Unloading muscle activation enhances force perception

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ABSTRACT
In this study, we examined (1) weight discrimination capability of human subjects with different body postures, and (2) sensorimotor capability of human subjects when using a muscle assistive equipment. According to previous studies, humans can sense the intensity of external stimulus more accurately when voluntary muscle activation is less. We developed a three-dimensional musculoskeletal model based on an upper extremity model, and calculated the muscle activity required to keep a posture. We also conducted human experiments and revealed that the weight discrimination capability improves as voluntary muscle activation is less. Based on the experimental results, we developed a muscle assistive equipment that unloads the weight of one's upper limb and evaluated the improvement in the sensorimotor capability when using the equipment. The results show that assisting the muscle load is effective to improve the sensorimotor performance.

Author Keywords
Force perception capability; Muscle assistive equipment; Sensorimotor enhancement.

ACM Classification Keywords
H.5.2. Information Interfaces and Presentation (e.g. HCI): Haptic I/O

INTRODUCTION
Recent advances in assistive technologies provide technical aids for improving quality of life not only for disabled and elderly individuals but also for healthy people who work under extreme environments. To support human motions in a safe and acceptable manner, understanding musculoskeletal dynamics of humans and building models of human's sensation and motion are helpful to evaluate the subjective efforts associated with intuitive, safe, and easy-to-use design. Many studies have confirmed the effect of muscle activation on weight discrimination[5, 2, 3]. Human's skeletal muscles have sensory system, such as muscle spindles and Golgi tendon organs. It is known that the muscle spindles primarily detect changes in the length of muscle, and the Golgi tendon organs primarily detect changes in muscle tension. These receptors are believed to be involved in the proprioceptive sense of a body posture and neuromuscular activation. There is a sense of force associated with voluntary muscle activity. Our research group has proposed the evaluation method of the perception characteristics of force during a steering wheel operation based on the estimation of voluntary muscle activity by using a three-dimensional musculoskeletal model[6]. The experimental and simulation results revealed that the perception characteristics of force changes depend on the physical capacity of the human body. In particular, the results suggested that humans can sense the intensity of external stimulus more accurately when voluntary muscle activity is less.

In this study, we measure the force perception capability of human subjects with different postures in order to investigate how differences in voluntary muscle activation affect the force perception capability of humans. Based on the experiment, we develop a muscle assistive equipment that unloads one's upper limb and evaluate the improvement in the sensorimotor capability when voluntary muscle activation is reduced using the developed equipment.

WEIGHT DISCRIMINATION CAPABILITY TEST
Muscle activity in different postures
To investigate the influence of the muscle activation on the force perception capability of humans, a weight discrimination capability was measured in two body postures. Fig. 1 shows the poses measured in this study. Pose 1 and Pose 2 are the postures where the elbow is extended (a) and flexed (b), respectively. The muscle activations required to exert the

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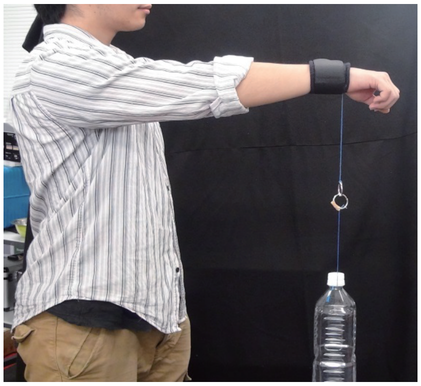
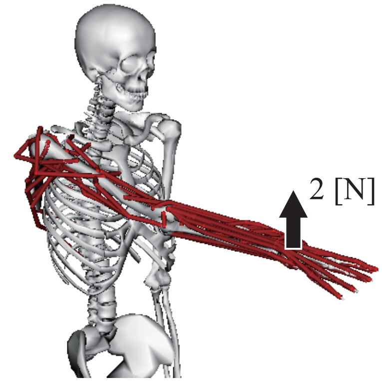


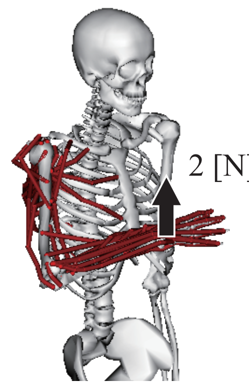
(a) Pose 1 (elbow extended)

(b) Pose 2 (elbow flexed)

Figure 1. Weight discrimination capability test



(a) Pose 1 (elbow extended)



(b) Pose 2 (elbow flexed)

Figure 2. Musculoskeletal models for the weight discrimination capability test

upward force of 2 [N] at the wrist for keeping these postures were calculated by using OpenSim, which is an open source software system for biomechanical modeling, simulation and analysis[1]. A three-dimensional musculoskeletal model was developed based on an upper extremity model[4] (see Fig. 2). Physical parameters of the upper extremity and muscles were given based on [6].

When the elbow is extended, the center of mass of the upper limb is further away from the torso, and a larger joint moment along the shoulder is generated than that when the elbow is flexed. This indicates that greater voluntary muscle activation related to shoulder motions is required for maintaining the posture with the elbow extended than flexed. Fig. 3 shows the mean muscle activity of involved 50 muscles for keeping the postures calculated by the OpenSim. Pose 1, where the elbow is extended, needs larger voluntary muscle activity than Pose 2, where the elbow is flexed. According to the previous study[5], it is expected that Pose 2 will have a higher force perception capability than Pose 1.

Experimental results

We conducted human experiments to examine the weight discrimination capability in Pose 1 and Pose 2. Six male subjects aged 22-24 participated in the experiment. The subjects gave informed consent before participating. The subjects were instructed to close their eyes. First, the experimenter hanged a bottle of 200[g] weight at the wrist of the subject and asked the subject to remember the force perception of holding weight. Second, the experimenter changed the weight in ascending and descending manners with the weight interval of 10[g]. The subjects were asked to report when they judged the weight reached 200[g]. The experimental results are shown in Fig. 4. In the ascending case, the weight that the subjects judged same as 200[g] was lower than 200[g]; in contrast, in the descending case, the weight that the subjects judged was higher than 200[g]. In both of the ascending and descending cases, Pose 2 was found to have a better weight discrimination capability. This results suggest that the weight discrimination capability improves as voluntary muscle activation is less.

SENSORIMOTOR CAPABILITY TEST

Muscle force assistive equipment

To enhance the force perception capability of humans, we developed a muscle force assistive equipment. The developed equipment is shown in Fig. 5. This equipment is made of stretch fabric and employs a passive assistive style. One side of the stretch fabric is fixed at one's waist and the other side is fixed at one's upper arm. The stretch fabric has spring constant of 392[N/m], and it generates the flexion moment at the

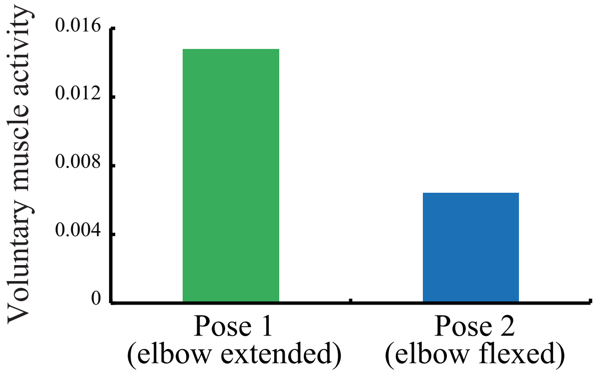


Figure 3. Estimated voluntary muscle activity across involved muscles for the different poses

shoulder joint as shown in Fig. 6. This shoulder flexion moment generated by the equipment unloads a part of shoulder extension moment generated by the weight of the arm.

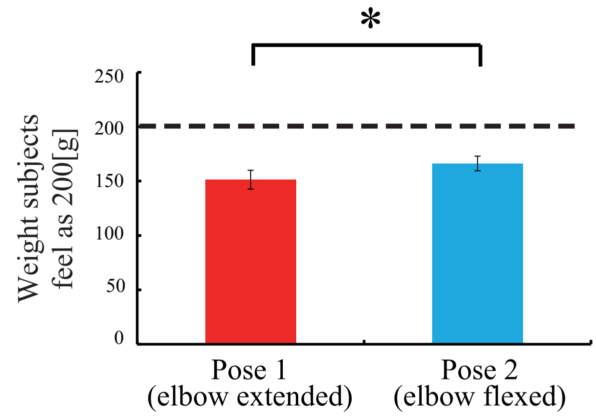
Experimental results

We conducted human experiments to confirm the improvement of the force perception capability by using the proposed assistive equipment. Ten male subjects aged 22-24 participated in the experiment. The subjects gave informed consent before participation. The subjects were instructed to stretch their arm forward with extended elbow and close their eyes. First, the experimenter hanged an empty container at the wrist of the subject, put a weight of 1500[gf] into the container as shown in Fig. 7, and asked the subject to remember the perception of holding the weight. Second, the experimenter detached the container and put a force transducer at the subject's wrist as shown in Fig. 8. The subjects were asked to exert the force upward (shoulder flexion torque) to match the force with the weight they hanged before. Each subject underwent three trials for the conditions with and without the assistive equipment alternately. 30-second rest periods were provided between trials.

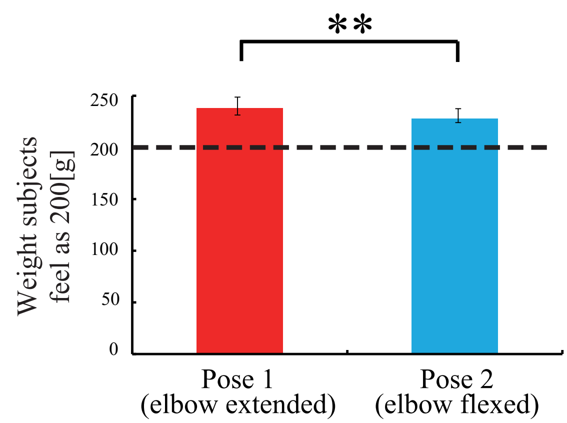
Fig. 9 shows the difference between the remembered load (1500[gf]) and the exerted force by the subjects based on their memory. 450[gf] and 350[gf] errors, on average, were observed without and with assistance of the equipment, respectively. A statistically significant difference was found by Student's t-test. This suggests that the developed equipment can significantly improve the sensorimotor function of the subjects. To sense a weight and to exert force at the wrist with a stretched arm posture, shoulder muscles, e.g. deltoid muscles, infraspinatus muscle, and biceps brachii muscles, play an important role. The developed muscle assistive equipment mainly supports the flexion moment about the shoulder. Counteracting the shoulder extension moment unloads the voluntary muscle activation related to the flexion of the shoulder. The observation obtained suggests that the less voluntary muscle activation required to keep the posture contributes the improvement of the sensorimotor performance.

CONCLUSIONS

In this study, we examined (1) the weight discrimination capability of human subjects with different body postures, and



(a) Ascending case



(b) Descending case

Figure 4. Results of the weight discrimination capability test. Statistically significant differences were observed by the Student's T-test ($* : p < 0.05; ** : p < 0.01$)

(2) the sensorimotor capability of human subjects when using a muscle assistive equipment. The results of the weight discrimination capability test show that the weight discrimination improves when the subjects take the posture where the elbow is flexed rather than extended. The results of the sensorimotor capability test show that unloading voluntary muscle activation is effective to improve the sensorimotor performance of the subjects.

Future work includes improving the muscle assistive equipment to be able to unload larger force on broader ranges of muscles. Continued research may lead to the development of an equipment that helps individuals working in workplaces.

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Figure 5. Muscle assistive equipment

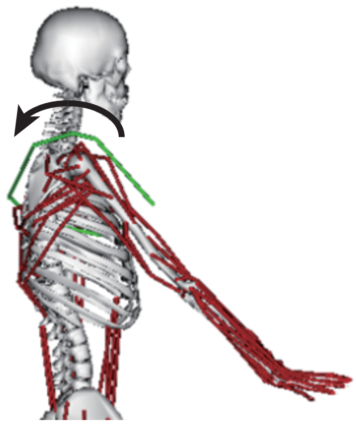

Figure 6. Assistive effect of the developed assistive equipment

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Figure 7. Experimental condition: the load is given at the wrist

Figure 8. Experimental condition: the subjects exert force on the force sensor

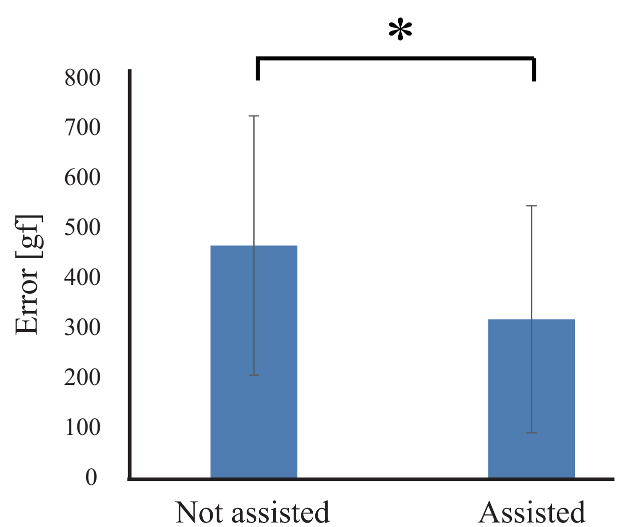

Figure 9. Error between the remembered and exerted force. Statistically significant differences was found by the Student's T-test ($* : p < 0.05$)