https://doi.org/10.2352/ISSN.2470-1173.2017.9.IRIACV-260

The acceleration effect to the perception of velocity difference in passive elbow flexion movement

Fumihiro Akatsuka, Yoshihiko Nomura
Department of Mechanical Engineering, Graduate School of Engineering, Mie University; Tsu, Japan

Abstract

Haptic devices have been studied as useful tools for motor learning. In use of the devices, proprioceptors are used for movement perception. Therefore, it is important for designing the devices to characterize proprioceptor performance. This study focuses on the scheme to perceive velocity differences from before-acceleration velocity for various accelerations. We measured the velocity JNDs (Just Noticeable Differences) in one-way elbow flexion movements to examine the following two hypotheses. (1) "Local scheme"; the magnitude of the present acceleration, which can be regarded as a local velocity difference, plays a crucial role. (2) "Global scheme"; the global velocity difference, which is defined as the difference between the present accelerating-velocity and the before-acceleration velocity, does so. For each of the schemes, the following characteristics are expected. (1) If acceleration magnitude affects the perception, humans cannot notice the velocity differences in acceleration conditions less than a threshold. It results in a tendency that velocity JNDs in small acceleration conditions would be much larger than those in large acceleration conditions. (2) If acceleration does not, but if the global velocity does, the velocity JNDs stay unchanged even though acceleration varies because humans perceive the velocity differences, just referring two different absolute velocities.

Introduction

Humans learn motor skills with motions such as sports and handwriting by training. At that time, in general, the desired movement information is obtained by using textbooks, movies or by getting guidance from instructors. Also, they improve the skills by repeating movement reproductions, comparing their performance with the desired movement. In recent years, the use of haptic devices has been studied as a method of learning motor skills [1][2][3]. The haptic devices can supply force- and position-feedbacks to users. In the case of training with haptic devices, the learner can be given feedbacks related to the desired motion, while performing. It is expected for learners to obtain movement information in real time and to be noticed with the mistake of their own movements. In this research, we focus on the way in which the user's limb is passively moved under a force-feedback system using the device, based on velocity control scheme. There are many studies in order to evaluate learning effects after passive movement experiences with desired position- and/or velocity-trajectories: learning effects were evaluated, based on movement reproduction performances. The reproduction processes after experiencing the passive movements can be divided into the following phases [4],

1) perceiving stimuli,
2) recognizing the perceived stimuli as motion information,
3) memorizing the recognized motion information,
4) reproducing the memorized motions.

Therefore, for designing haptic devices, human characteristics investigation is necessary for each of these phases. In this research, we focus on 1) phase of perceiving stimulus, in particular, on perceiving velocity stimulus. When learning time-varying velocity (hereinafter, called "velocity trajectory") being enforced by the device, users perceive the velocity trajectory of their own limb which is passively moved. For the velocity trajectory perception, proprioceptors are principally used. The proprioceptor, in particular, the muscle spindle is a receptor embodied in the muscle: it detects the muscle length and the muscle contraction velocity and plays an important role in perceiving limb position and velocity [5]. It is known that the velocity change perception is affected by the momentary states such as the used muscle, the muscle length, the contraction velocity, the muscle strength, the movement direction (concentric/eccentric contraction). Besides the momentary state, it is also reported that the integral factor-related conditions such as the duration time of presentation affect the velocity perception [6][7][8]. However, in investigating velocity perception characteristics, many of studies have been conducted under a scheme of consecutively presenting double velocities: it was studied whether the velocity difference between the 1st and 2nd time movements was noticed or not. Therefore, it cannot be said that sufficient investigation has been done in a specific situation where the velocity change occurs during one movement. That is, for the velocity perception characteristic, Graham, K. et al. measured the minimum velocity differences that human can perceive, comparing consecutively presented different-velocity movements [8] where subjects were enforced to extend the elbow joint in separate different-velocity movements. Their result showed that the relationship between the reference velocity and the noticeable minimum velocity differences agrees on Weber's law, that is, as the reference velocity increases, the noticeable minimum velocity difference also increases in proportional to the reference velocity. Thus, due to the threshold of velocity perception, it is considered for humans not to perceive the complete velocity trajectory when their limbs are enforced to move by the device. In addition, the relationship by Weber's law indicates that the velocity-difference perception does not occur by directly detecting the magnitude of acceleration which is the temporally defined rate of change, but by comparing the two different absolute velocity: the former is called "local scheme ("local matching" in [11])", and the latter "global scheme (global matching" in [11].)" in this paper. However, for the case that the velocity-change occurs during one movement, it has still not clarified what kind of time domain scheme such as the local and global scheme the comparative perception is conducted in.

Objective and Hypothesis

In this study, we examine what kind of time domain scheme the velocity change perception is conducted in when the velocity-change occurs within one movement. For this issue, we investigate the effect of accelerations on velocity change perception when limb-moving velocity changes within the passive movement enforced by the device. Then, we take the elbow flexion movement as an example and measure Just Noticeable Difference (JND). JND is defined as the minimum additional value with which human can notice. It is also used as an index value for measuring perceptual performance; the smaller value indicates keener perception, the larger value indicates more insensitive perception. The velocity change pattern used in this study consists of 1) uniform angular velocity (before-acceleration velocity) for a fixed time and 2) subsequent uniform angular acceleration (accelerating-velocity). Here, when human perceives that own elbow flexion velocity is changed from the before-acceleration velocity, the effect of acceleration on the perception and the framework of perceptual process are considered as follows.

(1) Local scheme (shown in fig. 1): This is a scheme in which the velocity difference is defined in the local time domain, that is, the magnitude of "acceleration × minute time (constant value)" is a crucial factor for velocity change perception. In the case where the stimulus of the momentary acceleration is larger than the threshold, the velocity change perception is easy. On the other hand, under the condition where the acceleration is smaller than the threshold, it is difficult to perceive the velocity change. Therefore, if the framework of this Local scheme is established, the following JND characteristic is expected.

· Velocity JNDs in small acceleration conditions would be much larger than those in large acceleration conditions.

(2) Global scheme (shown in fig. 2): This is a scheme in which the velocity difference is defined from the global viewpoint of the time domain, that is, the difference between the before-acceleration velocity and the current accelerating-velocity is a crucial factor for the velocity change perception. In this case, the acceleration of the velocity change does not affect the velocity change perception because human just compares the two absolute velocities (before-acceleration velocity and the current accelerating-velocity). Therefore, if the framework of this Global scheme is established, the following JND characteristic is expected.

· Regardless of the magnitude of the acceleration, when the velocity difference from the before-acceleration velocity reaches to a certain JND, the velocity change perception occurs. Therefore, the JND stays unchanged even if acceleration condition varies

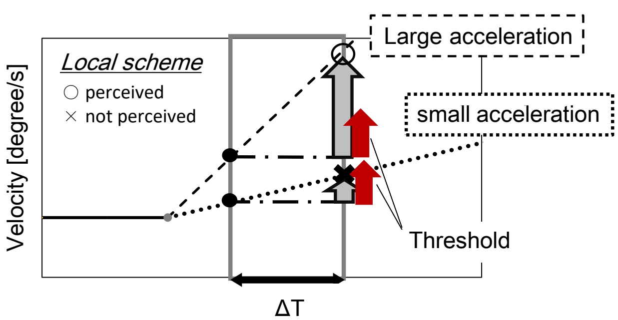


Figure 1. *Velocity difference perception in local scheme: gray arrows represent human-given velocity difference stimulus, red arrows represent threshold of acceleration.*

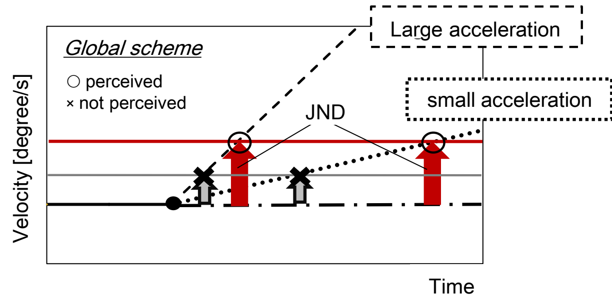


Figure 2. *Velocity difference perception in Global scheme: gray arrows represent human-given velocity difference stimulus, red arrows represent JND of velocity.*

Experiment

Subjects and Experimental Setup

Six male subjects (right-handed, age from 22 to 24 years) voluntarily participated in the velocity difference perception experiments. The device for this experiment, shown in Fig. 3, consists of a brushless DC servomotor-driven manipulator designed for elbow-flexion displacement in the horizontal plane. The servomotor can exert enough torque to enforce subject's elbow-joint to flex passively at target velocity. Then, subjects received manipulator-exerted force based on a velocity control scheme. The manipulator is sustained by wire for gravity compensation so that subjects can keep their arm muscles relaxed.

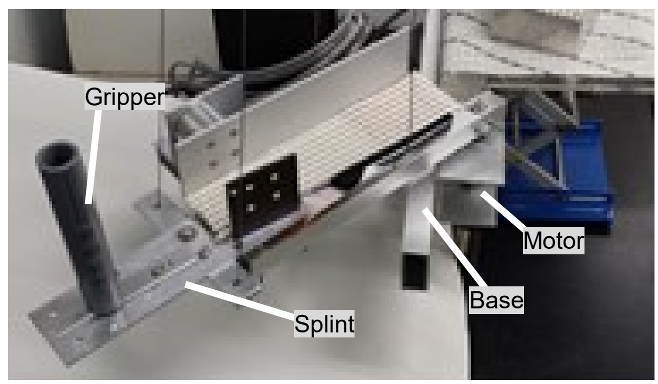


Figure 3. *Experimental device*

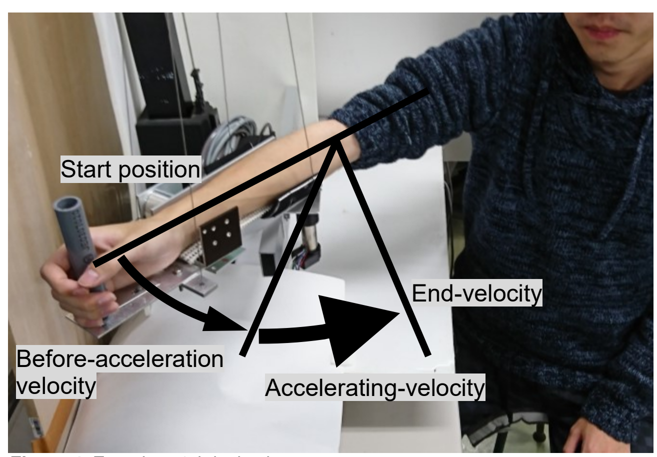


Figure 4. *Experimental device in use*

Method

Subjects were seated with forearms resting comfortably on height-adjustable manipulator and lightly grasped the vertical gripper, shown in Fig. 4. Closing their eyes, i.e., without visual stimulus, subjects performed this experiment. Subjects were instructed to keep their arm muscles in a relaxed state during each trials. Subjects' forearms were passively flexed by the manipulator on the way of one-way flexion movement. During the movement, they focused on their own hand velocity. After the movement, they reported their perception, if the velocity changed from the before-acceleration velocity in the one-way passive flexion movement or not. Enforced elbow flexion movement started from 0 degree of flexion angle with before-acceleration velocity of 10 degree/s for 2 seconds in all the trials. Then, the movement accelerated with accelerating-velocity (uniform acceleration) until the velocity reached the predetermined end-velocity. The velocity trajectory is shown in fig.5. The uniform acceleration was set at 4, 8, 12, 16, 20, 24, 28 or 32 degree/s^2. End-velocity and the JNDs were decided by a psychophysical experimental procedure, i.e., Parameter Estimation by Sequential Testing (PEST) [10]. The PEST procedure was repeated twice for each acceleration conditions. The JND in each procedure was defined as the average value of the end-velocities at the *n*-th and the (*n*-1)-th trial sequentially set by PEST. The conditions in PEST, i.e., the first trial velocity difference between the before-acceleration velocity and the end-velocity, the first step and the finish step were set at 10deg/s, 8deg/s and 1deg/s, respectively.

The experiment was conducted according to the following procedure for measuring JNDs in each acceleration condition

[Step1]
Experimenter decides the acceleration condition from 4, 8, 12, 16, 20, 24, 28 or 32 degree / s^2.

[Step2]
Experimenter sets the end-velocity with the first difference in PEST procedure.

[Step3]
Subject performs the trial, described later.

[Step4]
The next trial end velocity is decided by the subject's perceptual answer following the PEST procedure.

[Step5]
[Step3], [Step4] are repeated until the PEST finish condition is satisfied, i.e., current step in PEST is less than the finish step.

[Step6]
The JND in the acceleration condition, decided in [Step1], is obtained.

Each of trials, in [Step3] above, was conducted according to the following procedure.

[Step3-1]
The device fixes subject's forearm at start position (0 degree of flexion angle).
A subject closes his eyes and makes his arm muscles relaxed after confirming his own hand position.

[Step3-2]
The device enforces the subject to flex his forearm at before-acceleration velocity (10 degree/s).
From the second to fourth steps, the subject keeps his arm muscles relaxed and concentrates his attention to his own hand velocity.

[Step3-3]
The device starts positively accelerating with some constant acceleration two seconds after the movement start, of which the subject was not informed, from movement start.

[Step3-4]
The device stops movement when the current accelerating-velocity reaches the end-velocity, predetermined by PEST.

[Step3-5]
The subject reports whether he noticed the velocity increased from the before-acceleration velocity or not.

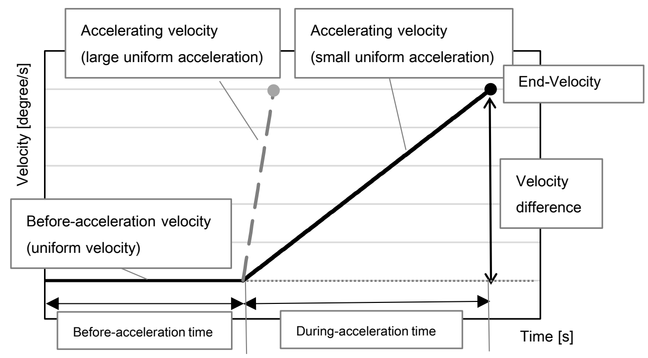


Figure 5. *Velocity trajectory in this experiments*

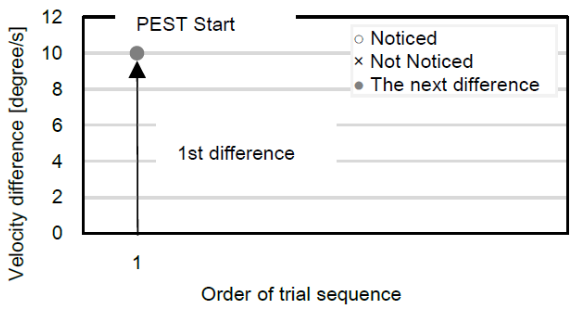
Result and Discussion

Figure 6 shows example of the series of PEST procedure and the velocity trajectory examples for 4 degree/s^2, which followed the PEST procedure, realized in experiments.

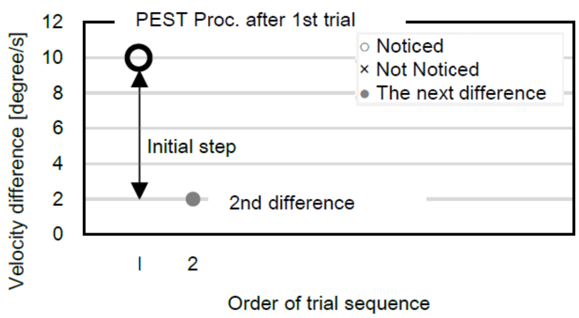
Figure 7 shows the experimental results of the JND for each acceleration condition. The symbol (■) represents the average values of the JND under each acceleration condition, and the error bar represents the standard error. The average values of the JND are 7.8, 7.7, 8.8, 8.5, 9.3, 9.6, 9.3, 8.5 degree / s for 4, 8, 12, 16, 20, 24, 28, 32 degree / s acceleration conditions respectively. One-way analysis of variance was applied to these data and acceleration factor effect on the perception was tested. As the result, it did not show significant difference among themselves [F (7, 88) = 0.6268, p = 0.7324]. This result supposes "global scheme" in which velocity perception is not affected by acceleration conditions and velocity perception occurs just referring the two absolute velocity, i.e., the before-acceleration velocity and the current accelerating-velocity.

As a previous study of velocity difference perception by proprioceptors, Graham K .el measured the JNDs in elbow extension movement [8]. In this experiment, constant velocity movement (reference velocity) and constant different-velocity movement (comparison velocity) are presented separately. In this result, JND of approximately 5 degree / s was shown under the condition of the reference velocity of 15 degree / s which is the closest condition to our experimental condition. The result of this previous study is slightly smaller than the result of our experimental result (8.7 degree / s) at the reference velocity (after-acceleration velocity in our paper) of 10egree / s.

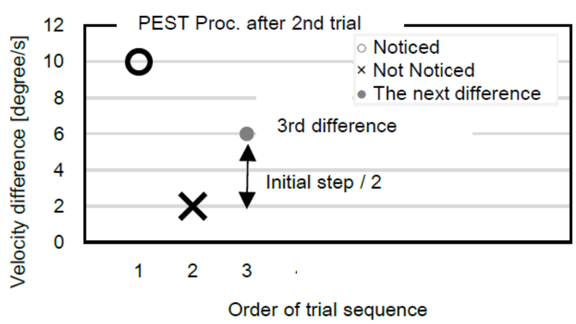
As a previous study of the velocity change perception process, Tayama investigated the velocity change perception process by visual sensation [11]. In this experiment, visual stimulus, accelerating from a certain initial velocity with various accelerations, was presented to the subjects. When the subjects perceived the velocity change, they informed the perception. The experimenter measured the velocity difference at the perception point. The experimental results showed that the perception occurred when the velocity reached a certain velocity difference no matter what the acceleration condition is. This result is the same as the "global scheme" supposed in our experiment which is performed for velocity change perception by proprioceptors.



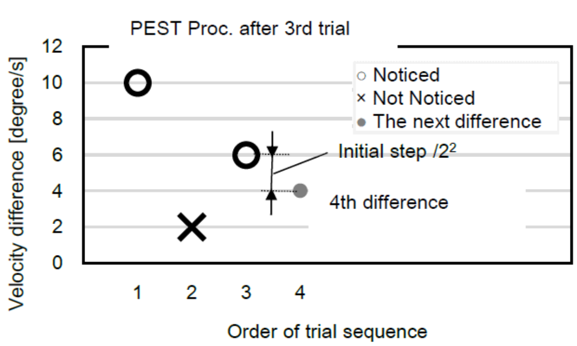
***(a-1)** The determined difference for 1st trial*



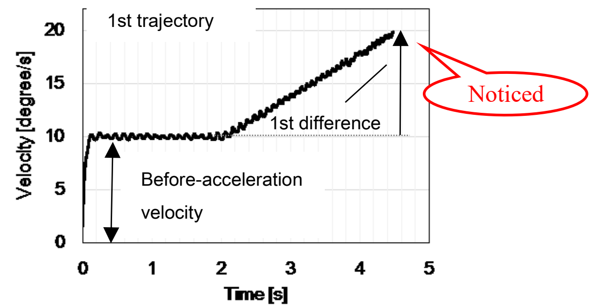
***(a-2)** The answer records and the determined difference for 2nd trial*



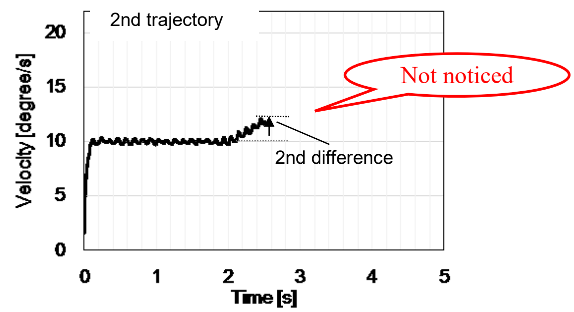
***(a-3)** The answer records and the determined difference for 3rd trial*



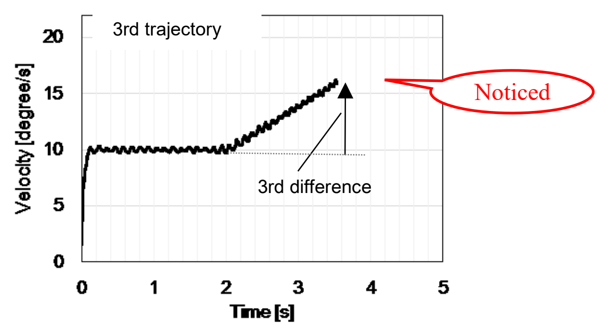
***(a-4)** The answer records and the determined difference for 4th trial*



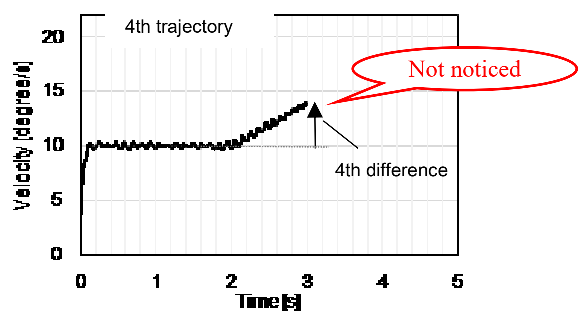
***(b-1)** The velocity trajectory in 1st trial*



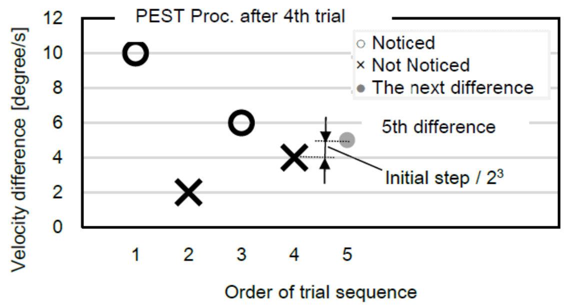
***(b-2)** The velocity trajectory in 2nd trial*



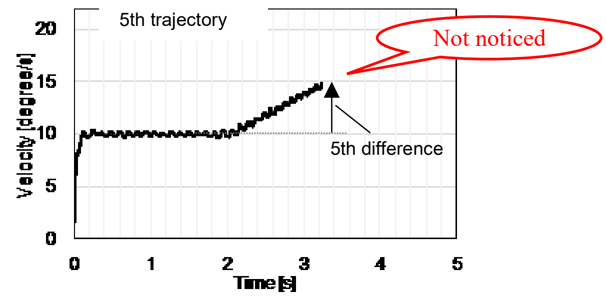
***(b-3)** The velocity trajectory in 3rd trial*



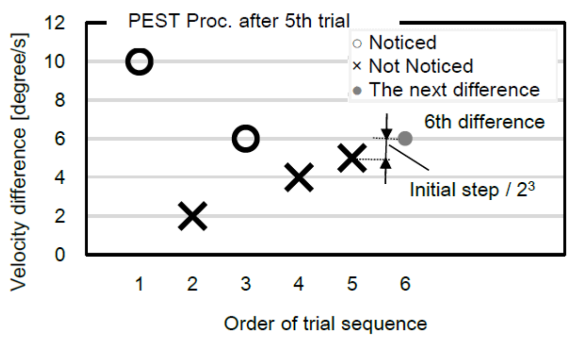
***(b-4)** The velocity trajectory in 4th trial*



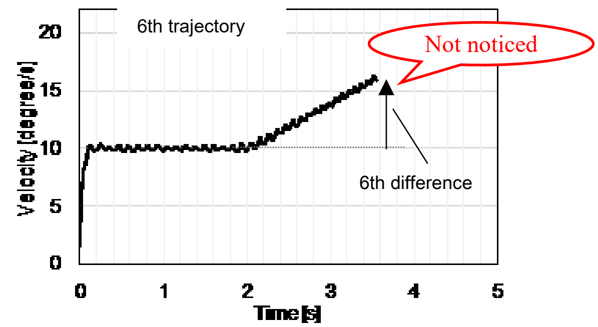
***(a-5)** The answer records and the determined difference for 5th trial*



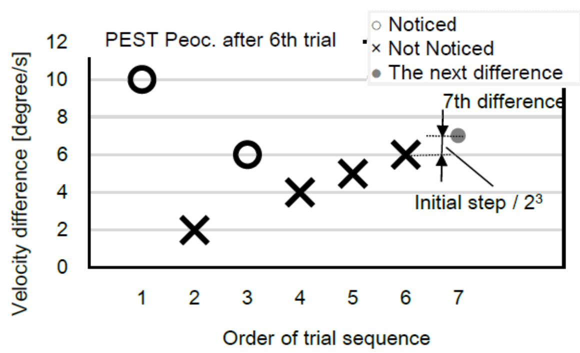
***(b-5)** The velocity trajectory in 5th trial*



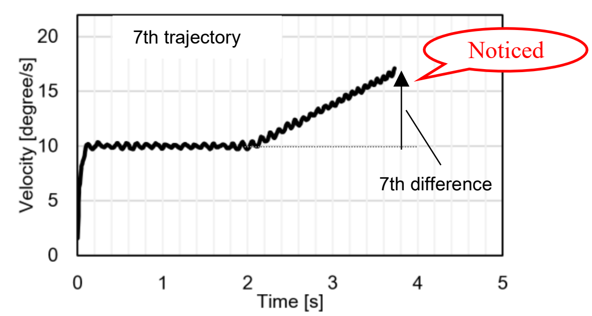
***(a-6)** The answer records and the determined difference for 6th trial*



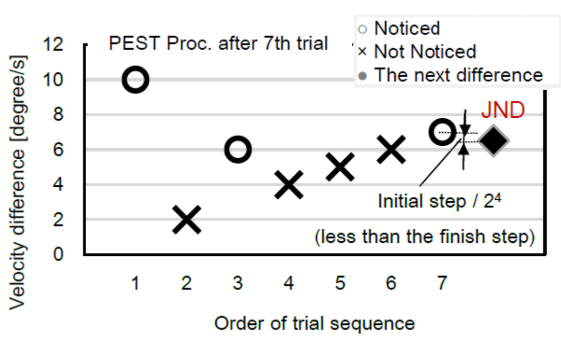
***(b-6)** The velocity trajectory in 6th trial*



***(a-7)** The answer records and the determined difference for 7th trial*



***(b-7)** The velocity trajectory in 7th trial*



***(a-8)** The answer records and the determined JND*

***Figure 6.** Figure (a-1) - (a-8) show an actual example of a series of PEST procedure which determines the velocity difference to be presented in the next trial. , (b-1) – (b-7) show the actual velocity trajectory examples presented in each trials for 4 degree/s^2, following the PEST procedure shown in (a-1) – (a-8).*

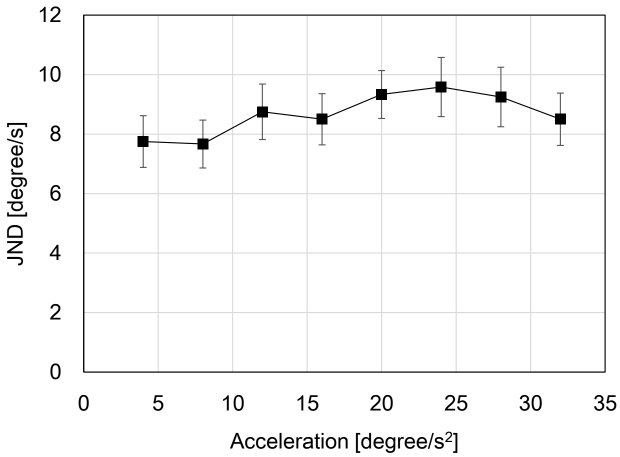


Figure 7. *Mean JNDs (error bar: standard error)*

CONCLUSIONS AND FUTURE WORKS

In this study, we investigated the effect of the acceleration on the velocity perception in passive elbow flexion movement. In the experiment, the velocity changed with various accelerations and the JNDs was measured. The JNDs showed no significant difference, i.e., the JNDs were not affected by the acceleration condition. It supported "global scheme", just comparing the before-acceleration velocity and the current accelerating-velocity. This indicates that regardless of the manner of the change, when the velocity reached a certain velocity difference, velocity change perception occurs. It also suggests that the velocity image of their own elbow flexion will continue at the before-acceleration velocity until the velocity difference is perceived. As a future work, we will investigate that, when velocity trajectory in which multiple velocity change perception occurs is presented to human, how human recognizes the movement as a velocity trajectory from the perceived velocity differences.

ACKNOWLEDGMENTS

This work was supported by KAKENHI (Grant-in-Aid for scientific research (B) 15H02929 from JSPS).

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Author Biography

Fumihiro Akatsuka

He is a graduate student in the Dept. of Mechanical Eng. Grad. School of Eng. at Mie University. He was given his Bachelor Degree at Mie University in 2016. His research interests lie in the area of human haptic perceptual characteristics, specially, those by the proprioceptor.

Yoshihiko Nomura, Ph.D.

He is a Professor in the Dept. of Mechanical Eng. Grad. School of Eng. at Mie University where he has been a faculty member since 1997. During the period, he had also served as an Executive Vice President in Educational Development from 2007 to 2011. His research interests lie in the area of mechatronics and their application to intelligent robots, ranging from theory to design to implementation.