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Original Article

Exercise loading for cardiopulmonary assessment and evaluation of endurance in amputee football players

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Abstract. [Purpose] It is difficult for amputees to perform conventional cardiopulmonary exercise testing. Values were determined for two-legged, one-legged, and two-armed exercise testing in healthy adult males (Study 1), for comparison with preliminary measurements of endurance in amputee football players (Study 2). [Participants and Methods] In Study 1, cardiopulmonary exercise testing was performed in healthy adult males. Correlations between oxygen uptake in two-legged and one-legged/two-armed exercise were calculated and a comparison was made between one-legged exercise and two-armed exercise for each measured value. In Study 2, cardiopulmonary exercise testing was performed on male amputee football players using a two-arm-driven ergometer. The measured values obtained for healthy adult males and amputee football players were compared. [Results] In Study 1, peak work rate and peak heart rate values of healthy participants were significantly higher in two-armed exercise than in one-legged exercise. The correlation between peak oxygen uptake values for two-legged and one-legged exercise was decreased. In Study 2, peak work rate of two-armed exercise was significantly higher in amputee football players than in healthy participants. [Conclusion] Study 1 suggested that musculoskeletal factors might have greater significance for one-legged exercise than for two-armed exercise. Study 2 suggested that para-sports, including amputee football, may contribute to physical strength and health maintenance in lower leg amputees.
Key words: Amputee football, Endurance, Cardiopulmonary exercise test

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INTRODUCTION

Para-sports are important not only for the purpose of health promotion and disease prevention, but also for the social participation of disabled people. Therefore, the necessity of sports activities for disabled people has been advocated. As a result, in recent years sports participation of disabled people has definitely progressed, and para-sports have developed from recreational to competitive, with events such as the Paralympic Games, which are equal to the Olympic Games.

Although there are various types of para-sports events, the popularity of amputee football has rapidly spread around the world and recognition of the sport is increasing. Endurance is required for amputee football because the athletes play using

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one leg and both arms supported by crutches. It is important to evaluate the endurance of amputee football players since it will have a significant impact on competition results.

One common method of evaluating endurance is the cardiopulmonary exercise test (CPX) using a treadmill or a bicycle ergometer; however, it is difficult for a person with a lower limb disability to perform this test in the same manner as healthy two-legged persons. As an alternative, endurance measurement based on one-legged or two-armed exercise can be performed[1)], with several reports examining the difference in measured values between two-legged exercise and two-armed exercise[2–5)] and between two-legged exercise and one-legged exercise[6)]. However, there are no reports examining the differences in measured values between two-legged, one-legged and two-armed exercise, and the mutual relationship between the values obtained in each exercise is not clear.

Because there are many kinds of wheelchair competitions and many competing populations, medical science studies such as endurance evaluation are performed actively; this also applies to strength training and guidance for parathletes[7–10)]. However, amputee football is a relatively new sport, and to the best of our knowledge, there are no reports evaluating the strength of amputee football players. Therefore, we conducted a preliminary study to evaluate the endurance of amputee football players. The first objective was to examine the difference in measured CPX values among two-legged, one-legged and two-armed exercise in healthy participants (Study 1), and the second objective was to preliminarily evaluate the endurance of amputee football players through CPX with two-armed exercise (Study 2).

PARTICIPANTS AND METHODS

The participants were 20 healthy adult males (average age ± standard deviation (SD), 28.3 ± 5.6 years old). CPX was performed for two-legged, one-legged, and two-armed exercise using a Strength Ergometer (Strength Ergo 8; Mitsubishi Electric Engineering Co., Ltd., Tokyo, Japan) (Fig. 1). In one-legged exercise, the participants used the leg on the dominant hand side. For CPX, a multistage, Ramp-wise upgrading continuous load was used (two-legged: Ramp 25 W/min; one-legged: Ramp 15 W/min; two-armed: Ramp 15 W/min) and the expired gas was measured breath-by-breath using a cardiorespiratory exercise monitoring system (AE-310s; Minato Medical Science Co., Tokyo, Japan). As outcome measures, the anaerobic threshold value of oxygen uptake/Weight (VO_2/W-AT) and the peak value of oxygen uptake/Weight (VO_2/W-peak), heart rate (HR), ventilation amount (VE), and work rate (WR) were obtained, and after exercise, the Modified Borg Scale was recorded to obtain the peripheral rate of perceived exertion (p-RPE) and central rate of perceived exertion (c-RPE). The correlation between VO_2 during two-legged exercise and one-legged/two-armed exercise were calculated using Pearson's correlation test and the values of $p<0.05$ were considered statistically significant. In addition, each measured value was compared between one-legged exercise and two-legged exercise using a paired t-test, and $p<0.05$ was regarded as significant.

The participants were eight male amputee football players (average age ± SD, 36.4 ± 5.7 years old) (Table 1) and CPX for two-armed exercise was performed. As outcome measures, the peak value of VO_2/W, HR, VE and WR were obtained. The values obtained for healthy adult males and amputee football players during two-armed exercise were compared using an unpaired t-test, and $p<0.05$ was regarded as significant.

This research was reviewed and approved (Epd-1055) by Ethical Committee for Epidemiology of Hiroshima University. Sufficient explanations of the purpose of the research were given to all participants and written informed consent was obtained from all participants.

RESULTS

The measured values for each exercise in healthy participants are shown in Table 2. The HR-peak value was about 90% of the maximum HR (220 − age) in the two-legged exercise, about 80% in the two-armed exercise, and about 70% in the one-legged exercise. WR-peak and HR-peak of the healthy participants showed significantly higher values in two-armed exercise than in one-legged exercise. There was no significant difference in any AT values, VO_2/W-peak value or VE-peak value between one-legged exercise and two-armed exercise. VO_2/W-AT value was about 55% of the peak value for two-legged and two-armed exercise and about 60% of the peak value for one-legged exercise. In addition, for both one-legged and two-armed exercise, VO_2/W-peak value was about 70% of the value for two-legged exercise. VO_2/W-AT value for two-legged exercise and VO_2/W-AT values for one-legged/two-armed exercise showed moderate correlation. In the correlation between VO_2/W-peak value for two-legged exercise and VO_2/W-peak values for one-legged/two-armed exercise, each of the r values was low compared with the value at AT, and a moderate correlation was observed between two-legged exercise and two-armed exercise; however, there was a low correlation between two-legged exercise and one-legged exercise (Figs. 2, 3). In all exercises, c-RPE was lower than p-RPE, but when looking at the difference between p-RPE and c-RPE by type of exercise, the differences for two-legged and two-armed exercise were 2.0 ± 1.0 and 2.3 ± 1.0, whereas the difference for one-legged exercise was 3.7 ± 1.2 [mean ± SD], respectively.

For two-armed exercise in amputee football players, WR-peak was 122.6 ± 18.5 W, HR-peak was 161.6 ± 10.8 bmp, VO_2/W-peak was 30.3 ± 6.2 $ml.kg^{-1}.min^{-1}$ and VE-peak was 80.8 ± 16.1 $l.min^{-1}$ (mean ± SD), respectively. WR-peak of amputee football players was significantly higher than that of healthy participants. There were no significant differences between healthy adult males and amputee football players in HR-peak, VO_2/W-peak, or VE-peak values for two-armed exercise.

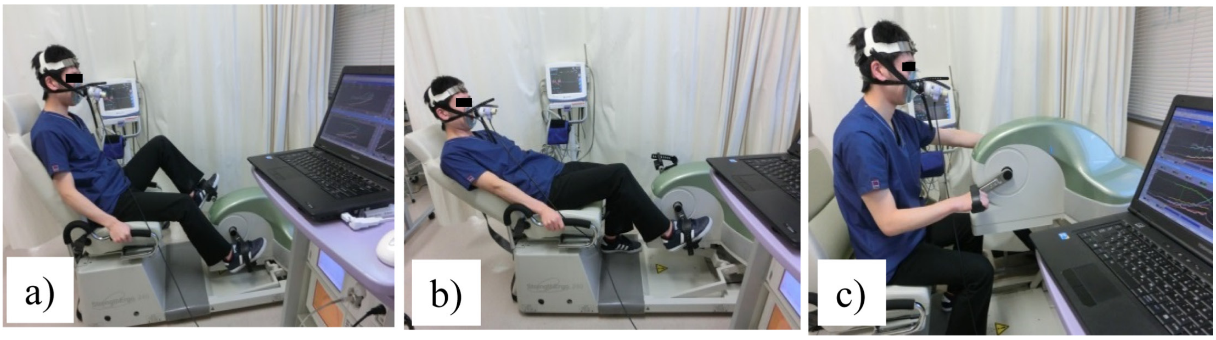

Fig. 1. Cardiopulmonary exercise test for a) two-legged-, b) one-legged- and c) two-armed-driven ergometer. (Published with the participant's permission).

Table 1. Characteristics of the amputee football players

Age (years)	Height (cm)	Weight (kg)	Cause	Site	Years after amputation	Years playing football
37	177.2	68	Other	AKA	4	2
35	176	50	Trauma	AKA	12	2
28	164	60	Trauma	AKA	5	1.5
49	167	63	Trauma	AKA	28	5
34	174	49	Trauma	HD	11	3
35	175	70	Buerger's disease	BKA	0.6	0.4
33	167	83	Trauma	KD	3	1.6
40	177	83	Trauma	BKA	15	1

HD: hip disarticulation; AKA: above-knee amputation; KD: knee disarticulation; BKA: below-knee amputation.

Table 2. Summary of physiological data of the healthy male participants (n=20) and amputee football players (n=8)

	Healthy male participants (n=20)			Amputee football players (n=8)
	Two-legged exercise (SD)	One-legged exercise (SD)	Two-armed exercise (SD)	Two-armed exercise (SD)
WR-AT (watt)	128.4 (21.9)	57.8 (15.3)	61.8 (13.8)	
WR-peak (watt)	238.4 (37.0)	91.6 (14.0)	106.8 (16.2)*	122.6 (18.5)†
HR-AT (bpm)	132.2 (14.9)	114.2 (11.7)	120.6 (16.2)	
HR-peak (bpm)	176.9 (9.7)	146.9 (14.5)	158.6 (11.0)*	161.6 (10.8)
VO_2/W-AT (ml.kg^{-1}.min^{-1})	20.6 (2.5)	16.8 (2.2)	14.6 (1.8)	
VO_2/W-peak (ml.kg^{-1}.min^{-1})	36.4 (3.7)	27.2 (4.0)	26.1 (2.9)	30.3 (6.2)
VE-AT (l.min^{-1})	36.3 (8.0)	32.8 (5.8)	32.0 (6.4)	
VE-peak (l.min^{-1})	102.9 (20.2)	70.0 (12.8)	74.7 (14.3)	80.8 (16.1)
p-RPE	8.5 (0.9)	8.6 (0.7)	8.0 (0.7)	
c-RPE	6.5 (1.3)	4.9 (0.9)	5.5 (1.3)	

WR: work rate; AT: anaerobic threshold; HR: heart rate; VO_2/W: oxygen uptake/weight; VE: ventilation amount; p-RPE: peripheral rate of perceived exertion; c-RPE: central rate of perceived exertion.
*$p<0.05$ one-legged vs. two-armed exercise, †$p<0.05$ Healthy male participants vs. Amputee football players.

DISCUSSION

In exercise physiology, endurance is considered the comprehensive power of each element constituting physical strength, and it is representative of physical fitness. In recent years, the necessity of evaluating the physical fitness of disabled people has increased, and increasing endurance is particularly important to improve the health and competitiveness of disabled

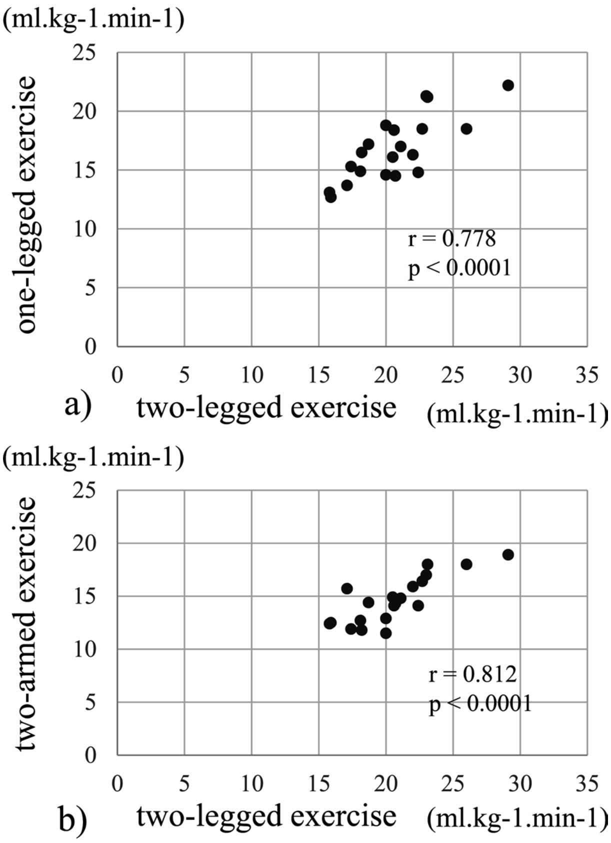

Fig. 2. Correlation of VO_2/W-AT (ml.kg^{-1}.min^{-1}) values between a) two-legged and one-legged exercise, and b) two-legged and two-armed exercise. The correlation between VO_2/W-AT during two-legged exercise and one-legged/two-armed exercise were calculated using Pearson's correlation test. Values of $p<0.05$ were considered statistically significant.

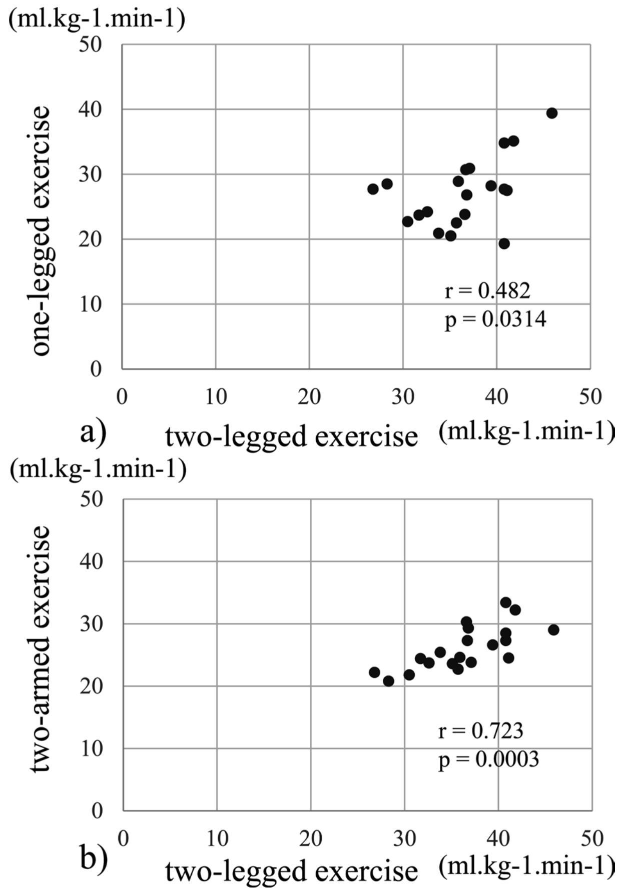

Fig. 3. Correlation of VO_2/W-peak (ml.kg^{-1}.min^{-1}) values between a) two-legged and one-legged exercise, and b) two-legged and two-armed exercise. The correlation between VO_2/W-peak during two-legged exercise and one-legged/two-armed exercise were calculated using Pearson's correlation test. Values of $p<0.05$ were considered statistically significant.

people. CPX using both legs on an ergometer is generally performed to measure endurance; however, it is difficult for a person with a lower limb disability to perform two-legged exercise, so endurance is instead measured for one-legged exercise or two-armed exercise[1]. This method is used to measure the endurance of amputee football players, but considering the differences in measured values due to the difference in exercise loading method is also important in understanding the endurance of lower limb amputees.

Recently, Orr et al.[3] showed the correlation of CPX results between two-legged exercise and two-armed exercise in healthy adult women. This report showed that VO_2/W-AT values were about 50% of the VO_2/W-peak value in two-legged and two-armed exercise, and that both the VO_2/W-AT and VO_2/W values of two-armed exercise were about 65% of the value of two-legged exercise. Martin and Weisman[4], Myers et al.[5] and Phillips et al.[7] presented similar results to Orr et al[3]. Although we focused on healthy adult males in Study 1, the VO_2/W-AT values were about 55% of the peak value for two-legged and two-armed exercise and VO_2/W-AT/ VO_2/W-peak values of two-armed exercise were about 70% of two-legged exercise. In this study, all measured values for two-legged exercise were the maximum, and the correlation between VO_2/W-AT values and VO_2/W-peak values in the two-legged and two-armed exercises were consistent with the previous reports.

The correlation of the VO_2/W-AT values between two-legged exercise and two-legged/one-legged exercise, and that of the VO_2/W-peak value between two-legged exercise and two-armed exercise showed a moderate correlation. However, the correlation of VO_2/W-peak value between two-legged exercise and one-legged exercise declined. Since a large difference between p-RPE and c-RPE was observed in one-legged exercise, musculoskeletal factors might be a larger restriction than cardiopulmonary factors, especially in one-legged exercise.

In AT values, there was no significant difference between two-armed exercise and one-legged exercise. However, WR-peak and HR-peak were significantly higher in the two-armed exercise than in the one-legged exercise. Since the muscle mass used in two-armed exercise was lower than that of the one-legged exercise, a stronger exercise intensity might be required to show equivalent VO_2. On the contrary, in the one-legged exercise with greater muscle mass, VO_2/W-peak was equivalent to that of the two-armed exercise. This also means that sufficient exercise intensity could not be acquired and that musculoskeletal factors might be a limiting factor in one-legged exercises.

Ogita et al.[6] examined the differential VO_2 response between one-legged and two-legged exercise and showed that VO_2/W-peak value for two-legged exercise was significantly higher than that for one-legged exercise and that VO_2/W-peak is limited peripherally in one-legged exercise. However, their study was not conducted on amputee athletes and did not compare legged and armed exercise. Chin et al.[11] conducted CPX using one-legged-driven-ergometer with lower limb amputees, showing the usefulness of evaluating AT. However, their examination was limited to one-legged exercise and did not evaluate other types of exercise. In addition, their study did not investigate the peak value needed for amputee athletes.

Regarding the selection of exercise loading method, it is important to select the type of exercise that minimizes the influence of motor impairment as much as possible. In the case of lower leg amputees, two-armed exercise or one-legged exercise are performed; however, participating muscles that work effectively in exercise are decreased, so the limitations of the CPX are shifted from cardiopulmonary factors to musculoskeletal factors. The results of this study suggest that musculoskeletal factors might be a greater limiting factor in one-legged exercise compared to two-armed exercise and CPX for two-armed exercise might be preferable for measuring the endurance of amputee athletes. However, since the exercise intensities were lower for both one-legged exercise and two-armed exercise than for two-legged exercise, it is necessary to always keep in mind that endurance evaluation of disabled people will be obtained under various constraints due to disability.

In this study, the endurance of amputee football players was preliminarily measured based on the results of Study 1. Since the purpose of this study was to evaluate the endurance of disabled athletes in the future, only peak values were measured. When comparing amputee football players and healthy men, WR-peak of amputee football players in two-armed exercise was significantly higher than that of healthy participants. VO_2/W-peak, HR-peak and VE-peak values of amputee football players in two-armed exercise were not significantly higher than those of healthy participants. However, these values were slightly higher than those of healthy participants and the endurance of amputee football players was not inferior to that of healthy adult men. Although prosthetic gait requires higher energy than normal gait[12–14], it is reported that endurance decreases due to motor impairment in lower leg amputees[15]. From the results of the present study, para-sports such as amputee football might contribute to physical strength and health maintenance in lower leg amputees.

This study had some limitations. First, in Study 1, only healthy men were treated as participants. However, Orr et al.[3] conducted a study only on healthy women, and the results of their study and the present study were similar. Therefore, the influence of gender on the correlation between two-legged exercise and two-armed exercise may not be significant. Second, in the measurements for one-legged exercise, differences between the left and right legs were not considered. In this study, exercises were performed only on the dominant hand side; however, lower values might be obtained on the non-dominant hand side and further examination of CPX for one-legged exercise is required. Third, in Study 2, the number of participants was small. This was a preliminary study and it is impossible to determine the endurance of lower leg amputees based on this study alone. In the case of athletes, it is reported that higher measured values can be obtained when they are performing the same types of exercises as their ordinary training[16]. This indicates that a person's exercise ability is easily demonstrated when they perform exercises in which they have high skill. Therefore, when measuring the endurance of a person with disabilities, it may be necessary to choose the exercise loading method based on their exercise habits and sports characteristics. To evaluate and discuss the endurance of amputee football players, we need further examination and it is necessary to increase the number of athletes studied in the future.

In conclusion, from the results of Study 1, endurance measurements for disabled people are obtained under various constraints due to disability, and in one-legged exercise, musculoskeletal factors might be a greater limiting factor than in two-armed exercise. Therefore, CPX for two-armed exercise might be preferable for measuring the endurance of amputee football players.

Although the present study was a preliminary examination in Study 2, we found the endurance of amputee football players was not inferior to that of healthy adult men. Para-sports such as amputee football may contribute to physical strength and health maintenance in lower leg amputees; however, further examinations are necessary to determine the endurance of amputee athletes.

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Conflict of interest

There are no conflicts of interest.

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