Simulation Study on the Effects of Adaptive Time for Assist Considering Release of Isometric Force During Elbow Flexion

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Abstract. The increasing trend of development of assistive technology allows for the use of assistive robots such as power assist devices to be prevalent in various social domains. Such power assist devices usually provide incidental power to their users, requiring human-machine force interaction. If the power assist device requires users to release their muscular force without considering adaptive time, users might be confused to control the level of their manual performance in response to the external force. This study investigated adaptive time with varying release rates of isometric force during one-arm elbow flexion, focusing on muscle activity and force control. Eight participants conducted graphical force-tracking tasks designed to simulate power-assist condition. Electromyography signals and the tension forces of the biceps brachii and triceps brachii were measured. The results implied that sufficient adaptive time for muscular force release induced better performance level with a smaller difference between the target force and the actual force. However, higher subjective exertion was also accompanied during the longer time for muscular force release. This study suggests that in designing power assist devices, the duration for muscular force release and consequent characteristics should be considered to maintain the precise level of force control.

Keywords: Power-assist simulation · Adaptive time · Muscular force release

1 Introduction

Assistive technology focuses on developing any device or system that is usually attached to the human body and helps humans physically. Power assist devices, for instance, have been designed to generate assistive movement to users to facilitate easier human action and relieve physical stress. However, since assistive devices are usually attached directly to the human body and involves physical interaction, users inevitably experience various issues of practical use, such as adaptability to the assistive force [1, 2]. In the interaction stage, during which users receive and adapt to the assistive force from the devices, muscular force is released down to a certain level, allowing muscular ability to control the task performance. However, if such a force release is induced by the power assist device without considering the appropriate time to adapt, users might be confused to control the level of their task performance in a moment.

S. Bagnara et al. (Eds.): IEA 2018, AISC 820, pp. 347–350, 2019.
https://doi.org/10.1007/978-3-319-96083-8_46

In this study, the power assist condition was simulated with a series of graphical force-tracking tasks performed in isometric elbow flexion. We aimed to elucidate the effect of adaptive time with varying release rates of isometric force toward certain levels of assistive force, mainly exploring force control performance.

2 Methods

Eight healthy male participants without prior or current functional disorders were recruited (age, 23.3 ± 1.3 years). The hand dominance of the participants was determined using the Edinburgh Handedness Inventory.

The participants were positioned in an upright sitting posture with a display in front of them. The upper body was straightened, and the right forearm was supinated and fixed at 90° elbow flexion. A wrist strap was equipped at the styloid process of the right radius, and a tensile sensor (T.K.K. 1269f, Takei Scientific Instruments Co., Ltd, Niigata, Japan) was connected with chain between the strap and the floor.

On the basis of the environment for isometric elbow flexion, the force tracking task was simulated [3]. This simulation facilitated the modeling and observation of muscular force release for varying adaptive time, before taking account of practical assistive devices. In this study, three sequential phases were defined as follows: (1) before assist (40% MVC, 7 s), (2) adaptive time for muscular release, and (3) constant assist (7 s). The adaptive time was set at 1 and 5 s, and each force was sloped and linearly guided to be released to the phase of constant assist, at a level of either 33% or 67% assist for the 40% MVC. The corresponding graphics of three segments were sequentially presented on a computer screen as a target force. The actual force output of each participant, which was measured using a tensile sensor in real time, was also graphically demonstrated. The graphical visualization was implemented using data analysis software (LabChart 7, ADInstruments, Dunedin, New Zealand).

Before the simulation, a maximal isometric voluntary contraction (MVC) and the corresponding maximum exerted force (N) for the elbow flexion of each participant were obtained to construct a graphical guide for the force tracking task. In the main experiment, the participants were asked to track the force lines as accurately as they could by exerting isometric contraction of elbow flexion. The learning effect was minimized by considering two additional conditions of fake slope and complete counterbalancing. Each trial was repeated twice.

A multi-channel data acquisition system (Powerlab 16/30, ADInstruments) was used to obtain the force signals from the tensile sensor. Samples were calculated using the relative percentage difference (RPD) of the individual force output against the target force from the graphics, which is the percentage of (target force − output force)/target force (Fig. 1).

The data for the two phases of adaptive time and constant assist were considered in this study. Two-by-two repeated-measures analysis of variance (ANOVA) was used to analyze the two factors of adaptive time (1 and 5 s) and the simulated level of assist (assist level; 33% and 67%). All statistical analyses were conducted using SPSS Statistics 23.0 (IBM, NC, USA).

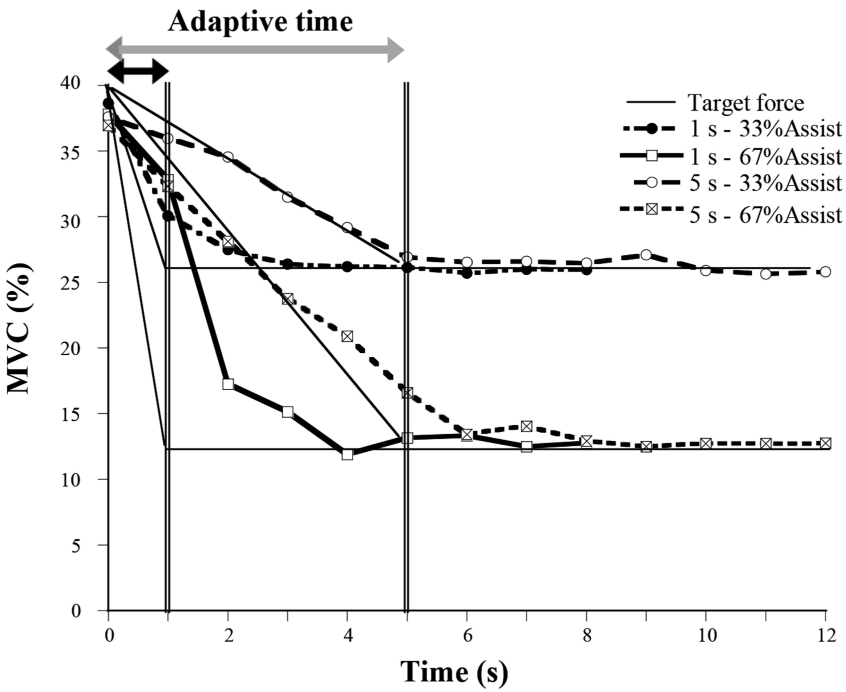

Fig. 1. A representative result for the two latter phases of adaptive time and constant assist during one trial. The difference between the target force and the individual force output for each condition was calculated for the RPD.

3 Results and Discussion

The data normality was verified using the Shapiro-Wilk test (all p values > 0.185). The ANOVA revealed the significant main effect of adaptive time ($F(1,15) = 100.31$, $p < 0.01$), indicating a higher RPD in the adaptive time of 1 s (M = 11.37, SE = 0.70) than that of 5 s (M = 5.13, SE = 0.31). The main effect of the assist level was also significant ($F(1,15) = 112.75$, $p < 0.01$), indicating that a 67% assist demonstrated a higher RPD (M = 12.39, SE = 0.81) than a 33% assist (M = 4.11, SE = 0.21). The interaction between the adaptive time and the assist level was significant ($F(1,15) = 49.80$, $p < 0.01$), and the follow-up t tests revealed that the longer adaptive time for muscular force release showed a significant decrease in RPD throughout the assist level, especially for the 67% assist (Fig. 2).

As was expected, the longer adaptive time lessened the gap between the target force and the actual force, deriving less percentage difference in force control. The interaction showed, however, that the gap was dramatically reduced at the 67% assist, demonstrating that the sufficient adaptive time for muscular force release should be considered if a higher assist level needs to be delivered with more accuracy.

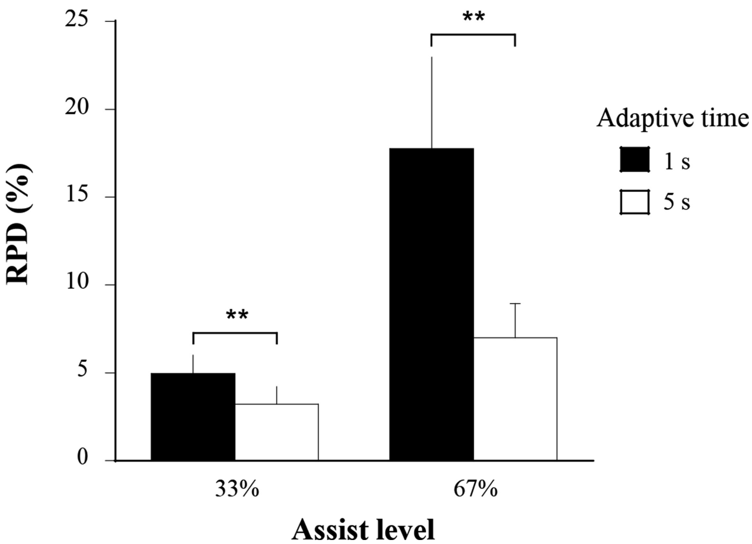

Fig. 2. Average RPD according to adaptive time for simulated levels of constant assist. The asterisks indicate a significant difference between the conditions (**: $p < 0.01$).

Future studies should include a more sophisticated methodology to observe and analyze the force control such as force variability or instant reaction against assistive force, taking into account the related muscle activity as well.

References

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