution of the body occur regardless of the kind of actor that provides the stimulus.

Next, we verified this phenomenon in a probing situation and looked for the kind of elements that influence the out-of-body sensation. We used the active tactile stimulation by telexistence, and not the passive stimulation by a third person. Consequently, the activity of the person may dominate the localization and attribution of the body. As a next step, we will reconstruct the experimental environment and examine the body sensation in detail.

No.	Question
Q1	I experienced that I was located at some distance behind the visual image of myself, almost as if I was looking at someone else.
Q2	I felt as if my head and eyes were located at the same place as the cameras, and my body just below the cameras.
Q3	I experienced that my hand was directly touching other back (with the rod).

Figure 11: Illusion statement.

No.	Question
Q4	I experienced that my back was touched by other hand (with the rod).
Q5	I felt that I had two bodies.
Q6	I experienced that my (felt) body was located at two locations at the same time.
Q7	I felt that I had three bodies.
Q8	I experienced that my (felt) body was located at three locations at the same time.
Q9	I experienced a movement-sensation that I was floating from my real body to the location of the cameras.
Q10	I felt as if my head and body was at different location, almost as if I had been decapitated.
Q11	I did not feel the touch on my body but at some distance in space in front of me.

Figure 12: Control statement.

Q11 : I did not feel the touch on my body but at some distance in space in front of me.

Q10 : I felt as if my head and body was at different location, almost as if I had been decapitated.

Q9 : I experienced a movement-sensation that I was floating from my real body to the location of the cameras.

Q8 : I experienced that my (felt) body was located at three locations at the same time.

Q7 : I felt that I had three bodies.

Q6 : I experienced that my (felt) body was located at two locations at the same time.

Q5 : I felt that I had two bodies.

Q4 : I experienced that my back was touched by other hand (with the rod).

Q3 : I experienced that my hand was directly touching other back (with the rod).

Q2 : I felt as if my head and eyes were located at the same place as the cameras, and my body just below the cameras.

Q1 : I experienced that I was located at some distance behind the visual image of myself, almost as if I was looking at someone else.

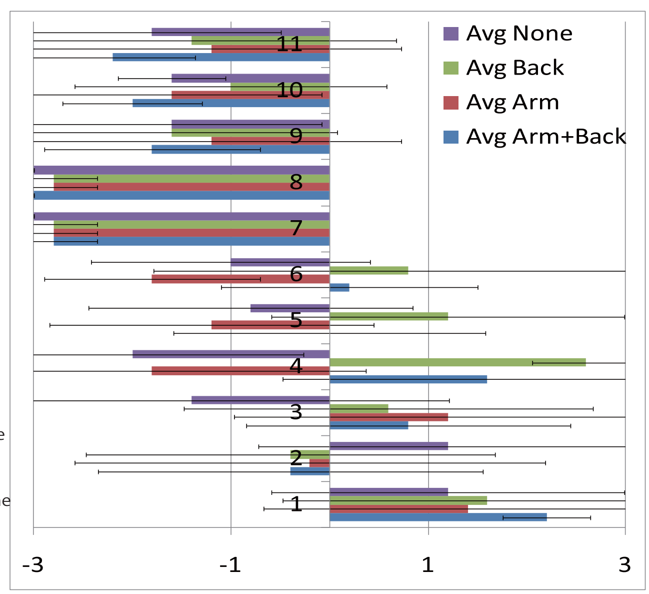

Figure 13: Experimental result.

Acknowledgements

This work was partly supported by SCOPE: Strategic Information and Communications R&D Promotion Programme.

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