Human Adaptation, Plasticity and Learning for a New Sensory-Motor World in Virtual Reality

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Abstract. Human perception and action adaptively change depending on everyday experiences of or exposures to sensory information in changing environments. I aimed to know how our perception-action system adapts and changes in modified virtual-reality (VR) environments, and investigated visuo-motor adaptation of position constancy in a VR environment, visual and vestibular postural control after 7-day adaptation to modified sensory stimulation, and learning of event related cortical potential during motor imagery for application to a brain-machine interface. I found that human perception system, perception-action coordination system, and underlying neural system could change to adapt a new environment with considering quantitative sensory-motor relationship, reliability of information, and required learning with real-time feedback. These findings may contribute to develop an adaptive VR system in a future, which can change adaptively and cooperatively with human perceptual adaptation and neural plasticity.

Keywords: Adaptation, Plasticity, Position constancy, Galvanic vestibular stimulation, ERD/ERS.

1 Introduction

Environments are not static or constant. We are living in changing environments. Thus, our perception and action adaptively change depending on everyday experiences or exposures to sensory information in changing environments. Neural processing underlying basis of the perception and action seems also plastic and adaptive for new environments. My colleagues and I have investigated how our perception-action system adapts and changes in modified virtual-reality environments. In this paper, I describe three topics relating to adaptive change and plasticity of our perception and action, and neural learning of motor imagery.

2 Adaptive Change of Position Constancy

Though our retinal image is always moving during head and body movements, we perceive a stable environment. This is called 'position constancy' or 'visual stability' in

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perceptual psychology. Our brain has a compensation mechanism to stabilize the perceptual representation against motion of head and eyes [1]. It is well investigated whether the visual-motor system can be adaptively changed with an inter-sensory conflict situation. The most famous and traditional paradigm to investigate the adaptation of the visual-motor system is 'inverted vision' with a prism scope [2]. When one wears the prism scope, the perceptual world is inverted and he/she cannot help staggering around. After prolonged adaptation (1-4 weeks), the perceptual world gets back to proper orientation, and he/she becomes able to walk normally.

The experimental paradigm 'adaptation to a new visual-motor world' is a useful tool to investigate how the visual-motor system stabilizes our perceptual world [3]. We measured the position constancy during head turning in virtual reality environments to test its generality and selectivity [4-5]. Participants put on a head-mounted display (HMD) to observe a cloud of random spheres, which were stationary in the virtual environment. When participants turned their head rightward and leftward back and forth, the visual image presented on the HMD correspondingly moved by tracking head rotation with a Polhemus Fastrack sensor (Fig. 1). We varied the visual/motor gain for each trial. The visual/motor gain is 1.0 in the real world: when we rotate (yaw) our head rightward for 60 deg the retinal image moves leftward equivalent for 60 deg head yaw. In an experimental condition, we set the visual/motor gain 0.5, where the visual image on the HMD moved for 30 deg when participants moved their head for 60 deg. Participants observed the visual image during turning their head back and froth at the 0.5 visual/motor gain. Only after 2-min adaptation of the gain 0.5, the participants judged a smaller visual/motor gain than 1.0 as stable. This suggests that visual stability during active observation adaptively changes after only 2-min adaptation.

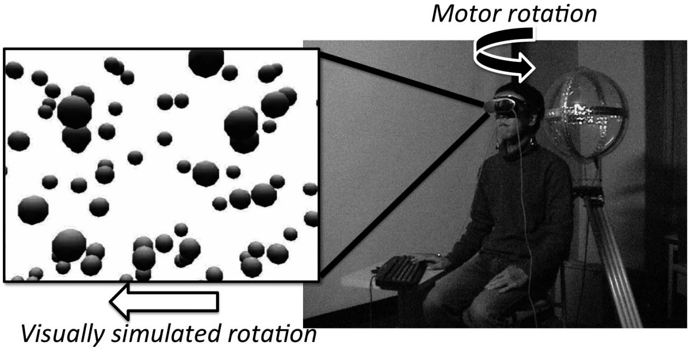

Fig. 1. Schematic of position-constancy experiment. Visual image changes depending on the head rotation. The visual/motor gain is ratio of visually simulated rotation by motor rotation.

This visual-motor adaptation occurred irrespective of amount of visual stimuli, active and passive head motions, and transferred between left and right eyes [4]. Thus, the visual-motor adaptation for visual stability quickly occurs and has high generality. However, the adaptation is partial, and only 13-37% of perfect adaptation (Fig. 2). It may due to our lifelong and robust adaptation to the real word of constant gain 1.0.

This visual-motor adaptation is good for surviving in changeable environments and using a virtual-reality system with limited spatio-temporal resolution. In subsequent studies, we found that the visual-motor adaption for the position constancy was more effective if both the adaptation and test are performed on the left visual field than the other cases [5]. Thus, the left visual field appears to be more weighted to present visual information for effective adaptation than the other fields in a future adaptive virtual reality system.

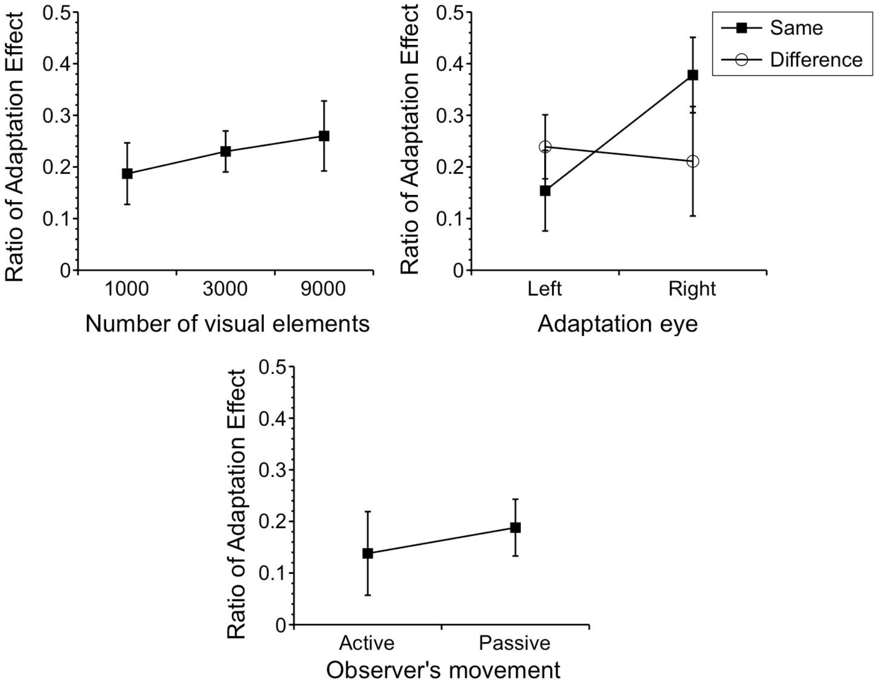

Fig. 2. Results of position-constancy experiments. Adaptation effects of visual-information richness (top left), effects of eyes (top right), and effects of active or passive movements (bottom) are shown. All conditions except for a condition of both adaptation and test with left-eye indicated significant adaptation effects ($p<.05$). There were no significant main effects of the number of visual elements, adaptation eye, adaptation-test eye combination, or active-passive head motion ($p>.05$).

3 Contributions of Vision and Vestibular Sense to Control of Posture

Human posture is controlled by multimodal process of visual, vestibular, and proprioceptive information. When a visual field contains a large visual motion, observers' body sway occurs at the identical frequency of the visual motion [6]. To investigate contribution of vestibular information to postural control, galvanic vestibular stimulation (GVS) is used. When a small current is applied to left and right mastoid processes, the observer inclines in the direction of anodal ear [7].

We measured postural sway induced by visual motion and galvanic vestibular stimulation (GVS) to investigate adaptive change of our visual and vestibular control of posture [8]. Participant's head position was monitored by a Polhemus sensor, and corresponding visual motion or GVS was continuously presented in real-time (Fig. 3).

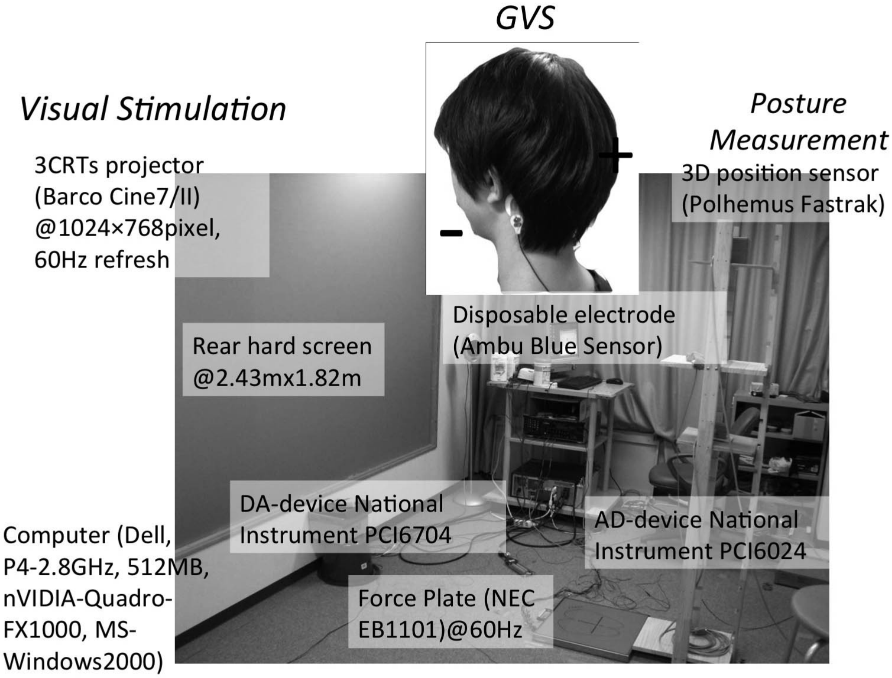

Fig. 3. Apparatus of visual and vestibular postural sway experiments

Participants were divided into 4 groups: visual and GVS enhancing groups and visual and GVS inhibiting groups. For participants in visual or GVS enhancing groups, visual motion or GVS was presented to increase their voluntary sway (30 cm leftward and rightward at 0.2Hz). For participants in visual or GVS inhibiting groups, visual motion or GVS was presented to decrease their voluntary sway. After seven days adaptation (10 times of 1-min trial per day), participants in the visual and GVS enhancing groups showed more postural sway induced by visual motion and GVS, respectively (Fig. 4). However, we did not obtained equivalent results for the visual and GVS inhibiting groups. These results suggest that the long-term adaptation to enhancing action-yoked visual motion and GVS can modify weights on vision and vestibular senses to control posture.

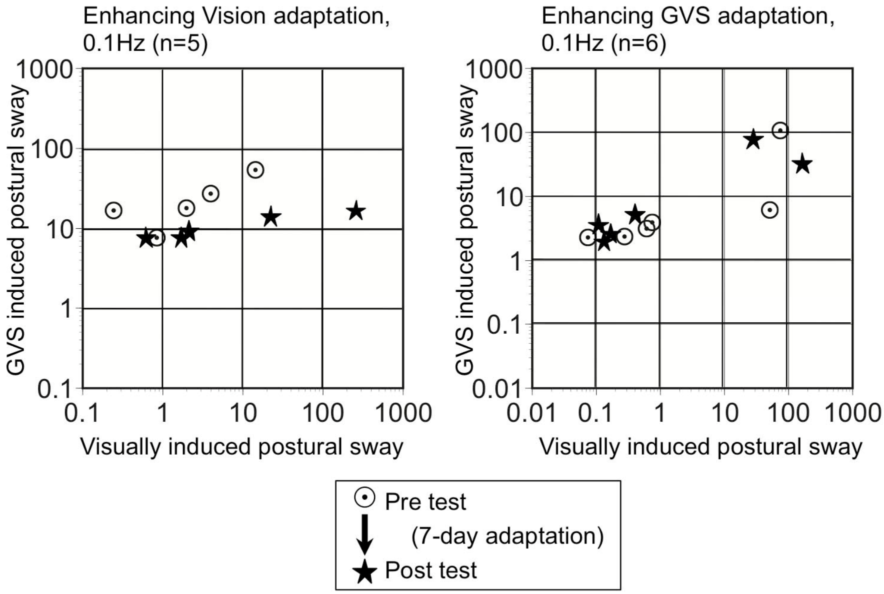

Fig. 4. Results of adaptation in visual and vestibular postural sway. Horizontal axis indicates sway power induced by visual motion, and vertical axis indicates sway power induced by GVS. Each mark indicates each subject's averaged result. Circles with a center dot are data of pre test, and stars are data of post test after 7-day adaptation.

4 Neural Learning of Motor Imagery

Finally, we measured brain activity during motor imagery. When human move their body such as fingers, event related de-synchronization (ERD) at approximately 8-13 Hz (mu-suppression) is observed at parietal lobe (motor cortex) by measuring electroencephalogram (EEG), and event related synchronization (ERS) is observed after ceasing movements. This ERD/ERS activity can be observed during motor imagery without actual movements (Fig. 5), and is used for brain-computer interfaces (BCI) [9-11]. Since the ERD/ERS occurs with silent reading [12], conversation without voice may be implemented to a BCI using ERD/ERS in future.

We made a real-time ERD/ERS feedback system for training and enhancing ERD/ERS induced by motor imagery [13]. When the averaged EEG power of C3 (center left channel) and C4 (center right channel) at 10-12 Hz was smaller than the power at the rest period before the feedback experiment (ERD), we presented a red bar whose length was increased upward corresponding to strength of ERD. When the EEG power was larger than the rest period (ERS), a blue bar was lengthened downward. The EEG power for ERD/ERS was calculated using 2s time-window data, and the visual feedback was updated at 10 Hz. Participants were asked to imagine clasping their own left hand or right hand. They repeated 10 times of left-hand and right-hand motor imageries separately per a day with the visual feedback, and performed

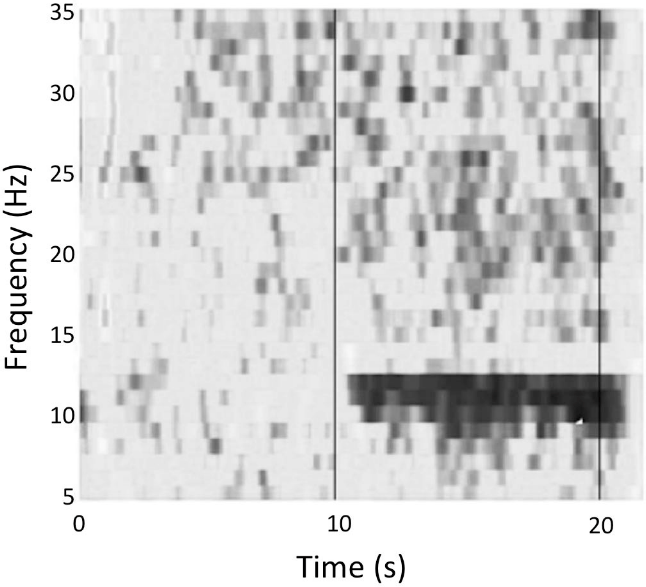

Fig. 5. Example EEG spectrogram of ERD during motor imagery. Horizontal axis indicates time, and the subject was asked to image his hand movements (open and close his hand) during 10 - 20 s period. Vertical axis indicates frequency of EEG, and gray scale of data represents power calculated by short-time fft. Dark color indicates lower power and bright color indicates higher power than the rest period (0 - 10 s). ERD is found at 8-13 Hz during motor imagery period.

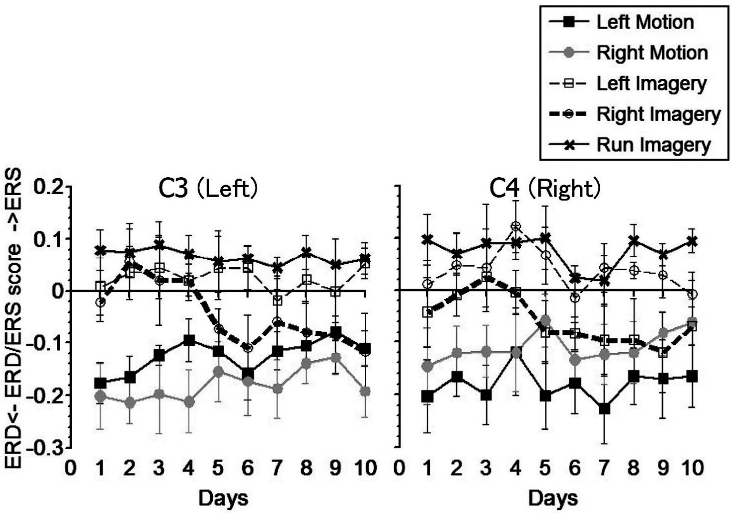

Fig. 6. Results of motor imagery learning. Horizontal axis indicates learned days. Vertical axis indicates ERD/ERS score. For both left and right hand motor imageries, the ERD at the contralateral channels (C3 for right hand, C4 for left hand) gradually increased as the learning progressed.

the training for nine days. We found contralateral increments of ERD during motor imagery as the training progressed (Fig. 6). These results suggest that human brain activity can be gradually changed or enhanced by the real-time visual feedback of brain activity contingent with motor imagery.

5 General Discussion

These three studies suggest that human perception system, perception-action coordination system, and underlying neural system could change for adapting to a new environment with considering quantitative sensory-motor relationship, reliability of information, and required learning with real-time feedback. A traditional aspect of virtual reality is that creating artificially most accurate sensory inputs is important to make virtual-reality systems. However, artificial engineering systems have limitation of spatio-temporal resolution and delays between inputs and outputs, thus it is difficult to perfectly mimic sensory inputs. A virtual-reality system can be designed adaptively by utilizing human perceptual and neural plasticity. The system may not require very accurate spatio-temporal resolution. It might be effectively implemented if both human perception-action system and virtual-reality system can change adaptively and cooperatively.

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