Motor control characteristics of assisted and voluntary force release

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Abstract

In order to work with power-assist devices, humans need to control muscle force, mainly, force release. However, not only humans are unfamiliar with the motor control for force release, but also it is possible that physiological characteristics of force release caused by operation of the mechanical assistance may be different from that of voluntary force release. In this study, the motor control characteristics of assisted and voluntary force release during isometric elbow flexion were compared. Thirteen right-handed male participants (age: 24.7 ± 1.8) performed trajectory tracking task, which included sequential phases of (1) 5 s of keeping a reference force with 47 N, (2) 5 s of force release to a reduced level, and (3) 5 s of keeping the reduced force level. The second phase of force release included visually guided or mechanically assisted force release, and final keeping phase included two levels of reduced force (25% and 50% from the reference force). A linear actuator was used to simulate conditions of power assistance. A two-way repeated measures analysis of variance was conducted for type of force release and reduced force level. Tension during the isometric contraction and electromyography of biceps brachii and triceps brachii were recorded, and computed parameters of force variability and co-contraction rate were explored. The results showed that during force release, force variability was not affected by the type of force release, while co-contraction rate was higher for mechanically assisted force release than that for visually guided force release.

Keywords: Motor control, Force release, Trajectory-tracking, EMG

1. Introduction

Power-assist devices, which are used to reduce human workload, are expected to be applied for activities of daily living in the near future beyond the current fields of welfare and industry. Since such devices are utilized for partial reduction of workload rather than complete replacement, users interact and work with the devices by releasing their force to a certain level.

However, releasing force seems difficult under assistance, with problems of ineffective muscle activity and movement speed [1, 2]. It can be explained by feedforward mechanism of motor control that predicts and reacts to the external force, often causing resistance for postural stabilization [3]. Therefore, optimal interaction with these devices might depend not only on the power assistance itself, but also on how humans control their movements during force release. A previous study postulated power assistance by providing visually guided feedback for voluntary force release and showed that task accuracy varied according to the duration of force release and reduced force level [4]. However, it is yet to be explored whether such a motor control for visual feedback to guide voluntary force release is equated with that for mechanically assisted force release, especially for physiological responses such as force variability and co-contraction rate between agonist and antagonist muscles.

In this study, we investigated motor control characteristics of both mechanically assisted and voluntary force release during elbow flexion. The force release conditions were conducted identically to be reduced by certain level from a reference force in a fixed duration. We hypothesized that both force variability and co-contraction rate would increase under mechanically assisted force release.

2. Method

Thirteen male participants were involved in this study (age: 24.7 ± 1.8). All of them were right-handed and the dominance was confirmed using the Edinburgh Handedness Inventory.

The participants were asked to sit on the chair and flex their elbow to 90˚ from sagittal view. Straps were attached to the wrist point and center of the forearm, respectively. The strap at the wrist point was connected by wire to the ground, with a tensile sensor “A” equipped between them. The other strap at the center of the forearm was also connected by a wire to a linear actuator mounted overhead, with another tensile sensor “B” between them. In order to adjust the
assistance level, one of two different types of springs was mounted between the actuator and tensile sensor.

Then, each participant was asked to perform a trajectory tracking task provided on the monitor in front of them by exerting tension of isometric force upward. The tension required in the experimental task was calculated by the tension measured from the tensile sensor “A” – 1/2 \times the tension measured from the tensile sensor “B.” The task included sequential phases of (1) 5 s of keeping 47 N of a reference force, (2) 5 s of releasing force to a reduced level, and (3) 5 s of keeping the reduced force level. The second phase of release involved either visual guidance or mechanical assistance, and following phase included two levels of reduced force (25% and 50% from the reference force). During mechanical assistance, the linear actuator was operated to assist force release. All participants repeated the task six times.

A repeated measures analysis of variance (ANOVA) was conducted for the type of force release (mechanical assistance and visual guidance) and reduced force level (25% or 50% from the reference force). Tension and electromyography (EMG) of biceps brachii and triceps brachii were measured throughout the task. Before the main experiment, maximal voluntary contraction (MVC) of biceps bracii and triceps brachii were measured, and the EMG values of each participant were normalized to the %MVC. From the measurement, we analyzed force variability and co-contraction rate during 5 s of force release. Those parameters were calculated (Equation 1 and 2), as follows.

1. Force variability (%) = \frac{SD\ of\ tension\ for\ 100Hz}{Mean\ of\ tension\ for\ 100Hz} \times 100

2. Co-contraction rate (%) = \frac{\%MVC\ of\ Triceps\ brachii}{\%MVC\ of\ Biceps\ brachii} \times 100

3. Results

The results of ANOVA for force variability showed that the type of force release had no significant effect, along with the interaction between type of force release and reduced force level. However, significant main effect of reduced force level was found (F(1,12) = 952.3, p < 0.01), indicating a higher force variability under the 50% reduced level from the reference force (mean = 18.4, SD = 1.6) compared to that of the 25% reduced level (mean = 8.2, SD = 0.9).

Next, the results for co-contraction rate yielded significant main effect of force release type (F(1,11) = 4.9, p < 0.05) (Figure 1), indicating that co-contraction rate was higher for mechanically assisted release (mean = 27.8, SD = 9.3) than that for visually guided release (mean = 25.4, SD = 7.9), regardless of the levels of reduced force. However, a reduced force level and interaction between the two factors had no significant effect.

4. Discussion

This study showed that while force variability remained constant regardless of the type of force release, co-contraction rate increased under the mechanically assisted force release. Thus, it is likely that motor control for force release requires higher recruitment of antagonist muscles, specifically for mechanical assistance, even if force variability appears to be similar in both types of force release. Future study should include additional durations of force release to clarify if the results of current study are consistently maintained.

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References

[1] N. Nasir, K. Hayashi, P. Y. Loh, and S. Muraki, “The effect of assistive force on the agonist and antagonist muscles in elbow flexion,” Movement, Heal. Exerc., 6(2), pp. 29–41, 2017.
[2] J. Rosen and J. Perry, “Upper limb powered exoskeleton,” Int. J. Humanoid Robot., 4(3), pp. 529–548, 2007.
[3] D. J. Ostry and A. G. Feldman, “A critical evaluation of the force control hypothesis in motor control,” Exp. Brain Res., 153(3), pp. 275–288, 2003.
[4] J. Choi, P. Y. Loh, and S. Muraki, “Simulation study on the effects of adaptive time for assist considering release of isometric force during elbow flexion,” Proceedings of the 20th Congress of the International Ergonomics Association, pp. 347-350, 2019.