**Effects of Single-handed and Dual-handed Tasks on Myoelectric Hand Prosthesis Operability of Unilateral Transradial Amputees**

Jumpei Oba, Sumiko Yamamoto, Kengo Ohnishi, Isamu Kajitani, Yaeko Shibata, Koki Asai

1. Background

Myoelectric prostheses were reported to be practical and effective by Hermansson et al. based on their myoelectric prosthesis usage survey of myoelectric prosthesis users (n=75) [1]. Moreover, there are reports affirming that myoelectric prostheses play an important role in achieving rehabilitation goals [2-4]. However, this previous research involved survey-based retrospective studies. Therefore, while these studies support the usefulness of myoelectric prostheses, their findings are not based on firm scientific evidence [1]. Furthermore, Resnik reported that the effects of myoelectric prosthesis training on the ability of amputees to operate upper limb prostheses are unclear [5]. Hence, it is necessary to clarify the effects of myoelectric hand operation training based on objective data.

Myoelectric prosthesis operation training was proposed by Atkins in 1992 [6], and associated guidance was formulated by Johnson et al. in 2015 [7]. The training was organized into single-handed and dual-handed tasks, and it was recommended that dual-handed tasks should be performed after practicing single-handed tasks [6,7]. However, there are no objective data to verify how single-handed and dual-handed tasks affect amputees’ ability to operate myoelectric prostheses. The

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**Abstract:** Objective: The influence of myoelectric hand training on the ability of amputees to operate a prosthetic hand has not been fully verified. This study aimed to investigate the effects of single-handed and dual-handed tasks on the ability of amputees to use a myoelectric prosthetic hand in training.

Method: The subjects were unilateral transradial amputees (n=12). The training effects of each task were measured by assigning the myoelectric hand prosthesis users to two groups and conducting a crossover study: one group performed the single-handed task first followed by the dual-handed task, and the other group did the opposite. The Southampton Hand Assessment Procedure (SHAP) score was used to assess the subjects’ ability to control the myoelectric prosthetic hand.

Results: The training effect differed significantly between the single-handed task, SHAP score: 6.3 (5.8–8.5) points, and the dual-handed task, SHAP score: 10.3 (8.8–14.2) points; however, the effect was insufficient (p = 0.008, r = 0.20).

Conclusion: The dual-handed task improved the subjects’ ability to accurately operate a myoelectric hand more effectively than the single-handed task. This suggests that the dual-handed task is more effective at developing control of opening/closing movements and object handling with a myoelectric hand than the single-handed task.

Keywords: myoelectric hand prosthesis, single-handed task, dual-handed task, unilateral transradial amputees
same applies to the relationship between the results of single-handed and dual-handed task [8]. In a study in which able-bodied subjects practiced operating a myoelectric prosthesis using a simulated myoelectric prosthesis, it was reported that dual-handed tasks resulted in greater improvements in object manipulation skill than single-handed tasks [8].

The aim of this study was to clarify the effects of single-handed and dual-handed tasks on myoelectric prosthetic hand training among transradial amputees, and the differences between the effects of the tasks. Our hypothesis was that dual-handed tasks are more effective than single-handed tasks.

2. Methods

2-1. Subjects

The subjects were unilateral transradial amputees with no experience of myoelectric prosthesis use or training. The inclusion criteria were being a unilateral transradial amputee, who is over 20 years of age, does not have difficulty donning prosthetic arms due to muscular weakness or a limited range of motion, and has no history of rehabilitation. The exclusion criteria were an amputated limb length of <10 cm, skin conditions that make it difficult to collect myoelectric signals, having difficulty donning prosthetic arms due to cognitive dysfunction or intellectual disability, experience of myoelectric prosthetic use, and refusal to consent to the experimental conditions. Twelve unilateral transradial amputees met the above criteria and participated in this study. The subjects’ attributes were as follows: 8 males and 4 females, mean age: 42.9 ± 13.9 years, mean height: 162.8 ± 7.0 cm, mean weight: 58.9 ± 6.5 kg, mean residual length of the amputated forearm: 18.2 ± 5.7 cm, mean residual percentage length of the amputated forearm: 66.3 ± 18.9%, mean maximum circumference of the amputated forearm: 22.8 ± 2.6 cm, side of amputation: 9 right and 3 left. In the experiment, none of the subjects had impaired proprioception due to diabetes or other diseases.

The subjects were randomly divided into two groups, a group in which the dual-handed task was performed after the single-handed task (group A) and another group in which the single-handed task was performed after the dual-handed task (group B). The significance of differences between the groups was analyzed using Fisher’s exact test for sex and the amputated side and Mann-Whitney’s U test for age. Height, body weight, residual amputated forearm length, residual percentage amputated forearm length, and maximum amputated forearm circumference were analyzed using the Student’s t test. No significant intergroup differences were found for any of the examined background factors (p>0.05) (Table 1).

This research complied with the tenets of the Declaration of Helsinki and was conducted with the approval of the institutional review board of Kobe Gakuin University (approval code: HEB101207–4).

2-2. Design and Protocol

This study involved a crossover design. In the baseline period, the subjects practiced controlling the opening and closing movements of a virtual myoelectric hand using a software program on a personal computer for 20 minutes per day for 5 days as practice before donning the myoelectric prosthesis. Next, groups A and B performed both tasks. Group A performed the dual-handed task after performing the single-handed task, and group B performed the single-handed task after performing the dual-handed task. Each task was conducted

| Table 1. Group A and Group B profile |
|-------------------------------------|
| Group A n=6                        | Group B n=6                        | p (ns) |
|-------------------------------------|
| Sex [M/F]                           | 3/3                                | 5/1    | n.s    |
| Age [year]                          | 43.8 ± 12.8                        | 42.0 ± 16.1 | n.s    |
| Body height [cm]                    | 161.0 ± 7.3                        | 164.5 ± 6.9 | n.s    |
| Body weight [kg]                    | 56.2 ± 6.6                         | 61.7 ± 6.7 | n.s    |
| Side [R/L]                          | 5/1                                | 4/2    | n.s    |
| Stump length [cm]                   | 17.3 ± 52                          | 19.0 ± 6.5 | n.s    |
| Stump ratio [%]                     | 66.3 ± 17.5                        | 66.3 ± 21.8 | n.s    |
| Stump max girth [cm]                | 22.8 ± 1.9                         | 22.8 ± 3.4 | n.s    |
| Amputation history [month]          | 112.0 ± 250.8                      | 140.2 ± 236.3 | n.s    |
| etiology [trauma/congenital]        | 5/1                                | 4/2    | n.s    |
| Body prosthesis history [mo nth]    | 4.0 ± 2.6                          | 4.0 ± 5.2 | n.s    |

Notes. Sex and amputation ratios in both groups were determined using Fisher’s exact test, age was determined using Mann-Whitney’s U test, Body height, Body weight, Stump length, ratio, and maximum girth using Student’s t test. n.s.: not significant
for 20 minutes per day for 5 days, for a total of 10 days. The washout period was set to 2 days. Both groups underwent a myoelectric hand operation test before and after each period (Figure 1).

The myoelectric hand used in this study was the Ottobock MyoBock electric hand (8E38 = 6 DMC plus 7.1 / 4). The electrodes for opening and closing the myoelectric hand were positioned on the extensor carpi radialis longus and flexor carpi ulnaris of the residual forearm.

The single-handed and dual-handed tasks selected as training methods for this study were based on those used in clinical practice and previous myoelectric prosthesis studies [7–9]. The single-handed task involved picking up and placing (holding, moving, and releasing) a block (a cube; side length: 1 to 3 cm) or a disk (diameter: 1 to 3 cm) on a desk and was performed for 20 minutes a day for 5 days [9]. Each day, the subjects were asked to perform the task 50 times at their own pace. The subjects were also instructed not to assist the myoelectric prosthesis with their intact hand. The dual-handed task was also a 5-day assignment. In this task, macrame was performed for 20 minutes, twice a day. Specifically, the subjects were required to create 20 flat knots on a desk [9]. They were instructed to use their intact hands as they would in a normal dual-handed task. We pilot-tested the macrame task to confirm whether it had direct effects on the outcome measure of this experiment. The results showed that it had no recognizable influence. The assessment procedure did not involve string manipulation or repeated hold-and-release operations; therefore, we concluded that the macrame task was an independent task and would not interfere with the assessment procedure.

2-3. Outcome measure

The Southampton Hand Assessment Procedure (SHAP) score [9,10] was used as the outcome measure in this study. The SHAP test’s credibility and validity for measuring the controllability of opening/closing myoelectric hand movements and the ability of subjects to manipulate objects using a myoelectric hand during daily activities were confirmed by Hill et al. [9,11]. The capability to manipulate objects represents the ability 1) to appropriately manipulate an object as intended, 2) to adjust the contact position and force applied so that they are appropriate for the target object, 3) to hold and move the object without dropping it, and 4) to accurately release the object at the target location [9–11]. The SHAP test consists of 6 abstract objects and 14 activities of daily living. Each task is timed by the subject and recorded on an assessment sheet by the assessor. The score is computed from the time and normalized to a 100-point scale [12] (Figure 2).

As for the experimental environment, the subjects donned the myoelectric hand and sat in front of a desk. The height of the desk was adjusted so that the angle of the elbow joint was 90 degrees during the performance
of the task [13]. Prior to the test, each task was practiced only once by the subjects to confirm that the prosthetic hand could be used to execute the task. An occupational therapist, other than the primary researcher, with experience of training amputees to operate myoelectric prosthetic hands performed the examinations.

2-4. Statistical analysis

In this study, we used the crossover method to investigate the differences in the changes in myoelectric prosthetic hand operation ability between the single-handed and dual-handed tasks.

The carryover effect was examined by assessing whether the results obtained in the first half of the intervention were carried over to the beginning of the second half of the intervention. The carryover effect was analyzed by comparing the median of the sum of the scores for the first and second interventions between the groups. When the difference was insignificant (p > 0.10), we judged that there was no carryover effect, and tested the timing effect and training effect. The timing effect is the potential effect of conducting the intervention at a particular time. In this study, the timing effect was calculated by subtracting the results for the second intervention from those for the first intervention in group A, and subtracting the results for the first intervention from those for the second intervention in group B. The training effect is the difference between the effects of two or more tests [14,15]. We compared the change seen in the single-handed task with that seen in the dual-handed task in the first half of the intervention, and the change seen in the single-handed task with that seen in the dual-handed task in the second half of the intervention. The effect of the task was determined based on which task’s change value was significantly higher [14,15]. The difference in the effects of the single-handed and dual-handed tasks was considered to represent the training effect in this study. We analyzed the results of groups A and B with the Mann-Whitney U test. The statistical significance level was set at 0.1 for the carryover effect test and 0.05 for the timing effect and training effect. The results obtained before and after

Fig. 2  The Southampton Hand Assessment Procedure (SHAP)

Notes. This test evaluates the ability to control the opening and closing of the myoelectric hand and the ability to operate items. It consists of six types of object tasks for manipulating the object whose shape is to be grasped and 14 types of daily life movement tasks [11–13]
the single-handed and dual-handed tasks were analyzed with the Wilcoxon signed rank test, using the results for the first half of the intervention. This was done in order to exclude the effects of prior training experience [14,15]. The significance level was set at 0.05. In each test, the effect size (\( r \)), which indicated the magnitude of the effect, was calculated in addition to the significance of the difference in the training effect.

Statistical analyses were conducted by performing the Mann-Whitney U test and Wilcoxon signed rank test using statistical analysis software (IBM SPSS Statistics ver.24.0). The effect size was calculated with Microsoft Excel ver.16.0, using the Z-value obtained from the Mann-Whitney U test and Wilcoxon signed rank test.

3. Results

The results of this study are shown in Tables 2, 3, and 4.

Table 2 shows the SHAP scores for each subject in groups A and B. The results for the first to fourth tests are represented as median and interquartile range values. In group A, the scores for the first, second, third and fourth tests were 43.5 (40.0–44.5) points, 47.0 (45.5–47.0) points, 46.0 (43.0–47.5) points, and 55.0 (54.3–56.7) points, respectively. In group B, the scores for the first, second, third, and fourth tests were 41.5 (38.0–43.5) points, 53.0 (52.0–54.8) points, 51.0 (49.3–52.0) points, and 60.0 (58.5–60.0) points, respectively.

Table 3 shows the results of comparisons of the SHAP scores obtained before and after the single-handed task and those obtained before and after the dual-handed task.

### Table 2: Result of SHAP of all subjects (A group and B group)

|       | I           | II          | III         | IV          |
|-------|-------------|-------------|-------------|-------------|
| Group A | 43.5 (40.0–44.5) | 47.0 (45.5–47.0) | 46.0 (43.0–47.5) | 55.0 (54.3–56.7) |
| Single-handed task | Dual-handed task |
| Group B | 41.5 (38.0–43.5) | 53.0 (52.0–54.8) | 51.0 (49.3–52.0) | 60.0 (58.5–60.0) |
| Dual-handed task | Single-handed task |

Notes: The results of SHAP for each subject in Groups A and B. Data are represented as median (interquartile range), SHAP score.

### Table 3: Results of statistical analysis in the SHAP crossover test method

|               | median (IQR) | p-value | effect size (\( r \)) |
|---------------|--------------|---------|-----------------------|
| carryover effect |              |         |                       |
| Group A       | 13.5 (11.3–15.8) | 0.421   |                       |
| Group B       | 21.0 (16.3–25.8) |         |                       |
| timing effect |              |         |                       |
| first half of the intervention | 1.8 (−4.3–0.4) | 0.31 |                       |
| second half of the intervention | 0.8 (0.5–3.3) |         |                       |
| training effect |              |         |                       |
| single-handed task | 6.3 (5.8–8.5) | 0.008*** | 0.20†                 |
| dual-handed task | 10.3 (8.8–14.2) |         |                       |

Notes: Comparison of SHAP score Group A and Group B was conducted using the Mann-Whitney U test. Comparison of SHAP first half of the intervention and second half of the intervention was conducted using the Mann-Whitney U test. Comparison of SHAP single-handed task and dual-handed task was conducted using the Mann-Whitney U test and the effect size.

*\(p<.05. **p<.01. ***p<.001. \) †\( r \geq .01. \) ‡\( r \geq .03. \) §\( r \geq .05. \)

### Table 4: Comparison of SHAP before and after single-handed task and before and after dual-handed task

|               | Before     | After      | p-value | effect size (\( r \)) |
|---------------|------------|------------|---------|-----------------------|
|               | median (IQR) | median (IQR) |         |                       |
| single-handed task | 44 (40–45)  | 47 (45–48) | 0.045*  | 0.59†                 |
| dual-handed task | 42 (38–44)  | 53 (52–55) | 0.001*** | 0.78§                 |

Notes: Comparison of SHAP score before and after single-handed task and dual-handed task was conducted using Wilcoxon signed rank test and the effect size.

*\(p<.05. **p<.01. ***p<.001. \) †\( r \geq .01. \) ‡\( r \geq .03. \) §\( r \geq .05. \)
dual-handed task. There was no significant difference in the carryover effect between groups A (13.5 (7.0–28.0) points) and B (21.0 (8.0–26.0) points) (p = 0.421). There was no significant difference in the timing effect between the first (-1.8 (-4.3–0.4) points) and second halves (0.8 (0.5–3.3) points) of the intervention (p = 0.310). There was a significant difference in the training effect between the single-handed task (6.3 (5.8–8.5) points) and the dual-handed task (10.3 (8.8–14.2) points), but the effect size was small (p = 0.008, r = 0.20). The score change seen in the dual-handed task was larger than that observed in the single-handed task.

The comparison between the results obtained before and after the training showed a significant difference (Table 4). The result obtained before the single-handed task was 44 (40–45) points, and that obtained after the single-handed task was 47 (45–48) points, and the effect size was moderate (p = 0.045, r = 0.59).

There was a significant difference between the results obtained before the dual-handed task (42 (38–44) points) and those obtained after the dual-handed task (53 (52–55) points). The effect size was large (p <0.001, r = 0.78).

4. Discussion

This study adopted a crossover design due to the limited number of subjects, which was affected by the fact that it targeted unilateral transradial amputees and the conditions for the myoelectric hand training would have discouraged some potential subjects from taking part.

As for the results, the SHAP score increased during both the single-handed and dual-handed tasks. Furthermore, statistical analyses showed that 1) the changes seen after both the single-handed and dual-handed tasks were significant; 2) the effect of the single-handed task was moderate, and that of the dual-handed task was large; and 3) the dual-handed task had a greater effect on myoelectric hand operation than the single-handed task. Therefore, the implementation of single-handed task and dual-handed task training based on clinical experience is justified, but it is important to carefully consider the detail of such tasks.

Furthermore, when comparing the single-handed task and the dual-handed task, the carryover effect and time effect were not significant, while the training effect was significant. This indicates that the dual-handed task had a superior training effect compared with the single-handed task.

Hill reported that the aim of such dual-handed tasks is to acquire cooperative dual-handed movement between the myoelectric prosthesis and intact hand [10]. The dual-handed task required the opening and closing of the myoelectric hand to be controlled more precisely than the single-handed task and involved cooperation with the intact hand. The significantly higher score seen in the dual-handed task implies that the dual-handed task was effective at helping the subjects to acquire the ability to grasp objects accurately, adjust their grip properly, and grasp and release objects. Also, the purpose of such dual-handed tasks is to enhance the speed, accuracy, and hand-eye coordination of the myoelectric prosthesis hand [8, 9]. Hand-eye coordination, which is often referred to as visuomanual pursuit tracking, requires coordination between various areas of the central nervous system [17]. Visuomanual pursuit tracking involves controlling the movement of the upper limb by capturing positional information about the target object and the upper limb [18]. It was reported that the position of the target object is an important factor, which affects the distance and direction of the object, body, shoulder, and hand, and that gazing at the target affects the speed of movement during reaching movements [18]. Therefore, the dual-handed task increased the movement speed of the myoelectric hand when grasping the target object. In the future, we would like to examine the possibility that the dual-handed task may have affected the subjects’ ability to gaze at the target object and adjust the direction of the appropriate hand as compared with the single-handed task. In addition, the dual-handed task requires cooperation with the intact hand and accurate control of opening and closing movements of the myoelectric hand, appropriately timed directional movement coordination of the myoelectric hand toward the object, and grasping and releasing the target object accurately.

Presumably, the somatosensory senses of the residual limb improve accordingly. The dual-handed task may involve more effective loops for controlling the opening and closing of the myoelectric hand and the manipulation of the target object operation than the single-handed task.

Macrame was used for the dual-handed task in this study. It is necessary to consider whether the macrame task affected the results of the SHAP test; i.e., whether the macrame and SHAP tasks were similar. Macrame involves repeatedly performing an operation involving the gripping of string, but none of the tasks in the SHAP test involved string, and repeating a gripping operation is not a hindrance. Therefore, the similarities between the macrame and SHAP tasks were minimal, and any direct effect was considered to be weak.

The results of this study demonstrated that both the single-handed and dual-handed tasks are effective tools for learning how to control the opening/closing movements of a myoelectric hand and use a myoelectric
hand to perform daily activities. Compared with the single-handed task, the dual-handed task was more effective. In occupational therapy, we recommend implementing dual-handed tasks in the early stages of training. By performing dual-handed tasks more frequently than single-handed tasks, patients’ ability to operate myoelectric prosthetic hands can be expected to improve more quickly. This should also reduce the length of the training period.

5. Limitations and future work

The number of subjects in this study was 12, and the number of samples was small. Therefore, the results of this study cannot be used as definitive proof of the universal effects of myoelectric prosthesis training. The results should be investigated for their reliability in a larger pool of transradial amputees. Also, whether the amputation measurement is a dominant hand measurement can affect effectiveness and learning. Therefore, the study group need to control the dominant hand on the amputee. However, in the clinical setting, the number of upper limb amputees is small, and it is extremely difficult to obtain research cooperation from unilateral upper limb amputees who have no experience of myoelectric prosthesis training. Therefore, this study was conducted with the cooperation of 12 transradial amputees.

Regarding the study design, the two-day washout period was short. It would be desirable to employ a one-week washout period between the intervention periods. The two-day washout period was recommended by the institutional review board to reduce the stress place on the subjects.

In this study, the Ottobock MyoBock electric hand was the only myoelectric hand used. It is recommended that our results should be verified with other myoelectric hands, e.g., the Össur i-Limb quantum and Ottobock bebionic hand.

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7. Authors’ contributions

All of the authors contributed equally to the preparation of this manuscript.

8. Declaration of conflicting interests

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