Posture-Angle Perception and Reproduction Characteristics with Wrist Flexion/Extension Motions

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***Abstract*—Comparing active and passive modes with wrist flexion/extension motions, the authors examined the posture angle perception and reproduction characteristics through psychophysical experiments using a mechanically haptic wrist interface: mean values and standard deviations of the perceptual/reproduced angle errors were obtained, and were examined by ANalysis Of VAriance (ANOVA). The characteristics can be applied to wearable haptic interfaces employing kinesthetic sensations in a form of an instruction scheme referred to as a "restrained instruction": the restrained instruction is based on the idea that the just-noticeable small amount of externally applied forces being would be enough for learners to trigger voluntary motions with their body elements.**

Keywords-motion instruction; wrist; flexion; extension; perception: reproduction

I. INTRODUCTION

In recent years, exoskeleton robotic-suits and rehabilitation-systems have been developed in various forms such as full-bodies [1][2], gait rehabilitations [3], arms [4][5][6]. It was also realized as grounded instruction systems [7]. They exerted large enough forces for person body elements to be moved passively

Contrary to these power assisting systems, pose and kinesthetic senses embodied in human bodies can be utilized for motion instruction in the form of body-worn haptic interfaces. As with the kinesthetic-sensation-based motion instruction schemes, J. Iqbal et al. presented a prototype of hand exoskeleton-type finger motion-assisting device for accomplishing common daily life activities, and showed some optimization algorithms for mechanical design [8][9]. Muscle spindles are so sensitive to notice muscle contractions, and, therefore, noticeable threshold levels of human joint flexion/extension movements were reported to be a very small level of less than 0.1 degrees [10][11]. Thus, the thresholds were very small, which give us a suggestion that we need not a large amount of external stimuli for notifying us of the movements.

Considering this point, the authors have been developing interfaces that are characterized by featuring a novel instruction scheme, i.e., just-noticeably small-force scheme: it is assumed that the just-noticeable small external forces would be enough to trigger learners to voluntarily move their muscles. We call the voluntary motion as "active", and the scheme as a "restrained instruction". The restrained instruction scheme has an advantage of small power, and makes systems compact and light weighted. Furthermore, the actively-inspired-motion-based instruction scheme is expected to be effective for learning motions compared to the passively-forced-motion-based instruction scheme. Here, as for the with/without human-initiative effects on the performances, some results were summarized by Proske and Gandevia [12]. As for the effects of muscle conditioning on position sense at the human elbow flexors, T. J. Allen et al. reported in the left/right forearms matching task that there were not significant differences with respect to the effect of the sense of effort [13]. Contrary to this, S. C. Gandevia et al. showed a role for efferent outflow signals in the mean that motor commands contribute to human position sense [14], and the effects of human initiative were not confirmative. Thus, paying attention to the initiative factor, the authors have studied on absolute-angle perceptual characteristics with the wrist flexion/extension using a mechanically haptic wrist interface as well as the elbow joint [15].

Learning some specific postures is one of the important processes in motion learning processes: for examples, still-posed postures are essential for some exercises such as "yoga" positions, and, even in dynamic motions, instantaneous postures at the motion-phase transitions are also crucial. Especially in the case of the restrained instruction, we shall feel it difficult to notice the external exhilarated motions than in the other case of forcible instructions. Even in such cases, we would be able to notice the joint angle changes between the before-and-after instructions if the changes were larger than Just Noticeable Differences (JNDs). Therefore, the JNDs are useful for learning some specific postures, and were examined as well as the mean errors in this paper.

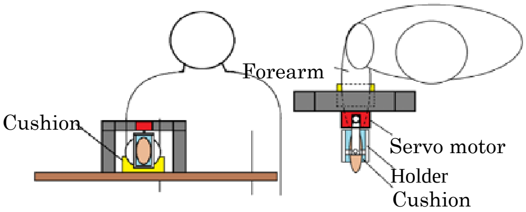
Section II explains the psychophysical experimental method, i.e., apparatus and procedures, for examining the wrist flexion/extension angle perceptual characteristics. Next, Section III first presents the experimental results, and examines the systematic and random errors: the former is given by the mean error and the latter is by the standard deviations. Both the errors suggest reproducibility in the still-posed posture reproductions after motion learning procedures. Finally, Section IV addresses the conclusion and future work.

II. EXPERIMENTAL METHOD

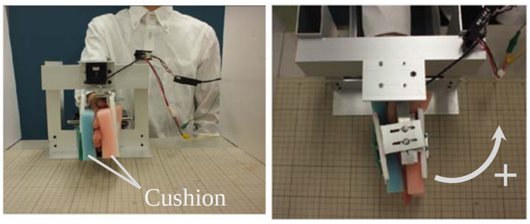
This section describes the psychophysical experimental method, i.e., apparatus and procedures, for examining the wrist flexion/extension angle perception/reproduction performances in the extension/flexion motions. Here, assuming that there might be a difference in the performances with respect to subject initiative, the authors introduced two levels of a subject initiative factor to make a comparative study: one level is an active haptic scheme, and the other one is a passive haptic scheme.

A. *Apparatus*

A simple wrist-bending apparatus was designed to carry out a psychophysical experiment for examining the wrist flexion/extension angle perceptual characteristics. Figure 1 shows the experimental apparatus. A servo-motor was attached to a lower side of the gate-shaped aluminum frame. The servo-motor exerts torques, and makes subject's wrist to forcibly do flexion/extension motions via cushion-buffered-holders.



(a) Equipment overview



(b) Front view (c) Top view (Flexion angle, 0°)

Figure 1. Experimental system setup

B. *Procedures*

1) Conditions: In this experiment, a back-and-forth motion from an initially instructed before-bend angle, via another angle that were given as mask stimulus, to the after-bend angle was tested. Relating to the back-and-forth motion, kinesthetic sense characteristics, i.e., wrist-bend perceptual characteristics, were examined.

Here, focusing attention to the motion initiative factor, the authors introduced two levels: one is a passive haptic mode, and the other is an active haptic mode. The passive haptic mode (Pa) is considered to be a representative passive-based instruction. The subject does not take initiative, but the actuator forcibly rotated the subject's wrist. An ability to notice the deviations of the after-bend angles from the before-bend angles was examined: perceptual errors of the differences between the initially instructed angles and the returned angles were examined in this mode. The active haptic mode (Ac) represents a realization concept of "the restrained instruction scheme" proposed in this paper. The subject takes initiative, and voluntarily activates the wrist flexion/extension. An ability to reproduce the initially instructed angles after an active bending process was examined in this mode. That is, the reproduction errors between the initially instructed before-bend angles and the returned after-bend angles, to which subjects voluntarily bent their wrist so as to reproduce the initially instructed angles, were examined.

In addition to the initiative, the subject and the interaction factors, the other two factors, i.e., an initial angle factor, and an angular velocity factor were examined. The levels of the initial angle factor were (1) the straight wrist condition, i.e., 0°, (2) a medium level of dorsiflexion condition of -30°. The other levels of the angular velocity factor were (1) a relatively higher speed of 30°/s, (2) a lower speed of 10°/s.

Right handed four male subjects aged 23 to 59 participated in the experiment. Thus, the total number of factor level combinations was given by 32(=2×2×2×4). As described in the next section, for each of the factor level combinations, tasks were repeated by 10 runs, and, therefore, the total number of runs was 320(=32×10).

2) Task and Procedure: The procedure was composed of pre-steps and perceptual steps as in the followings.

[Pre-step 1] The subject sat on a chair, and his right hand was held tight to the equipment via the opposing cushions, so that his forearm being horizontal and their upper arm being vertical.

[Pre-step 2] The subject closed his eyes, and a white noise sound was applied to the subject via headphones for masking any sound cues on the perception.

The perceptual steps were implemented for both the passive and active modes:

a) Passive mode: This mode was carried out by the following procedures (see Figure 2).

Preparatory step [Step1] Test target stimulus acceptance.

[Step3] Mask stimulus acceptance
[Step4] Pseudo-test stimulus acceptance

Figure 2. Experimental procedures in the passive mode

[Step1] Passive test target stimulus acceptance: the system forcibly bent a subject wrist from an arbitrary position to an initial angle using the servomotor. This step simulated a process of forcible initial position learning process.
[Step2] The subject was informed that his wrist angle had come to the initial position.
[Step3] Passive mask stimulus acceptance: the system forcibly bent the subject wrist to approximately -60° in the dorsiflexion direction. This process simulated a consecutively delivered passive instruction.
[Step4] Passive pseudo-test stimulus acceptance: the system, finally, forcibly returned the subject wrist to a destination angle chosen from a set of angles a little bit deviated from the initial angle: the deviations from the initial angle were -20°, -16°, -12°, -8°, -4°, 0°, 4°, 8°, 12°, 16°, 20°. Ten kinds of deviations were chosen for them and were presented. This process also simulated the second-consecutively delivered passive instruction.
[Step5] Looking at an answer board being set horizontally, the subject opened his eyes, and answered the amounts of his perceived value with the deviation of the destination angle from the initial angle: the answer board was a protractor-like scale, the fineness of which was 1° (see Figure 3). The ability to notice deviations was considered to be related to an ability for passive posture reproductions.

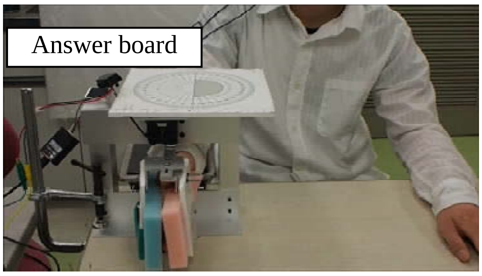


Figure 3. Answer board: subjects chose a character showing the amounts of their perceived angular difference between the before-and-after-bend angle.

b) Active mode: This mode was carried out by the following procedures (see Figure 4).

Preparatory step [Step1] Test target stimulus acceptance.

[Step3] Mask stimulus self-production
[Step4] Test stimulus self-reproduction

Figure 4. Experimental procedures in the active mode: there is no difference in the appearance between this figure and Figure 3. The crucial difference is in whether there is a subject's intention or not.

[Step1] Passive test target stimulus acceptance: the system forcibly bent the subject wrist to an initial angle using the servomotor. This step simulated a process of the forcible learning process.
[Step2] The subject was informed that his wrist had come to the initial position. Then, the electrical current of the driving servomotor was cut off, which made the subject wrist to move freely with small torque being enough to cancel frictions induced at reduction gears.
[Step3] Active mask stimulus self-production: the subject bent one's wrist up to the mechanical limit. This process simulated a process where learners themselves voluntarily change their postures.
[Step4] Active test stimulus reproduction: the subject bent one's wrist up towards the initial position. This process was another voluntarily changing process, and simulated a process to reproduce the specific postures instructed before.
[Step5] The system measured the subject wrist angle.
A series from Step 1 to Step 5 was repeated ten times.

III. EXPERIMENTAL RESULTS

In this section, the experimental results are first presented, and, then, they are examined from the viewpoint of the mean errors and the standard deviations. The mean errors represent biases, and are, so-called, the systematic errors. The standard deviations represent the widths of scattering, and are, so-called, the random errors. Both the errors suggest reproducibility in the still-posed posture reproductions after motion learning procedures. The latter standard deviations will be also related to JNDs.

A. Systematic Errors

In the passive mode, the errors were defined by the perceived angle errors, i.e., the angular differences of the perceived angles from the true angles that had been deviated by -20° to 20° from the initial angles. On the other hand, those in the active mode were defined by the angular differences of the reproduced angles from the initial angles.

As for the perceived/reproduced angle errors, the factors to be tested were the subject activity, the initial angles, the angular velocities, the subjects, and the interaction. Class means represent the systematic errors, and the experimental results with the global mean and the class means for three factors are shown in Figure 5.

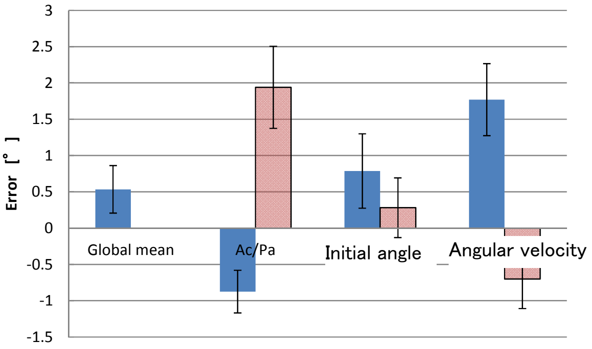


Figure 5. Experimental results of systematic errors of the reconstructed/ perceived angle errors: the main factor effects of the three factors and the global mean.(Error bars: standard errors.)

The differences from the global mean are, so-called, the main factor effects. The significances among the between-class variations of the factor effects were tested by repeated-ANalysis Of VAriances (ANOVA), as shown in Table I.

TABLE I. ANOVA TABLE WITH PERCEPTUAL ANGLE ERRORS

Factor	Item Level	Mean [°]	Factor effect [°]	Sample size	Variation [°^{2}]	DOF	Mean square [°^{2}]	Test statis. F-val.	0.1% point (Crit. val.)	Decision
	Glob.mean	0.534		320						
Initiative	Ac	-0.876	-1.41	160	318					
	Pa	1.94	1.41	160	318					
	Sum				636	1	636	29.2	11.0	***
Initial angle	0	0.786	0.252	160	10.2					
	-30	0.281	-0.252	160	10.2					
	Sum				20.4	1	20.4	0.94	11.0	NS
Subject				320	671	3	224	10.3	5.6	***
Angular velocity	10	1.77	1.24	160	244					
	30	-0.701	1.23	160	244					
	Sum				488	1	488	22.4	11.0	***
Interaction					2450	3	815	37.4	11.0	***
Error					6750	310	21.8			
Total				320	11000	319				

NS: not significant * $P<0.05$, ** $P<0.01$, *** $P<0.001$

TABLE II. ANOVA TABLE WITH JND OF PERCEPTUAL ANGLE ERRORS

Factor	Item Level	Mean [°]	Factor effect [°]	Sample size	Variation [°^{2}]	DOF	Mean square [°^{2}]	Test statis. F-val.	0.1% point (Crit. val.)	Decision
	Glob.mean	2.95		320						
Initiative	Ac	1.82	-1.13	160	178					
	Pa	4.07	1.13	160	178					
	Sum				255	1	40.5	54.6	13.9	***
Initial angle	0	3.14	0.192	160	176					
	-30	2.76	-0.192	160	109					
	Sum				109	1	1.18	1.59	13.9	NS
Subject					217	3	1.00	1.35	7.5	NS
Angular velocity	10	2.97	0.025	160	107					
	30	2.92	-0.026	160	107					
	Sum				214	1	0.02	0.03	13.9	NS
Error					3.44×10^3	25	0.74			
Total				320	4.30×10^3	31				

The initiative factor (Ac/Pa) shows a significant difference with a 0.1% level. In the case of the active mode, there can be seen a tendency of systematic errors in the dorsiflexion direction, while, in the other case of the passive mode, there was an opposite tendency in the palmar flexion direction. From the viewpoint of the magnitudes, the active mode was superior to the passive mode.

The angular velocity factor also shows a significant difference with a 0.1% level of significance. The factor effects of either the initiative factor or the angular velocity factor were 1 to 2 °. The subject factor and the interaction factor also show significant differences. The remaining initial angle factor alone shows no significant difference.

The factor effects can be applied in the practical motion instruction: they enable us to estimate systematic errors and to cancel the errors.

B. *Random Errors*

The Standard Deviations (SDs) of the perceived/reproduced angle error variations represent the random errors, and, furthermore, can be converted an important measure of JND. The JNDs suggest some limits of accuracies of angular instructions.

Here, note that the JND represents the difference between a pair of stimuli, and is defined by the 75 % point in the psychometric curve. Therefore, if the psychometric curve is to be approximated by the normal distribution, the cumulative probability of 75 % corresponds to 0.674×SD. Thus, JNDs are approximately converted from the SDs by

$$JND = 0.674 \times SD_{sum}. \qquad (1)$$

where SD_{sum} is given by the sum of the global mean SD_{gm} and the three factor effects, $E_{Ac/Pa}$, $E_{Initial\ angle}$, $E_{Angular\ velocity}$. That is,

$$SD_{sum} = SD_{\gamma m} + E_{Ac/Pa} + E_{Initial\ angle} + E_{Angular\ elocity}. \qquad (2)$$

As for the converted JNDs, some of the experimental results with the global mean and the class means for three factors are shown in Figure 6.

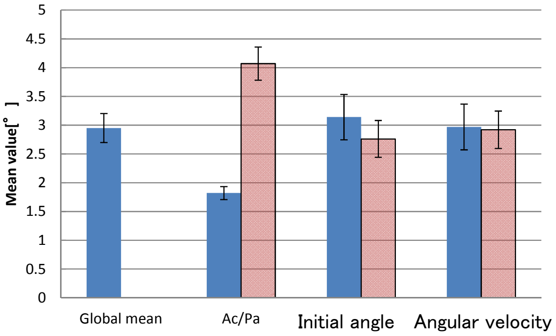


Figure 6. Experimental results of JNDs obtained from the random errors of the reconstructed/perceived angle errors: the main factor effects of the three factors and the global mean .(Error bars: standard errors.)

The significances among the between-class variations of class means were, also, tested by repeated-ANOVA as shown in Table II. We can find the initiative factor (Ac/Pa) shows significant difference with the significant level of 0.1%. Besides the initiative factor, we couldn't find any significant difference for the other factors of the initial angle, the angular velocity, and the subject.

IV. CONCLUSION AND FUTURE WORK

For establishing a new motion instructing scheme, i.e., the restrained instruction scheme, the authors have studied kinesthetic sensation with wrist bending motions.

- As for the subject's initiative, the active mode was superior to the other passive mode from both the viewpoints of the systematic errors and the random ones in an initial angle reproductions task.
- The former knowledge of the systematic errors enabled us to estimate and to cancel the errors.
- The latter results were converted into the JNDs, and the JNDs suggested some limits of accuracies of angular instructions.

In the future, we will make a profound study on the kinesthetic sensations of wrist bending motions and will extend to other joint motions.

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