Body ownership transfer to tele-operated android through mind controlling

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Abstract: This work examines whether body ownership transfer can be induced by mind controlling android robots. Body ownership transfer is an illusion that happens for some people while tele-operating an android. They occasionally feel the robot's body has become a part of their own body and may feel a touch or a poke on robot's body or face even in the absence of tactile feedback. Previous studies have demonstrated that this feeling of ownership over an agent hand can be induced when robot's hand motions are in synchronization with operator's motions. However, it was not known whether this occurs due to the agency of the motion or by proprioceptive feedback of the real hand. In this work, subjects imagine their own right or left hand movement while watching android's corresponding hand moving according to the analysis of their brain activity. Through this research, we investigated whether elimination of proprioceptive feedback from operator's real limb can result in the illusion of ownership over external agent body. Evaluation was made by two measurement methods of questionnaire and skin conductance response and results from both methods proved a significant difference in intensity of bodily feeling transfer when the robot's hands moved according to participant's imagination.

Introduction

During the past few years, development of Geminoids has opened new research areas regarding communication robots [1]. Geminoids are very human-like robots that resemble a particular person they were modeled from (Fig.1). There are multiple pneumatic actuators installed in their face and bodies to provide them noiseless and smooth movements similar to a human being. Using image tracking interface or motion capture devices, Geminoids can be operated by their real sources or any other person from a distant place.

When people have a conversation with a Geminoid, they are usually distracted by the appearance of robot at the beginning. However, after a few minutes talking, they start making eye contacts and having a natural interaction with it as if they are talking to the real person [2]. This is a major difference between Geminoid and other communication media such as telephone or videoconference system that it can eliminate the feeling of distance between two conversation participants and transfer a feeling of operator's existence to his partner through Geminoid's body.

There are evidences that not only interaction partners, but also operators can be affected by unusual illusions due to the operation of Geminoid. After a while of controlling, when operators could adapt to the system and have a natural conversation, their mouth movements become slow, their body motions become solid and unconsciously they try to adjust their actions to the robot. Moreover, some of them may even feel the irritation of a poke on robot's face or the happiness of a cuddle if robot is hugged as if they themselves have been touched instead of robot. This phenomenon is called "bodily feeling transfer" in which an external object is recognized as a part of one's own body [2]. This illusion

Fig.1 Geminoid F, HI, DK and their models

is not exclusive to the real models of Geminoids and can happen for other operators too.

However, it does not occur all the time and also it is difficult to be arisen by conscious effort. It is believed that by enhancing this feeling of ownership over Geminoid's body, operators will experience a transfer of their own existence to the robot's body, leading to improvement of tele-operation, conveyance of their presence to the partners more effectively and eventually a more natural communication through Geminoid.

Our previous work challenged verification of bodily feeling transfer during operation of Geminoid's hand from a distant place [2]. Results showed that when Geminoid's hand moved in synchronization with subjects' real hand, a sense of ownership could cause a reaction from subject if robot's hand was threatened by a pain causing stimulus such as injection.

What remained unknown from our past investigations is that due to what certain element the illusion of body ownership transfer is induced. Is it the motor agency by robot or is it the actual feedback form muscle movements and their correlations with information from vision?

In this research we take a novel approach for operating Geminoid by brain activities and examine inducement of body ownership over robot's body in the absence of operator's motions. The question here is weather bodily feelings transfer to an agent robot can be induced by only execution of operator's intentions and therefore elimination of proprioceptive feedback from his real limbs.

Related works

Research on the transfer of bodily sensation and ownership has been carried out widely in recent year. Researchers have applied different methods to induce and evaluate the illusion of bodily feeling extension to an external object.

Botvinick and Cohen provided a first description of the "Rubber Hand Illusion" [4]. Their experiments demonstrated that when a participant's hand was placed out of view and a life-size rubber model was placed in front of them, simultaneous strokes of paintbrush on both rubber hand and participant's hand resulted in a crossmodal perceptual illusion of possession over rubber hand.

Armel and Ramachandran investigated about the transfer of body sensations to a rubber using skin conductance response (SCR) [5]. SCR can measure autonomic nervous system arousal in anticipation of pain [6]. They performed the RHI procedure in two cases of synchronized and delayed stimulation and then threatened the rubber hand by bending a finger backwards to seem painful. The results showed a high SCR value at the bending time when the strokes on both hands were synchronized.

Slater et al. conducted similar experiments using computer-simulated environment [7]. They reported an illusion of ownership displacement through tactile stimulation on a person's hidden real hand with synchronous virtual visual stimulation on a virtual arm projecting out of his shoulder.

In all researches above and similar rubber hand experiments, the illusion is evoked by multisensory input of synchronous tactile stimulation and visual feedback.

However, further challenges are needed to confirm transfer of ownership in case of other perceptual correlations.

Watanabe el al. investigated about the transfer of bodily feelings to a robot's hand in the absence of tactile simulation [2]. They showed that movement synchronization between operator's hand and robot's hand under visual feedback can induce body ownership over robot's hand.

Perez-Marcos et al. used a virtual reality system to examine the illusion of ownership of a virtual hand induced by motor imagery [8] and showed that the subjective illusion of ownership of a virtual hand can also be induced by imagination of a motor act followed by movement of the virtual hand.

In our experiments, we explore weather the control of human-like robot's hand through a noninvasive BCI can enhance the illusion of ownership and agency towards that hand, in the absence of both tactile sensory stimulation and proprioceptive feedback from subject's real hand. Furthermore, to prove body ownership transfer to robot, not only self-assessment but also SCR measurements are taken during operation for evaluating subject's response to events occurring to robot's hands such as being threatened by a pain-causing stimulus.

BCI configuration

To investigate about the transfer of ownership feeling to a robot's body in absence of real movements, we developed a brain computer interface combining a cerebral activity classification system (g.USBamp amplifier and g.BSanalyse, Guger Technologies, Graz, Austria) and Geminoid's tele-operation system [2]. Fig.2 shows the system configuration. Operator is instructed to imagine a right or left hand movement while his brain signals are recorded from 27 electroencephalogram (EEG) electrodes installed over the primary sensori-motor cortex of his head. The acquired data are processed online under Simulink/MATLAB (Mathworks Inc. Natick, Massachusetts, USA) for real-time parameter extraction. This includes bandpass filtering between 0.5 and 30 Hz, sampling at 128 Hz, cutting off artifacts by notch filter at 60 Hz, and adopting Common spatial pattern (CSP) algorithm for discrimination of Event Related Desynchronization (ERD) and Event Related Synchronization (ERS) patterns associated with motor imagery task [9]. The results are classified with weight vectors and translated into commands for Geminoid's right or left hand motions. There is a delay of 200~800 (ms) in the system due to online analysis of brain signals and robot's operation system.

To provide subjects a visual feedback of robot's hands during tele-operation, a camera is installed in Geminoid's room (Fig.2).

Procedures

Experiments consisted of two stages of training and testing in order to achieve a satisfactory online performance during robot operation. Nineteen healthy participants (12 Male, 7 female) in the age range of 18~25 (M=20.7, SD=1.7) were selected for the experiment. All participants were naïve to the research topic and were paid for their participation. Each time they attended the experiment, they read and signed a consent form in accordance with the regulations of ethical committee of ATR.

Training stage

Before running main experiments for examining bodily feelings transfer during mind controlling of Geminoid, it was necessary to train participants to become familiar with motor imagery task and to become able to control their brain activities to a favorable level for EEG signals acquisition.

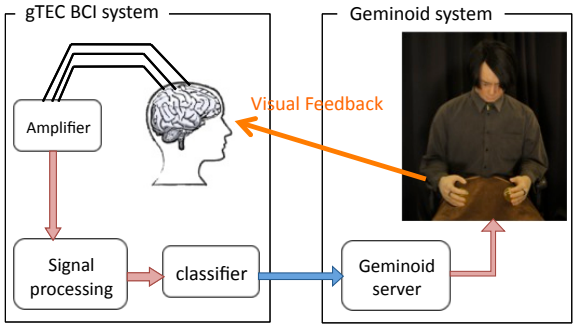

Fig.2 System configuration

In the training sessions, participants practiced motor imagery task to control a feedback bar on computer monitor to left or right side. They wore an electrode cap, sat in a comfortable chair in front of a computer screen and were asked to relax and not move. The first run consisted of 40 trials conducted without feedback and the recorded data was used to set up a subject specific classifier. In the following runs, participant had to control a horizontal feedback bar according to a cue for 40 trials. Each trial lasted 7.5 seconds and started with the display of a fixation cross that was shown in the center of screen. After 2 seconds a warning was given in form of a "beep". From second 3 to 4.25, an arrow pointing to the left or right was shown and depending on its direction the participant was instructed to imagine a left or right hand movement. It was recommended to participants to hold image of a powerful movement such as grasping firmly, pushing or punching. Between second 4.25 and 7.5, the EEG signals were classified online and the result was translated to a feedback bar on the screen (Fig.3).

Subject's performance during experiments was recorded for evaluation of improvement after each session. At the end of training sessions, participants who could reach a performance of 60 to 100 percent were selected for testing stage.

Testing stage

Following the training sessions, the participants were invited for testing experiment that was measuring transfer of bodily sensations while controlling Geminoid's hands.

In the main session participants were required to do a left or right hand gripping just by imagining that movement. Two balls were set up in front of robot's hands to ease imagery task, and each of them lightened randomly during experiment to give a cue for imagination (Fig.4).

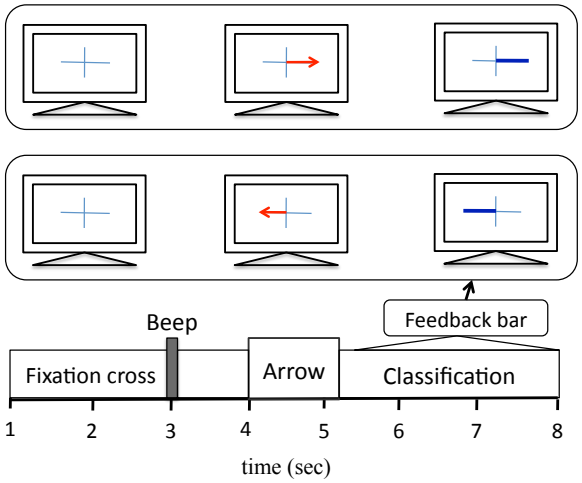

Fig.3 Experimental paradigm and timing

Participants visited Geminoid before starting the session and received explanation about their task. They wore the electrode cap, sitting in an armchair in a room next to the robot and wore a head mounted display (Vuzix iWear VR920) to have a first person view over robot's hands (Fig.4). During experiment they were instructed to look down as if they are watching their own hands and same blankets were laid on both robot's and participant's legs to give similar view of one's own body. Participants placed their arms in the similar position and orientation of robot's arms and SCR electrodes were installed on their left palm. (Fig.5). For SCR measurements, we used a bio-amplifier recording device (Polymate II AP216, TEAC, Japan) with sampling rate of 1000 Hz.

Experiment began with calibration session for adjusting the classifier to each subject, and continued to three main testing sessions. Prior to the testing sessions, participants watched injection to robot's hand through HMD, which was explained to them as an act of robot adjustment. Following Armel et al. [5], injection was applied until subject's SCR responses disappeared. Afterwards, testing sessions were carried out in a random

(a) (b)

Fig.4 (a) First person view of robot's hands (b) Robot's left hand grasps the lightened ball due to subject's imagination

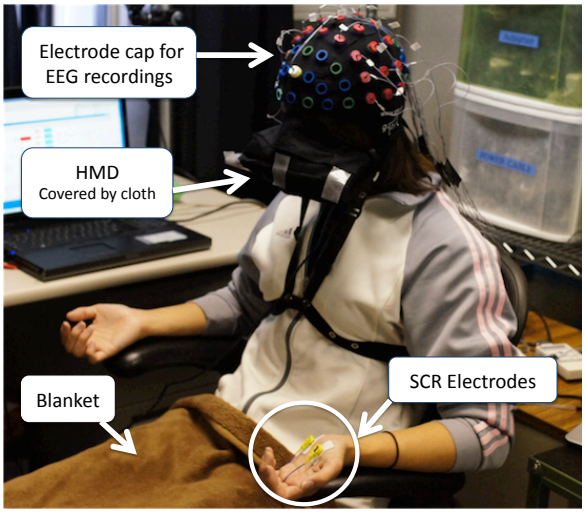

Fig.5 Experiment set-up

order under three conditions:

(1) Robot's hands do not move at all although subject holds imagination according to cue (Still)
(2) Robot's hand moves only if classification result is correct and same as cue. (Match)
(3) Robot's hands move even if classification result is wrong and in opposite of cue. (Raw)

In each session participants performed trials that were designed similar to training sessions regarding length and stimulus timing. After completing 20 trials, which lasted for 2 minutes and 40 seconds in total, an injection was applied to robot's left hand to examine if the illusion of ownership could cause a response to a pain-causing stimulus.

Evaluation

The response variables from the experiment were obtained from (i) Questionnaires and (ii) SCR recordings. In the questionnaire subjects were asked the following question and selected from three choices.

- How did you feel when the robot's hand was injected?

- I felt as if I my own hand was injected. (Myself)
- I felt as if some other person's hand was injected. (Other person)
- I felt nothing. (Nothing)

Since participants were wearing HMD and SCR electrodes and therefore were not able to write during the experiment, after each session they were orally interviewed and experimenter filled the questionnaire. There was also a post-questionnaire that was filled by participant after experiment was finished.

Generally SCR starts to rise 1~2 seconds after a stimulus is applied and finishes 5 seconds after it [5]. The peak value of response within this interval is selected for analysis. In this experiment injection was applied about 2 seconds after injection syringe enters participant's view. Since participants may also react to syringe as a result of bodily feeling transfer, SCR values were measured from 1 second after syringe appeared in participant's view to 5 seconds after the injection was actually applied. (Fig.6)

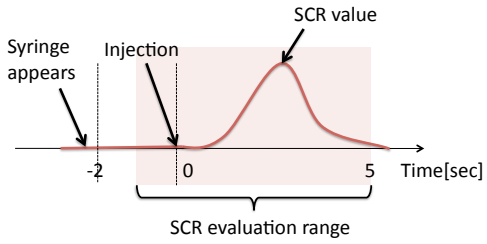

Fig.6 SCR evaluation range

Results and Discussion

The questionnaire answers and SCR measurements are presented in the following and a comparison between the results in each condition is made.

Questionnaire

Fig.7 shows participants number regarding their answers in each condition above. As it is seen, in all conditions the number of participants who felt they themselves were injected during the stimulus and participants who felt another person was injected is noticeably more than those who felt nothing. This can be resulted from the robot's appearance and movement that is very human-like and therefore is categorized differently from an object by participants.

During Stimulus session in which robot's hands moved only if imagination result was correct (same as cue), the majority of participants felt as if they themselves were injected when the robot was injected. In Raw condition the number of participants who felt the same way decreased and was equal to the number of those who felt as if another person was injected. This was to a certain extent dependant on participant's performance during the session. Those participants who were more capable of controlling robot's hands in correct direction had a stronger feeling of ownership and therefore felt the injection as if it was applied to their own hand. On the other hand, those who failed to operate robot's hands correctly could not experience ownership transfer to robot's body.

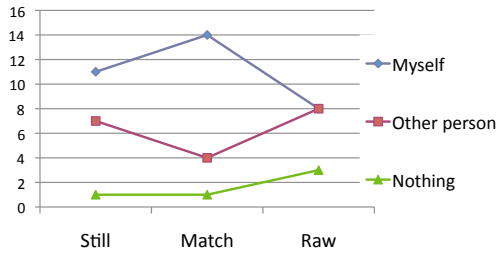

Fig.7 Number of participants depending on their answers in each condition

The results for Still condition in which robot's hands didn't move at all were unexpected. Except for one participant, the rest of participants answered with "Myself" or "Other person", and among these answers those who chose myself were more. This pattern was observed since the beginning of experiments and when the first six participants were interviewed, they explained that their reason for choosing "Myself" was that during the session although robot's hands did not move, they imagined them as their own hands to perform imagery task. Therefore when the hands were threatened by injection, they felt as if their own hands were threatened. According to interviews, this feeling was not as strong as Match condition when they could operate the robot successfully, but was stronger than Raw in which the distraction of a wrong movement interrupted their imagination and as a result weakened the illusion.

Therefore, for the rest thirteen participants an additional question was designed to measure the strength of their bodily feeling transfer in terms of numerical values. In this question, participant should score the following statement:

- When robot's hand was injected, I felt as if my own hand was injected.

Scores were rated according to a seven-point Likert Scale, 1 meaning "totally disagree" and 7 "totally agree". The obtained values from each condition were averaged and multiple comparisons were made between three conditions using Bonferroni test at a statistical significance level of 0.05. The average value, standard error and *p*-value from thirteen participants are demonstrated in (Fig.8).

Statistical significance was confirmed for Match condition in comparison with both Still and Raw ($p < 0.05$).

SCR:

SCR values in each condition are averaged and presented in (Fig.9) along with standard error and *p*-value obtained from multiple comparisons using Bonferroni method. Statistical significance was only

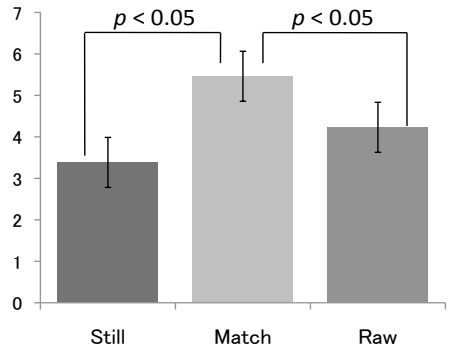

Fig.8 Averaged score of Questionnaire

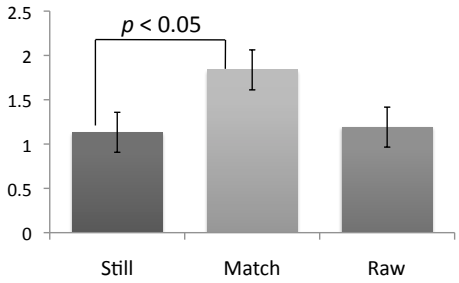

Fig.9 Averaged value of SCR

confirmed between Match condition and Still condition ($p < 0.05$).

Both questionnaire and SCR measurements showed a statistical significance between Match and Still conditions which proves our hypothesis in this research true: "Body ownership transfer to Geminoid's hands can be induced through mind controlling under visual feedback and in the absence of operator's actual movements."

On the other hand, although participants' answers resulted into a significant difference between two patterns of movement (Match and Raw), this difference was not proved by skin conductance values. This means that robot's mis-execution of target for those participants with a less accurate performance, resulted into a corruption of bodily feeling transfer and affected their judgment of ownership. However the physical response to the applied stimulus occurred, probably due to the correctly performed movements.

Another factor that should be discussed regarding SCR measurements is the order of sessions during the experiment. Usually after one or two times watching robot being injected, participant's response disappeared as a result of getting used to it. Especially for those participants that Still condition was experimented at the beginning and Match session at the end, usually SCR values became stable and unchanged against stimulus. We predict that if different conditions were tested with long intervals inserted in the middle of sessions, or more favorably on different days, responses from skin conductance would provide us a more reliable result.

Conclusion

It is generally believed that inducing illusion of ownership over an external object requires multi- sensory correlations such as tactile stimulation or synchronous movements under visual feedback. However, this work has demonstrated that body ownership transfer to a robot's hand can also be induced in the absence of sensory information such as touch or proprioception and merely by the imagination of a motor act followed by robot's motions under visual feedback.

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