



Original Article

Physique, range of motion, and gross muscle strength in hemiplegic para swimmers: a cross-sectional case series

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Abstract. [Purpose] The physical functions related to swimming should be evaluated to enhance competitive performance and prevent sports injuries. This study aimed to determine the physique, range of motion, and gross muscle strength of the limbs among hemiplegic para swimmers. [Participants and Methods] Three male para swimmers with hemiplegia and five male para swimmers with impaired vision were included in the study. The limb circumference, range of motion, quadriceps flexibility, and gross muscle strength were evaluated. The hemiplegic swimmers and swimmers with impaired vision were compared using an unpaired t-test. [Results] The maximum values of the upper and forearm circumferences; the range of motion for shoulder flexion, external rotation, ankle dorsiflexion on the paretic side; and the single-leg sit-to-stand test of the dominant limb were significantly lower in hemiplegic swimmers than in swimmers with impaired vision. [Conclusion] Hemiplegic swimmers had decreased upper limb circumferences on the paretic limb; the range of motion for shoulder flexion, external rotation, and ankle dorsiflexion on the paretic limb; and muscle strength on the dominant lower limb.

Key words: Swimming, Hemiplegia, Physical performances

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INTRODUCTION

Para swimming is an international sport practiced in nearly 100 countries, one of the inaugural sporting events of the Paralympic Games¹⁾, including swimmers with physical, visual, and intellectual impairments. Para swimmers with hemiplegia due to congenital or acquired brain injury commonly compete within classes of S5 to S9 depending on their level of physical impairment classified following the World Para Swimming Classification Rules and Regulations²⁾. Para swimmers have injury to the pyramidal or extrapyramidal tracts of the brain that causes altered efferent output and influences neuromuscular function³⁾. The clinical features presented by swimmers with brain injury include decreased central motor output, hypertonia, incoordination, and decreased coactivation of agonist and antagonist muscle groups. The distribution and severity of these features varies considerably depending on the etiology of brain injury³⁾. From an observational point of view, these swimmers show several characteristics in swimming strategies depending on their body function. S5 swimmers have hypotonic muscle tone on the paretic side and difficulty adjusting the catching position of the nonparetic arm. S6 swimmers have severe-to-moderate hypertonia and do not utilize the paretic arm when adjusting the catching position of the nonparetic arm.

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S7 swimmers swim with one arm or both arms using rotation of the body trunk; left-right asymmetry can be observed. S8 swimmers swim with both arms; left-right asymmetry can be observed in the entry position. S9 swimmers swim with both arms, with left-right asymmetry in the catching motion but no asymmetry in the entry position.

To improve competitive performance, swimmers need to maximize propulsive force and reduce hydrodynamic drag. In front-crawl swimming, approximately 90% of propulsive force is produced by the upper limbs⁴⁾. It has been reported that a major determining factor in front-crawl performance in unilateral arm amputee swimmers is high stroke frequency⁵⁾. Therefore, the nonparetic limb may be more exposed to overload stress than in swimmers without disabilities. It has been reported that fatigue due to swimming training can restrict range of movement (ROM) of the shoulder⁶⁾. Restricted shoulder ROM, including scapular dyskinesis, in swimmers causes shoulder pain and associated dysfunctions, such as subacromial impingement, labral damage, os acromiale, and suprascapular nerve entrapment^{7, 8)}.

The streamlined body position, which is a basic position for competitive swimming starts and turns, is considered to be important for reducing hydrodynamic drag^{9, 10)}. An effective streamlined body position⁹⁾ requires that arms are completely flexed at the shoulders and extended at the elbows and wrists, upper arms are in contact with the sides of the head, one hand is on top of the other, the head is positioned so that the swimmer is looking down, the feet are together, and the ankles are plantar flexed. For competitive swimmers, this requires good ROM of related joints.

Understanding the characteristics of functional performance in swimmers with hemiplegia may be useful as fundamental knowledge for their physical conditioning and dry-land training. However, few studies have investigated the physical characteristics of hemiplegic swimmers. The purpose of the present study is to clarify the characteristics of physique, ROM of the limbs, and gross muscle strength of the limbs in para swimmers with hemiplegia compared with those without motor impairments. We hypothesized that hemiplegic swimmers have decreased muscle strength and restricted ROM of paretic limbs. Restricted ROM of nonparetic limbs, due to increased load in swimming training, was also hypothesized.

PARTICIPANTS AND METHODS

Three Japanese male para swimmers with hemiplegia (two right, and one left hemiplegia) caused by cerebral infarction (height 174.6 ± 5.2 cm, body mass 68.0 ± 12.5 kg, aged 26.7 ± 6.7 years) and five male para swimmers with vision impairment (two blind, and three amblyopia) caused by congenital retinal detachment, retinitis pigmentosa or macular degeneration (174.0 ± 4.4 cm, 73.9 ± 12.4 kg, 22.2 ± 4.0 years) participated in this study. All swimmers were certified as elite or youth athlete by Japanese para swimming federation, competing national and international level. All hemiplegic swimmers competed in the sports class of S7/SB7/SM7. Two blind swimmers competed in the sports class of S11/SB11/SM11, and three swimmers with amblyopia competed in S13/SB13/SM13. Para swimming classification is an evidence-based classification system designed to allow for fair competition as following²⁾; The classes are prefixed with “S” for freestyle, butterfly and backstroke events, “SB” for breaststroke and “SM” for individual medley events. Swimmers with physical impairment are divided into ten classes based on their degree of functional disability. Those with visual impairments are placed in three additional classes: S11, S12 and S13.

Maximum circumference of the upper arm, forearm, and calf were measured using a tape measure in a supine position. In addition, thigh circumference was measured at 5 cm, 10 cm, and 15 cm above the base of the patella. Shoulder ROM for flexion, extension, external rotation, and internal rotation at 90° shoulder abduction were measured with a goniometer. Ankle ROM was evaluated using a goniometer to measure dorsiflexion. Heel–buttock distance (HBD) was measured to evaluate lower extremity flexibility¹¹⁾, reflecting quadriceps femoris and iliopsoas flexibility. HBD is the distance between the heel and buttocks, and was measured using a tape measure with the subject in a prone position with their knee bent passively.

Gross muscle strength of the upper limb was evaluated by grip strength, measured using a grip dynamometer (T.K.K.5401, Takei Scientific Instruments, Tokyo, Japan) in the relaxed standing position. The single leg sit to stand test (SLSTST) was used to evaluate the gross muscle strength of the lower limb. SLSTST is used to estimate weight bearing index (WBI), which can be calculated as quadriceps strength (kg) related to body mass (kg). WBI can be utilized quickly and easily in sports settings at low cost; the relationship between SLSTST and WBI has been reported by Muranaga et al¹²⁾. WBI was estimated in this study as follows: if the participant could perform the SLSTST from 40 cm, estimated WBI was 60%; for SLSTST from 30 cm, estimated WBI was 70%; for SLSTST from 20 cm, estimated WBI was 90%; and for SLSTST from 10 cm, estimated WBI was 100%. The SLSTST procedure was as follows: the participant sits in a 40-cm-high chair with his or her knee bent at 70°; the participant takes one foot off the floor and stands on the other leg. If the participant successfully performs the test, further tests are performed with chair heights of 30 cm, 20 cm, and 10 cm.

The streamlined body position was evaluated from digital photographs of a standing position in the sagittal planes. All measurements were implemented by two physiotherapists who each had more than 14 years of clinical experience.

For the data analysis, we compared each valuable between two groups (hemiplegic swimmers vs. swimmers with vision impairment). Initially, a Shapiro-Wilk normality test was used to assess data normality. The difference between hemiplegic swimmers and blind swimmers in each valuable and its side-to-side difference were compared using an unpaired t-test. All comparisons were performed using IBM SPSS statistics version 24 (IBM Corp., Armonk, NY, USA), with the statistical difference defined as a p-value <0.05. The streamlined body position of each swimmer taken by a digital camera was qualitatively analyzed referring to the ideal streamlined body position defined in the previous literature⁹⁾.

All study procedures were approved by the International University of Health and Welfare institutional review board (approval number: 14-10-161). All swimmers provided informed consent after having been explained the purpose of the study and procedures.

RESULTS

Comparison of physical characteristics including limb circumferences, ROM, quadriceps flexibility, and gross muscle strengths between hemiplegic swimmers and swimmers with vision impairment are shown in Table 1.

Maximum upper arm and forearm circumferences on the paretic limb of hemiplegic swimmers were 34.1 ± 4.5 cm/ 28.3 ± 1.2 cm (average \pm SD, dominant/paretic) and 26.5 ± 1.5 cm/ 23.5 ± 1.0 cm which was significantly smaller than that on

Table 1. Comparison of physical characteristics between the hemiplegic swimmers and swimmers with vision impairment

		Hemiplegia n=3	Vision impairment n=5
Maximum upper arm circumference (cm)	Dominant	34.1 \pm 4.5	32.7 \pm 1.3
	Non-dominant/Paretic	28.3 \pm 1.2	32.8 \pm 1.5*
Maximum forearm circumference (cm)	Dominant	26.5 \pm 1.5	26.5 \pm 1.4
	Non-dominant/Paretic	23.5 \pm 1.0	26.2 \pm 1.2*
Thigh circumferences (cm)			
5 cm above the base of the patella	Dominant	42.2 \pm 3.6	41.1 \pm 1.9
	Non-dominant/Paretic	39.0 \pm 4.4	41.2 \pm 3.1
10 cm above the base of the patella	Dominant	47.4 \pm 3.7	46.4 \pm 3.1
	Non-dominant/Paretic	43.7 \pm 4.4	47.3 \pm 3.9
15 cm above the base of the patella	Dominant	51.9 \pm 3.3	50.8 \pm 3.5
	Non-dominant/Paretic	48.5 \pm 3.7	51.4 \pm 4.2
Maximum calf circumference (cm)	Dominant	37.4 \pm 2.3	36.3 \pm 2.1
	Non-dominant/Paretic	33.3 \pm 3.1	36.5 \pm 2.3
Shoulder range of motion (degrees)			
Flexion	Dominant	189.7 \pm 14.6	185.2 \pm 13.9
	Non-dominant/Paretic	165.0 \pm 6.1	182.2 \pm 11.3*
Extension	Dominant	74.0 \pm 19.1	70.2 \pm 10.5
	Non-dominant/Paretic	46.7 \pm 35.0	69.2 \pm 13.6
External rotation	Dominant	102.0 \pm 2.6	101.6 \pm 15.7
	Non-dominant/Paretic	45.7 \pm 7.4	102.8 \pm 13.7*
Internal rotation	Dominant	54.0 \pm 22.9	47.2 \pm 6.8
	Non-dominant/Paretic	34.3 \pm 15.4	47.2 \pm 4.3
Elbow range of motion (degrees)			
Flexion	Dominant	150.7 \pm 4.0	152.0 \pm 4.2
	Non-dominant/Paretic	151 \pm 3.6	152.8 \pm 3.9
Extension	Dominant	3.7 \pm 1.5	7.0 \pm 5.2
	Non-dominant/Paretic	-24.3 \pm 20.6	7.8 \pm 7.7
Ankle dorsi flexion (degrees)	Dominant	38.0 \pm 11.1	51.8 \pm 6.6
	Non-dominant/Paretic	8.0 \pm 15.9	52.2 \pm 8.6*
Heel-buttock distance (cm)	Dominant	18.6 \pm 3.8	16.3 \pm 7.5
	Non-dominant/Paretic	20.3 \pm 1.6	16.9 \pm 6.1
Gross muscle strength			
Grip strength (kg)	Dominant	41.4 \pm 6.2	41.4 \pm 7.2
	Non-dominant/Paretic	n/a	40.8 \pm 4.3
Sit to Stand Test (cm)	Dominant	30.0 \pm 5.8	10.0 \pm 0.0*
	Non-dominant/Paretic	n/a	16.0 \pm 8.9

Mean \pm SD.

n/a: Not applicable due to inadequate muscle strength caused by hemiplegia.

Statistical analysis was not able to be performed for grip strength and SLTST on paretic limb/non-dominant limb due to inability to complete the testing procedure in some hemiplegic swimmers.

the non-dominant limb of swimmers with vision impairment of 32.7 ± 1.3 cm/ 32.8 ± 1.5 cm (average \pm SD, dominant/non-dominant) and 26.5 ± 1.4 cm/ 26.2 ± 1.2 cm ($p=0.004$ for upper arm and $p=0.018$ for forearm). There was no difference in circumferences of three positions on the thigh and the calf on both dominant and parietic/non-dominant limb.

Hemiplegic swimmers had significantly smaller ROM for shoulder flexion (hemiplegic swimmers $165.0 \pm 6.1^\circ$, swimmers with vision impairment $182.2 \pm 11.3^\circ$, $p=0.031$) and external rotation ($45.7 \pm 7.4^\circ$, $102.8 \pm 13.7^\circ$, $p=0.0003$) on parietic limb than that of swimmers with vision impairment on non-dominant limb. There was no difference in ROM of the shoulder and elbow on dominant limb between groups. ROM for ankle dorsi flexion on parietic side of hemiplegic swimmers was $8.0 \pm 15.9^\circ$ which was significantly smaller than that on non-dominant limb of swimmers with vision impairment of $52.2 \pm 8.6^\circ$ ($p=0.026$). There was no difference in values of HBD between groups.

The average values of the SLSTST on dominant limb were significantly smaller in hemiplegic swimmers than that of swimmers with vision impairment (hemiplegic swimmers, 30 ± 5.8 cm; swimmers with vision impairment, 10 ± 0.0 cm, $p=0.038$). The result also showed obvious difference between parietic limb of hemiplegic swimmers and non-dominant limb of the SLSTST, while hemiplegic swimmers were not able to perform the test due to inadequate muscle strength.

The relaxed standing and streamlined body positions of the swimmers in the standing position in the sagittal plane are shown in Fig. 1. A qualitative analysis of the streamlined position showed excessive lumbar lordosis in hemiplegic swimmers compared with their relaxed standing position while swimmers with visual impairment showed little postural difference between relaxed standing position and streamlined body position. Inadequate shoulder flexion was observed in all hemiplegic swimmers referring to an ideal streamlined body position showed in the previous literature⁹.

DISCUSSION

To our knowledge, this is the first study of the characteristics of physical performances in elite para swimmers with hemiplegia.

Maximum upper and forearm circumference of the parietic limb was significantly smaller in hemiplegic swimmers compared with non-dominant limb of swimmers with visual impairment. In addition, gross muscle strength on the parietic upper and lower extremities was obviously less than the dominant limbs while a statistical analysis was not able to perform. Stroke causes hemiplegia and subsequent muscle weakness contralateral to the brain lesion¹³, which affects functional performance, such as gait, in chronic stroke survivors¹⁴. From a morphological point of view, previous studies have shown that muscle

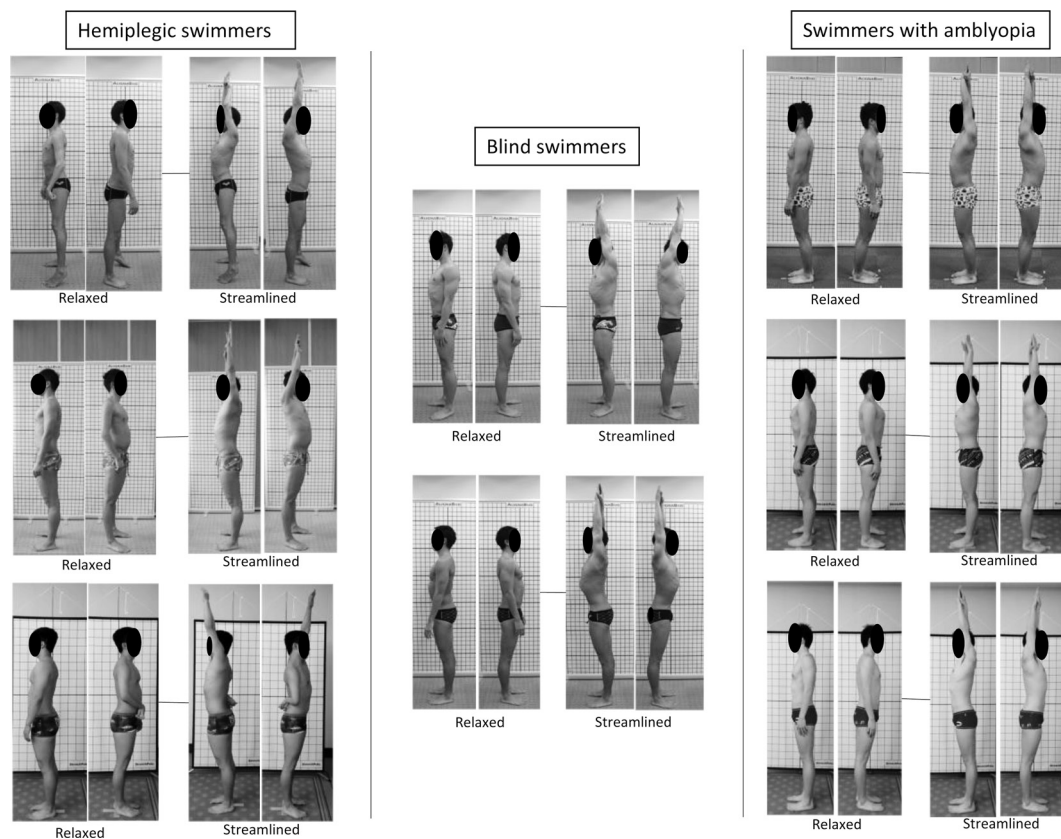


Fig. 1. Relaxed standing and streamlined body position of hemiplegic swimmers and swimmers with vision impairment.

size on the paretic limb of chronic stroke survivors was smaller in both upper¹⁵⁾ and lower extremities¹⁶⁾. In the present study, decreased muscle strength in lower extremities was observed in hemiplegic swimmers not only on the paretic limb but also on the dominant limb. The average values of the SLSTST on dominant limb were significant smaller in hemiplegic swimmers than that of blind swimmers. As previously explained, WBI can be estimated from the result of SLSTST¹²⁾. Estimated WBI which is calculated from the average value of SLSTST on the dominant limb was approximately 70%. This implies that quadriceps strength in hemiplegic swimmers was not great enough to stabilize their body weight using the dominant lower limb. It has been reported that chronic stroke survivors who are unable to walk independently have less muscle mass and excessive intramuscular adipose and fibrous tissue on both paretic and nonparetic sides¹⁴⁾. The hemiplegic swimmers of the present study were highly-trained swimmers, but their physical training and activity may not have been enough to overcome weakness due to decreased muscle strength caused by a stroke. In competitive swimming, starts and turns require high levels of power output from lower extremity musculature¹⁷⁾. To improve starts and turns performances, strength and conditioning program such as plyometric training¹⁸⁾ can be applied.

ROM is another value that can characterize the hemiplegic swimmers in this study. ROM for ankle dorsiflexion on the paretic side of hemiplegic swimmers was significantly smaller than that of swimmers with vision impairment. This may have been caused by prolonged spasticity of the ankle plantar flexors and decreased muscle strength of the ankle dorsiflexors since the onset of stroke. Ankle ROM restriction may affect postural stability on the starting block. The use of an ankle foot orthosis in daily life may be recommended. ROM for shoulder flexion and external rotation on paretic limb were significantly smaller than that of swimmers with vision impairment. Since the hemiplegic swimmers in this study did not use the paretic upper limbs when swimming, it was thought that decreased use of paretic upper limb in their daily training was affected to this result. We hypothesized the dominant upper limb was overloaded. But there was no difference in ROM on the dominant limb between groups. It has been reported that the latissimus dorsi muscle primarily induces extension, adduction, and internal rotation of the upper extremity, contributing to forward propulsive force during front-crawl swimming¹⁹⁾. Repetitive swim training likely results in muscle hypertrophy and may also lead to increased muscular stiffness and resistance to elongation, causing restricted ROM in shoulder flexion²⁰⁾. If hemiplegic swimmers do not use the paretic arm, they have to produce propulsive force using only the nonparetic arm. This may lead to restricted ROM in shoulder flexion, causing excessive lumbar lordosis in the streamlined body position due to compensatory movement. Because the latissimus dorsi muscle attaches to the iliac crest as its origin, its contraction tilts the pelvis tilts anteriorly. It has been reported that the latissimus dorsi muscle primarily induces extension, adduction, and internal rotation of the upper extremity, contributing to forward propulsive force during front-crawl swimming¹⁹⁾. Repetitive swim training likely results in muscle hypertrophy and may also lead to increased muscular stiffness and resistance to elongation, causing restricted ROM in shoulder flexion²⁰⁾. If hemiplegic swimmers do not use the paretic arm, they have to produce propulsive force using only the nonparetic arm. This may lead to restricted ROM in shoulder flexion, causing excessive lumbar lordosis in the streamlined body position due to compensatory movement. Because the latissimus dorsi muscle attaches to the iliac crest as its origin, its contraction tilts the pelvis tilts anteriorly. However, as a result, our hypothesis was not proved. The reason for this may be that the hemiplegic swimmer's healthy upper limb function adapted to the load of daily training. It is also possible that they frequently carried out self-care for their dominant shoulder on a daily basis. However, this study did not investigate the detailed evaluation of upper limb function including muscle strength, the amount of daily practice, and the frequency of self-care. These research design problems should be resolved in the future.

Lastly, the streamlined body position can characterize the hemiplegic swimmers. [Figure 1](#) shows the relaxed standing position and the streamlined body position of the swimmers in the sagittal plane. Excessive lumbar lordosis and inadequate shoulder flexion were observed in all hemiplegic swimmers, making their streamlined body positions corrugated compared with their relaxed standing positions. This may have arisen from several factors. One of them may be tightness of the quadriceps femoris muscles, which was evaluated using HBD. Results showed that there is no difference in quadriceps tightness between groups. However, the mean values of HBD of hemiplegic swimmers are 18.6 ± 3.8 cm on dominant limb, and 20.3 ± 1.6 cm on paretic limb which is greater than able-bodied Olympians of 12.0 ± 4.0 cm, and 12.3 ± 2.8 cm reported in the previous study²¹⁾. The rectus femoris muscle, which runs from the anterior inferior iliac spine to the tibial tuberosity, tilts the pelvis anteriorly because it is a two-joint muscle, crossing both the hip and the knee joint; it has a direct influence on the position of the lumbar spine²²⁾. It has been reported that swimmers with low back pain have greater lumbar extension when dolphin-kicking, and less hip extension ROM than those without low back pain²³⁾. Therefore, quadriceps tightness and anterior hip flexors should be addressed in order to prevent low back pain and improve swimming performance. Function of the deep trunk muscles, such as transversus abdominis, external and internal obliques is also important. The previous study reported that under water gliding performance is affected by cranial movement of abdominal organs which was caused by unconscious abdominal drawing maneuver in the streamlined body position²⁴⁾. We didn't evaluate the function of deep trunk muscles however, in the future, further study is needed to clarify the relationship between the streamlined body position and the body function of hemiplegic swimmers.

This study has several limitations. First, it may be difficult to describe the general characteristics of hemiplegic competitive swimmers with only three hemiplegic swimmers in this study. The number of participants is not sufficient for statistical analysis. However, the number of competitive swimmers with hemiplegia is quite small so that accumulation of case control study is needed to make more scientific evidence. Second, the study design is cross sectional. The ROM can be altered with

fatigue⁶⁾ so that the ROM and flexibility can vary depending on the volume of swim training and the time of measurement. Third, swimmers with vision impairment were involved in this study as control swimmers to compare the differences of physical characteristics with hemiplegic swimmers. They did not have any physical impairment however; physical characteristics may differ from those with able-bodied swimmers. In the future, prospective study should be implemented to identify risk factors associated to sports injury for swimmers with disabilities not only hemiplegia but also paraplegia, congenital limb deficiency, amputation and so on.

Conflict of interests

None declared.

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