Shaping Egocentric Experiences with Wearable Cybernic Interfaces

著者（英）	Jun Nishida
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博士（人間情報学）論文概要

Shaping Egocentric Experiences with Wearable Cybernic Interfaces (装着型サイバニック・インタフェースによる主体的な自己体験の変容)

グローバル教育院　エンパワーメント情報学プログラム

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Jun Nishida
University of Tsukuba, Japan / JSPS (-2019.03), University of Chicago, USA / JSPS (2019.04-)
jun.nishida@acm.org

ABSTRACT

Embodied experiences, such as muscle activity that should be shared between patients and therapists, or a lower perspective of a child that should be shared with designers are broadly categorized as embodied knowledge that cannot be acquired by conversations or visual media, but only through active physical experiences.

I hypothesize that changing a person's body, including one's perceptions, actions, and interactions, to that of another person such as a child or a patient, while allowing active interaction with the surrounding objects and people in a real-world environment, would provide more valuable as well as empathic knowledge to school teachers, product designers, and medical staff when designing living environments or communicating with others. To achieve these new paradigms to acquire embodied knowledge of personal experiences, I designed the following two types of corporeal changes: 1) changing the visual and haptic perspectives into those of a child, and 2) changing the kinesthetic perspective to that of a patient.

To achieve this, I developed wearable devices that can sense and intervene in human body functions directly for changing one's bodily sensation or perspective. This allows the wearer to experience changes in perception, action, and interaction while preserving the active, embodied, and social experiences within a real environment; this is a beneficial method for supporting the acquisition of embodied knowledge for the scenarios that are experienced.

I investigated the wearer's perceptions, actions, and interactions throughout lab and field studies, and discuss how the wearable systems contribute to the change of bodily sensation. These studies verified that the devices have changed the wearer's embodied and social experiences, and also gained embodied knowledge and empathy toward different people through the wearer's active engagement with existing environments. Interestingly, not only the wearer but also the surrounding people changed their interaction toward the wearer. It is assumed that the change in the wearer's body created new social context with surrounding people, enhancing the shaping of bodily sensation.

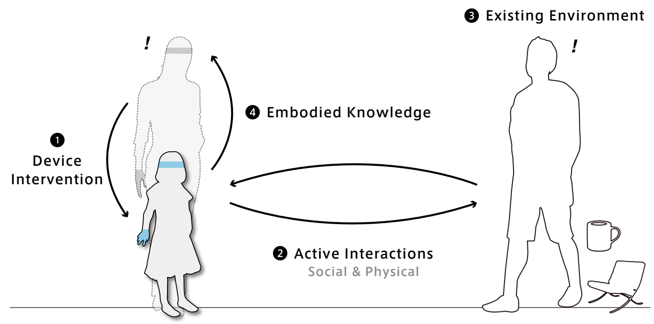

Figure 1: Acquiring Embodied Knowledge of One's Experience through Shaping Bodily Sensation

1 INTRODUCTION

Understanding the embodied and social experiences of a person can play an important role in gaining knowledge or empathy toward an individual or enhancing one's experience in the fields of rehabilitation, design, and education. These embodied experiences, such as muscle activity that should be shared between patients and therapists, or a lower perspective of a child that should be shared with designers are broadly categorized as embodied knowledge that cannot be acquired by conversations or visual media, but only through active physical experiences.

With the recent advancements in wearable technologies and virtual reality techniques, human's embodied experiences are being augmented beyond the limitations of space and time. Wearable devices have already achieved an extension of the user's presence in a remote place by sharing their first-person perspective [13] or by surrogating one's body into a robot [32] or other person as an actuator [19, 30]. Recent studies have also allowed users to not only extend their presence but also extend their sense of ownership into an another person's body [27] or another life form [15], to gaining knowledge by sharing multiple visual perspectives among people [11], or to provide a third eye on their back to see behind them [6]. Interestingly, it was mentioned that changing bodily sensations through such technologies also changes one's perceptions and actions [16]. Several design tools that assists in conveying or reproducing one's experience have been proposed based on changing bodily sensations.

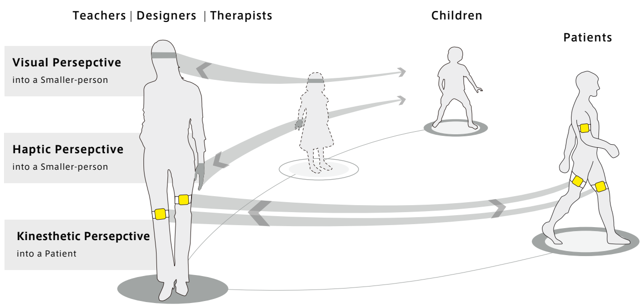

Figure 2: Shaping Visual, Haptic, and Kinesthetic Perspectives into that of a Smaller Person and a Patient

Reproducing One's Experience for Learning

Video materials [31], an illusion technique used for extending the sense of ownership to a small doll [33], or an immersive virtual reality technique for converting the user's body into a smaller avatar [1] have been used to create the sense of being a smaller person, through which the user's experience may feel passive. Several studies have achieved to change one's bodily sensation into that of elderly [5] and impaired individuals [28] by wearable visual, haptic, or kinesthetic systems while preserving the wearer's active interactions.

Active, Embodied, and Social Experiences should be Provided for Therapists, Designers, and Teachers

These conventional tools are able to partially transmit the characteristics or experiences of a person's embodiment and their special needs to other people symbolically and visually; however, the following drawbacks still remain:

(1) Users receive the bodily information in a passive manner from these media, while embodied knowledge can be acquired actively with physical actions.
(2) It is difficult to provide embodied interactions, which involve proprioceptive feedback that play important roles in learning or even altering bodily sensation.
(3) It is hard to generate social interactions with people through these tools, which is also an important form of feedback for the user's physical actions because the user is in a virtual space; this may result in isolation from the social and physical contexts.

If it becomes possible to understand one's experiences in a real-world environment in an active, embodied, and social manner, a more empathic experience will be provided for product designers and educational staff when trying to design living environments or communicating with other people.

2 SHAPING EGOCENTRIC EXPERIENCES

In this research, a new paradigm is proposed in order to change one's experience consists of perceptions, actions, and interactions by changing one's body into that of another person, while allowing active interactions with the surrounding objects and people in a real-world environment, as shown in Fig. 1. This would provide embodied and empathic knowledge of one's experience rather than describing or simply presenting it in a symbolical or visual manner. The three human factors; one's perceptions, actions, and interactions would play important roles in defining physical and social experiences and contexts with objects and people, thus constituting the sum of one's embodied and social experiences.

Because all actions and interactions in the proposed experience style should be performed in a same interaction manner with that in an existing daily life, the user's conscious act which consists of voluntarily initiating actions, defined as subjective agency [9], should be preserved.

I call this experience that particularly includes both subjective agency to initiate actions and active interactions with a user's intention, as **egocentric experience** in that a user is able to have an intention to initiate, then initiate, and freely perform actions and interactions with his/her own intention and timing.

Neuroscience studies have revealed that active interactions foster the change in bodily sensation, particularly body representation [17, 18, 26]; therefore I fully exploit a user's egocentric actions and interactions for changing the bodily sensation to change the user's bodily sensation.

It is assumed that a user's egocentric experience and bodily sensation would continue to be changed with the active interactions, thus I call this modification of the experience as **shaping**, as related studies in neuroscience also use the same term [7, 8].

Interfaces which satisfy design goals including wearable form factor, interactivity, and I/O correspondence, as a **wearable cybernic interface**.

Smaller-person Experience (Fig. 3)

Overview. In this research, I attempts to change the wearer's body representation to have a small-person's perspective in a real environment, with a capability of full body interaction by using wearable devices (Fig. 2). The feasibility and properties of active smaller-person experience in a RE were investigated through both field and lab studies to discuss its challenges and opportunities. To allow this, the concept of a body representation transformation into a smaller person using a wearable VR device has been proposed [21, 24, 25]. Visual stimuli plays an important role in recognizing the relationship between a user's own body representation. Changing the height of the eye level to a lower position while

Figure 3: A wearable visual device that allows a user to change their body representation, in realtime, to that of a small-person

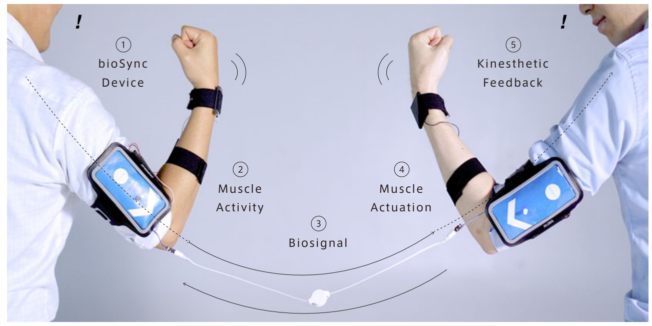

Figure 4: Representative Image of Blending Kinesthetic Experience

allowing for FOV control will allow an egocentric visual perspective of a smaller person to be achieved. Tiny hands and a shorter length of the upper limbs are other important factors enhancing the sense of being smaller [4, 14].

Contributions.

(1) **Conceptual representation** of shaping visual and haptic perspective into that of a smaller-person
(2) **Development of two wearable devices**: 1) a visual translator for mapping the wearer's eyesight level onto his/her waist position by using a head-mounted display (HMD) and a wearable camera module, and 2) a pair of passive hand exoskeletons for miniaturizing hand gestures by using motion conversion mechanisms
(3) **Conducted user studies** at a nursing school, a museum and a lab to explore how a wearer's experience regarding perceptions of interpersonal distance (study 1), actions during handshaking and a peg manipulation (study 2), and interactions (study 3) can be changed

Blending Kinesthetic Experience (Fig. 4)

Overview. In this research, I aim to assist mutual understanding of one's bodily activity during rehabilitations or sports training by sharing kinesthetic experiences with multiple persons, such as muscle contraction and joint rigidity, which are difficult to observe visually (Fig. 2). To achieve this, I propose a blended kinesthetic interaction that allows synchronizing, adding or subtracting muscle activities between two persons.

A novel style of interpersonal kinesthetic communication between two persons using wearable kinesthetic input-output (I/O) devices was proposed [22]. The system, called bioSync, is illustrated in Fig. 4. Using this system, which consists primarily of a pair of devices, muscle contractions of one user are detected by means of electromyogram (EMG) measurement and are reproduced, by means of electrical muscle stimulation (EMS), as muscle contractions of the other user, and vice versa.

Contributions.

(1) **Modeling** of the blending kinesthetic experience based on EMG measurement and EMS
(2) **Proposed** a method for muscular stimulation with dynamic adjustment over a wide frequency range while preserving EMG measurement capability
(3) **Implementation** of bioSync devices with the same electrodes used for EMG measurement and EMS to achieve kinesthetic I/O at 100 Hz via wireless communication
(4) **User studies** of the interaction and the system in which kinesthetic I/O with low communication latency (approx. 20 ms) allowed synchronization of rhythmic muscle contraction without visual and auditory feedback, and allowed perception of presented EMS contractions while users were contracting their own muscles

3 DEVICE IMPLEMENTATION

Smaller-person Experience

To realize the concept of changing a body representation into that of a smaller person, I have been developing a wearable device to change the visual perspective, as shown in Fig. 5. The visual translator comprises an HMD, a stereo camera module, a sensor belt, a single-board computer with processing software, and a mobile battery. The developed stereo camera module which is equipped with two fish-eye cameras (ELP-USBFHD01M-L180, Ailipu Technology Co., Ltd, HD@60fps) was developed. Each camera module has a 180° fish-eye lens.The wearer attaches the sensor belt at their waist position. It has a nine-axis motion sensor (MPU-9250, Invensense, Inc.) and a microcontroller (Atmel SAMD21, Atmel) for measuring the wearer's waist orientation in the yaw-pitch-roll format.

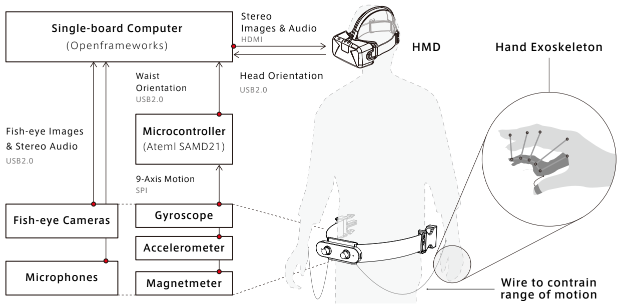

Figure 5: System Architecture

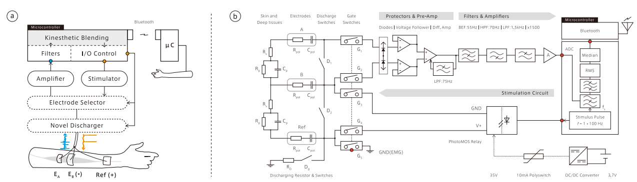

Figure 6: (a) System Architecture (b) Process Diagram

The exoskeleton transforms the scale of the wearer's hand gestures into the smaller hand size by using a custom link mechanism, called a multiple quadric crank mechanism. The exoskeleton has small urethane finger skins connected to the wearer's hand by link mechanisms so that the wearer's finger movement can be transmitted to the finger part directly. Because the urethane-made child hand is actuated by the mechanical link system, the wearer is able to receive real-time haptic feedback from objects while interacting.

Blending Kinesthetic Experience

To achieve the proposed interaction in an actual environment, I developed a paired wearable kinesthetic I/O devices, called bioSync (Fig. 6 (a)). Each bioSync device is equipped with a custom designed electrode system that performs EMG measurement and EMS simultaneously (Fig. 6 (b)). In order to achieve fast and simultaneous measurement and stimulation operations using common electrodes, a gate switching mechanism and a mechanism for discharging residual potential (the body retains a net charge following the stimulus) were implemented. Each bioSync is also equipped with a wireless communication module and a radio-frequency identification (RFID) tag which is used to detect and pair with other bioSync devices by touching the wearer's wrist to the partner's bioSync device.

4 USER STUDIES

Smaller-person Experience

To investigate how the wearer's perceptions, actions, and interactions can be modified through the proposed egocentric experience of a smaller person, the following three factors, which are essential for the understanding of the users, were investigated.

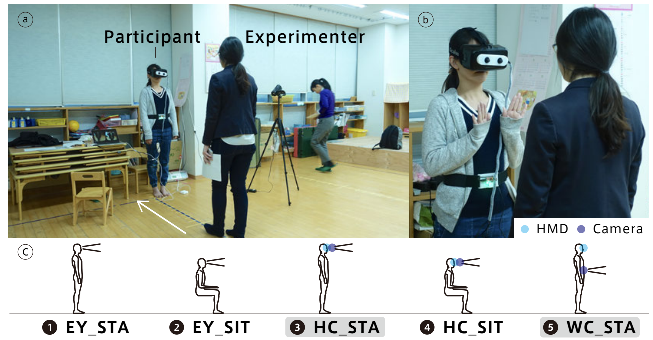

Figure 7: Wearer's Perception: (a) Experiment overview (b) When the participant calls "stop" (c) Experiment conditions

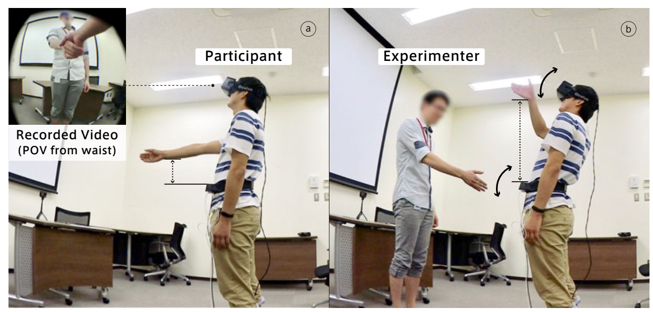

Figure 8: Wearer's Action: Experiment Setup and Conditions: (a) Watching a Video (b) Small-person Experience

1) **Wearer's perception:** In this study, which was a personal space evaluation, when the participant felt smaller using the developed device (WC_STA condition), the largest personal distance was observed (Fig. 7). This could have been caused by an oppressive feeling toward the approaching experimenter induced by the feeling of being small.

2) **Wearer's action:** It was observed that the participants raised their hands higher than usual when trying to shake hands with the experimenter because they perceived their own body representation as being smaller (Fig. 8). It was confirmed that the experience of being a smaller person changed the physical relationship of the wearer and the surroundings.

3) **Wearer's interaction:** The wearer's interactions with the developed device during demonstrations at conferences and exhibitions were observed (Fig. 9). It was often observed that the visitors behaved like a child, such as performing a protective pose when surrounded by adults, or talking like a child. Interestingly, surrounding people such as young students also treated the wearers like a child, and behaved as teachers or parents by acting in an overbearing manner.

Figure 9: Wearer's Interaction: Interaction Observation

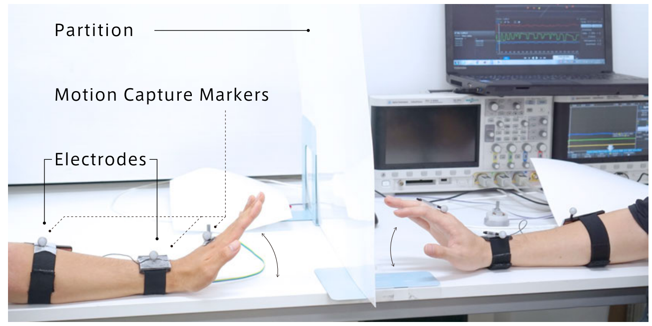

Figure 11: Rhythmic Activity Synchronization

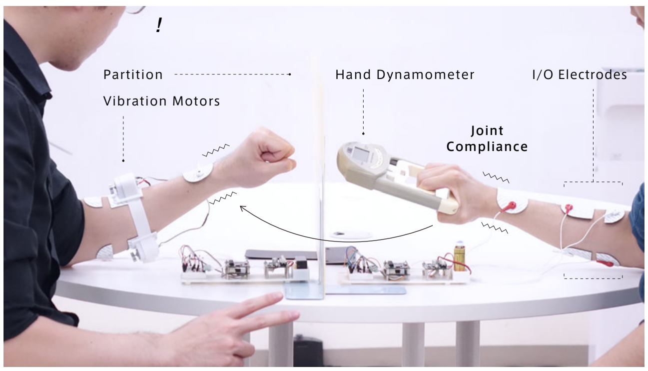

Figure 10: Transferring the wrist compliance by sharing antagonist muscle activity

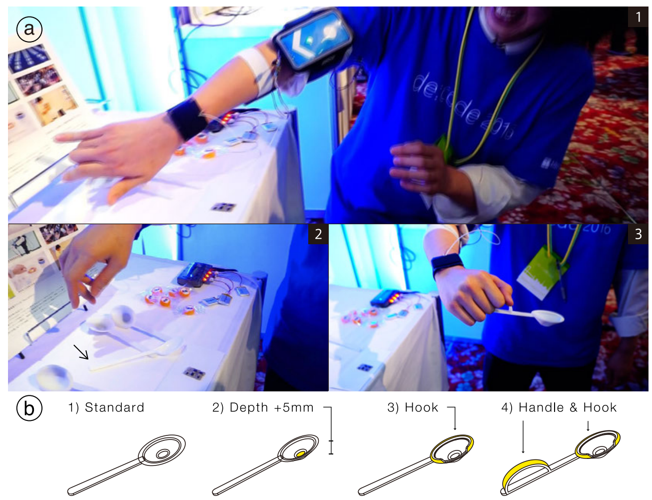

Figure 12: Demonstration: Impairment Experience

Blending Kinesthetic Experience

To investigate how the wearer's perceptions, actions, and interactions can be modified through the proposed egocentric experience of a patient, I investigated the following three factors.

1) **Wearer's perception:** Through the perceptual experiment, it was verified that the bioSync users were able to recognize reproduced muscle contractions and rate them on a five-point scale while they were contracting their own muscles at 50%, 25%, 0% maximum voluntary contraction. Another perceptual study of sharing the level of wrist compliance between two persons was also performed (Fig. 10), which demonstrated that the participants recognized the level of the confederate's wrist compliance at four levels [23].

2) **Wearer's action:** I conducted a series of tests to verify that the interpersonal communication via the kinesthetic channel could support the synchronization of two persons' rhythmic muscle contraction timing (Fig. 11). The results were used to assess whether the bioSync device could be employed in practical scenarios, such as clinical gait rehabilitation and sports training, in which the synchronization of timing plays an important role. The average measured sync time was 8.1s (SD=3.91s), and the average reported sync time was 13.8s (SD=3.94s).

3) **Wearer's interaction:** I also conducted a pilot study on providing a simulated embodied impairment experience at exhibitions and conferences (Fig. 12). The participants tried to grab a spoon, and to scoop up gummy candies with the reproduced tremor. The results suggested that reproducing the neurological action of Parkinson's tremors could enhance the understanding of the disease.

5 DISCUSSIONS

Smaller-person Experience

Eye level affected the personal space

From the result, the eye level of the participant affected the perception of interpersonal distance because there is a significant difference between (3)HC_STA and (5)WC_STA conditions. The difference in eye level would create an oppressive feeling toward the approaching experimenter. In addition, the large neck angle in pitch axis also affected the perception of social relationship with the experimenter, because the nursing teachers usually interact with 5-years-old children. One participant reported that he/she has a frustrating feeling rather than an oppressive or scary feeling, because the participant could not move the perspective higher although their legs were fully extended. It is also presumed that their internal body representation also contributed to the change of personal space.

Perceived arm length and distance

The participants could think their arm length had become shorter, as had their height, resulting in an increase in the perceived distance between hands. A similar phenomenon was also reported in which the arm length changed the perceived distance in a virtual environment [14].

Familiar objects as a reference

Several participants stated that they realized the change in eye level only after they saw the experimenter facing them, although they had visited the experiment room several times before and saw the desks positioned 2 m away from the standing location during the experiment. From such comments, it is assumed that the participants used more familiar objects as a reference to recognize the physical relationship between their body and space. It should be noted that the participants knew the height of the experimenter and had sufficient experience with each other through conversations because they are from the same local organization. The recorded head orientations also showed that the participants looked up higher under (2) smaller person condition than under (1) video condition. From the result and observations, many participants looked at the experimenter's face before the handshake, suggesting that the level of face could be used as a reference. Such existing knowledge based on motor and social experience could help the wearers recognize their space and physical relationship.

Blending Kinesthetic Experience

Subjective Perceptual Experiment

In the perceptual experiment, the participants could recognize reproduced muscle contractions and rate them on a five-point scale accurately, while they were contracting their own muscles. It was observed that the standard deviation increased when the pulse width increased. This might be the effect of the wearer's voluntary contractions on the perception of the reproduced contractions. Another perceptual experiment would be required to study this phenomenon in detail and to assess the relevance of the signal-dependency noise theory [10], which indicates that neural control signals are corrupted by noise that increases in variance as with the size of the motor control signal increases.

Rhythmic Activity Synchronization

In the user study of the synchronization of rhythmic action, subject 1 reported that excessive involuntary contractions affected the performance of the synchronization. This could have been caused by the electrode positioning and personal muscular characteristics. This indicates that a prior adjustment is required for each subject to normalize the perceptual and kinesthetic experience among users. Another aspect I would like to address is the learning effect, which I could not verify in the current experiment since the number of trials for each participant was small. However, I found that synchronization time is always shorter when the experimenter who had longer prior training and participated in the entire experiment, follows the participant's rhythmic action. Another preliminary experiment showed that the rhythmic actions of two persons could be synchronized even if they are not assigned as an experimenter or a follower, and are treated equally [29].

Embodied Impairment Experience

In the pilot study on the simulated embodied Parkinson's experience, I received considerable feedback comments that indicated the existence of kinesthetic memory after the experiment. This suggests that reproduced kinesthetic impairment experience may be more effective in learning the neurological characteristics of the impairment than learning through some other modality. Some visitors also reported experiencing the existence of a remote user's presence through the kinesthetic channel, while synchronizing muscle activity between two persons. Thus, interpersonal kinesthetic communication is capable of enhancing the feeling of togetherness and reality of existence, in a manner similar to that of interpersonal haptic communication [2, 3, 20].

6 CONCLUSION

Smaller-person Experience

In this research, I explored how human perceptions, actions, and interactions can be changed through the egocentric experience of a smaller person in a real world environment.

From study 1, which was a personal space evaluation, when the participant felt smaller using the developed device, the largest personal distance was observed. This could have been caused by an oppressive feeling toward the approaching experimenter induced by the feeling of being small.

In study 2, it was observed that the participants raised their hands higher than usual when trying to shake hands with the experimenter because they perceived their own body representation as being smaller. It was confirmed that the experience of being a smaller person changed the physical relationship of the wearer and the surroundings. In addition to this, using a rehabilitation peg board, it was observed that the developed exoskeleton decreased the user's chronological hand function which would reproduce a smaller-person's physical capability, while preserving the wearer's developmental hand function.

In study 3, I observed the wearer's interactions during demonstrations at conferences and exhibitions. It was often observed that the visitors behaved like a child, such as performing a protective pose when surrounded by adults, or talking like a baby. Interestingly, surrounding people such as young students also treated the wearers like a child, and behaved as teachers or parents by acting in an overbearing manner.

These findings, challenges, and design considerations will benefit further studies on the design of user experiences based on changes in body representation while preserving active and embodied interactions in a real-world environment.

Blending Kinesthetic Experience

In this research, I proposed and modeled a novel style of interpersonal kinesthetic communication, called the blended kinesthetic interaction that allows people to mutually perceive and interrupt each other's muscle activity.

Through the perceptual experiment, it was verified that the bioSync users were able to recognize reproduced muscle contractions and rate them on a five-point scale while they were contracting their own muscles. It was also verified that the kinesthetic interpersonal communication allows people to synchronize the rhythmic action without visual and audio feedback. I also conducted a pilot study on providing a simulated embodied impairment experience. The results suggested that reproducing the neurological action of Parkinson's tremors could enhance the understanding of the impairment.

The pilot study regarding faster kinesthetic reaction and the sense of agency not only demonstrated that the human's responsive action can be accelerated by wiring the two persons but also suggested that their stiff voluntary to perform actions with reward at the right timing allows their sense of egocentricity, the subjective feeling of producing a desired consequence or performance initiated by their own voluntary, to be generated. Further investigation regarding the intervention timing and the sense of agency have been investigated [12].

These findings would provide design ideas for the kinesthetic interaction, and contribute to potential applications such as education, design, and medical activities, that reveals new aspects of human behaviors for embodied and social experiences.

Shaping Egocentric Experience

The general conclusion regarding shaping egocentric experiences with wearable cybernic interfaces derived from design, development, and evaluation were described. In contrast to the related works that attempted to append or extend physical body functions, the proposed experience have successfully amplified the participants' knowledge, and particularly embodied the knowledge of one's embodied and social experiences. Hence, I proposed the conceptual representation of shaping a body representation in a real-world environment based on active interactions to reproduce one's embodied and social experiences.

A major attribute of the proposed experiences was that the interaction could be initiated by the participant's voluntary action. The participant must create, interpret, and review narratives of the experience by themselves through reaching, seeing, touching, and speaking, thus increasing their participation level toward the experience.

As another attribute, the interaction styles involved the surrounding people, thereby allowing the participants to increase their awareness of other people. This situation allowed for the surrounding people, apart from the wearer, to perceive as the wearer became a smaller person or a Parkinson's patient. These new social and physical contexts including an oppressive conversation, protective posture, conceited look, longer interpersonal distance, and more supportive behavior contributed to shaping the body representation repeatedly.

7 ACKNOWLEDGMENTS

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BIOGRAPHY

Jun Nishida is a PhD candidate in Human Informatics at University of Tsukuba, Japan. His research interests include designing experiences in which all people can maximize and share their physical and cognitive capabilities to support each other in the fields of rehabilitation, education, and design. The latest version of this manuscript is available on my portfolio site (http://junnishida.net).

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