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Effect of aqua exercise on recovery of lower limb muscles after downhill running

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Abstract

The aim of the present study was to examine how the recovery of physiological functioning of the leg muscles after high-intensity eccentric exercise such as downhill running could be promoted by aqua exercise for a period until the damaged muscle had recovered almost completely. Ten male long-distance runners were divided equally into an aqua exercise group and a control group. From the first day (Day 0) to the fourth day (Day 3), the participants completed a questionnaire on muscle soreness, and serum creatine kinase activity, muscle power, flexibility, whole-body reaction time and muscle stiffness were measured. After measurements on Day 0, the participants performed downhill running (three 5 min runs with a 5 min rest interval at -10%, $335.7 \pm 6.1\,\mathrm{m \cdot min^{-1}}$). The aqua exercise group performed walking, jogging and jumping in water on three successive days following the downhill running on Day 0 for 30 min each day. Muscle power was reduced on Day 1 in the control group ($P < 0.05$). Muscle soreness in the calf on Day 3 was greater in the control group than that in the aqua exercise group ($P < 0.05$). In the aqua exercise group, muscle stiffness in the calf was less than that in the control group over 4 days (time main effect: $P < 0.05$; group × time interaction: $P < 0.05$). We conclude that aqua exercise promoted physiological functioning of the muscles in the legs after high-intensity downhill running for a period until the damaged muscles had recovered almost completely.

Keywords: *Recovery, eccentric contraction, muscle soreness, muscle stiffness, delayed-onset muscle soreness*

Introduction

Aqua exercise, as represented by swimming, is widely accepted to promote people's health regardless of age and sex. Also, it has been used as rehabilitation for sports disorders by making the most of the properties of water (Golland, 1981). According to Archimedes' principle, when an object sinks and stops in a liquid, it should be forced upward by buoyancy equal to the amount of liquid displaced by its mass (Edlich *et al.*, 1987). It is believed that the human body's supporting load on the legs becomes 25–30% of the body mass when immersed in water up to the xiphisternum and it becomes 10% when immersed up to the shoulder (Bates & Hanson, 1996). Moreover, when an object moves in water, there are three kinds of resistance, namely: wave, form and viscous resistance. Since this resistance is in proportion to the square of the velocity of the moving object, it makes the movement in water slow and as a consequence eccentric muscular contractions should not occur (Evans, Cureton, & Purvis, 1978). In addition, it is known that water resistance exerts a mild massaging effect.

In contrast, field exercise, such as running, results in eccentric muscular contractions in the legs. Exercise including frequent eccentric contractions can cause severe muscle soreness for a few days after the exercise (Asmussen, 1956; Edwards, Mills, & Newham, 1981; Friden, Sjöstrom, & Ekblom, 1981). This muscle soreness reaches a peak 10 h after exercise at the earliest, but normally 24–48 h after exercise (Clarkson, Nosaka, & Braun, 1992). Such muscle soreness is known as delayed-onset muscle soreness (DOMS) and lasts for several days after exercise involving eccentric muscular contractions (Asmussen, 1956; Friden *et al.*, 1981; Talag, 1973). One report on the mechanism of DOMS suggested that consecutive stretching of the muscles during exercise results in high mechanical stress and breakdwon of the ultrastructures in the muscle (Friden, Sjöstrom, & Ekblom, 1983). On the other hand, another report suggested that there is a time lag

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between the onset of muscle damage and the peak of muscle soreness (Nosaka, Clarkson, McGuiggin, & Byrne, 1991), so a consensus has yet to be reached on this matter. The physiological responses to muscle soreness resulting from eccentric muscular contractions include a decline in muscular strength, a reduction in flexibility, an increase in muscle stiffness and an increase in muscle enzymes in the blood (Clark & Eston, 1992; Eston, Finney, Baker, & Baltzopoulos, 1996; Talag, 1973). Nosaka and Newton (2002) reported that muscle soreness and creatine kinase in the blood increased, and range of motion decreased, when the muscle was engaged in eccentric exercise during recovery, but not when the muscle was engaged in concentric exercise during recovery.

It has been reported that jogging results in eccentric tension on the extensor muscles of the legs when the speed is reduced after the foot touches the ground, and this can result in muscle damage (Armstrong, Ogilvie, & Schwane, 1983). It has also been shown that this damage is heightened when running downhill (Appel, Soares, & Warren, 1992). Therefore, when jogging on land is performed after highly intensive running, it is likely that the condition of the muscle damaged by the main exercise may be aggravated by additional eccentric contractions.

Since it is clear that buoyancy makes exercise in water possible without eccentric contractions of the muscles of the legs, Takahashi, Koga, Uchida, Ohnishi and Takaoka (2000) compared individuals who walked in water and those who jogged after playing a soccer game. Those in the walking in water group showed an enhanced recovery of flexibility of the legs compared with the jogging group on the following day.

There have been many reports of DOMS-related damage caused by eccentric contractions, but there is little information about the most effective method of recovery from DOMS. We believe that aqua exercise may be an effective method of recovery from DOMS-related damage in the leg muscles for the following reasons: (1) muscle stiffness can be reduced by the mild massaging effect of water resistance; (2) aqua exercise may alleviate muscle soreness because of the rise in muscle temperature and increase in muscle blood flow; and (3) aqua exercise may not expand muscular damage, because the muscles do not contract eccentrically into the water at all. Therefore, the aim of the present study was to examine how the recovery of physiological functioning of the leg muscles after high-intensity eccentric exercise such as running on a downhill slope that causes DOMS could be promoted by aqua exercise for a period until the damaged muscles had recovered almost completely.

Materials and methods

Ten male long-distance runners (age 20 ± 1 years, height 1.71 ± 0.03 m, body mass 58.2 ± 4.0 kg) participated in the study. They were divided equally into an aqua exercise group and a control group. On the first day (Day 0), the participants completed a questionnaire about muscle soreness; in addition, serum creatine kinase activity, muscle power, flexibility (sit and reach, stride length, range of motion of the ankle), whole-body reaction time and muscle stiffness were measured. The participants then performed three sets of 5 min downhill running exercise on a treadmill (−10%) at a speed corresponding to their individual best times for a 5000 m race ($335.7 \pm 6.1\,\mathrm{m \cdot min^{-1}}$), with a 5 min passive rest between sets. The aqua exercise group then moved to a pool and conducted aqua exercise for 30 min; the control group performed no recovery exercise. On the second day (Day 1) and third day (Day 2), each participant completed the same measurements as on Day 0 without the downhill running. On the fourth and last day (Day 3), each participant repeated the procedures of Day 0, but the aqua exercise group had no recovery exercise. The experimental procedures were approved by the Ethics Committee of Juntendo University. After receiving an explanation of the experimental protocol, written consent was obtained from all participants before the study commenced.

A 5 ml blood sample was taken from the antecubital vein and creatine kinase activity was determined by spectrophotometry using a biochemical autoanalyser (Fuji Drichem 3500, Fuji Film Medical, Japan). To measure muscle power of the extensor muscles of the legs, a maximum leg press movement was conducted using an Anaero Press (COMBI). The participants attempted the leg press five times and the best two values were averaged and recorded.

To compare the effects of downhill running on the flexibility of the legs, sit-and-reach flexibility (both legs together), stride length and range of motion of the ankle were determined. For stride length, the participants extended one of their heels as far as possible while keeping the other heel on the wall, and then the distance between the two heels was measured. The measured value was then divided by height and multiplied by 100 to give the result. The angle of the ankle from maximally dorsiflexed to maximally planterflexed was measured using a Flexon Meter (Takei Scientific Instruments, Japan).

For whole-body reaction time, beginning in a relaxed position and standing on a force plate the participants jumped to the side of the plate in response to random lighting from a stimulator. The time from the light to leaving the force plate was considered to reflect whole-body (jumping) reaction time. The time from the light to vertical loading on the force plate was taken as the onset time of the motor response (nerve reaction time), and the time from vertical loading to release of the feet was taken as the muscle contraction time (Ikai, Asami, & Shibayama, 1961).

The participants responded to a questionnaire on seven sites of muscle soreness using a scale of 1 ("not at all") to 5 ("very, very sore"): abdomen, back, hip, anterior/posterior region of thigh, and anterior/posterior region of calf. Using a muscle stiffness meter (PEK-1, Imoto Seisakusho, Japan), the anterior/posterior regions of the right thigh and calf were measured. As described previously (Yamamoto, Inoshita, Suzuki, & Konishi, 1999), we measured the centre point on the line dividing the posterior region of the thigh into upper and lower, the same point on the anterior region of the thigh, the most raised part of the gastrocnemius muscle on the posterior region of the calf, and the same part on the anterior region of the calf three times and averaged the measured values.

Aqua exercise consisted of randomly combined exercises such as walking ahead/backwards, jogging, and jumping in water for a total of 30 min. Water temperature was maintained at 29.2 ± 0.8°C throughout the study.

Statistical analysis

The data were analysed using a two-way analysis of variance. A Scheffé's *post-hoc* test was used for parametric data (serum creatine kinase activity, muscule power, flexibility, whole-body reaction time and muscle stiffness). For muscle soreness, we used the Kruskal-Wallis test for intra-group measurements and a Mann-Whitney *U*-test to compare values in the two groups.

Results

Creatine kinase activity in the blood, muscle power, flexibility, reaction time and muscle stiffness are shown in Table I.

In both groups, creatine kinase activity peaked on Day 1 and had declined to baseline values by Day 3 (time main effect: $P < 0.05$; group × time interaction: n.s.). Muscle power responded differently in the two groups (group × time interaction: $P < 0.05$). Muscle power was significantly reduced on Day 1 only in the control group (time main effect: $P < 0.05$); there was no statistically significant change in the aqua exercise group (see Figure 1).

Sit-and-reach flexibility, stride length and range of motion of the ankle were all reduced on Day 1 but had recovered almost completely to baseline values by Day 3. Stride length in both groups was significantly changed (time main effect: $P < 0.05$). There were no significant differences in sit-and-reach flexibility, stride length or range of motion of the ankle between the two groups.

Figure 2 shows the rate of change of whole-body reaction time from Day 0 to Day 3 in terms of nerve reaction time (A), muscle contraction time (B) and whole-body reaction time (C). Although whole-body reaction time of the control group from Day 1 to Day 2 tended to decline, and the value on Day 3 did not return to the baseline value of Day 0, the whole-body

Table I. Serum creatine kinase (CK) activity, muscular power, flexibility, reaction time and stiffness before and after downhill running (mean ± *s*) for the control group ($n = 5$) and aqua exercise group ($n = 5$).

	Serum CK activity ($u \cdot l^{-1}$)		Muscle power (W)		Sit and reach (cm)		Stride ($cm \cdot cm^{-1}$)	
	Control*	Aqua*	Control*	Aqua	Control	Aqua	Control*	Aqua*
Day 0	347 ± 195	278 ± 137	1652 ± 418	1568 ± 148	52 ± 2	52 ± 9	194 ± 6	197 ± 13
Day 1	555 ± 155	615 ± 337	1379 ± 477	1504 ± 130	46 ± 5	48 ± 8	191 ± 7	192 ± 11
Day 2	378 ± 72	402 ± 223	1556 ± 491	1525 ± 177	50 ± 5	51 ± 10	193 ± 7	196 ± 11
Day 3	283 ± 54	323 ± 214	1540 ± 344	1512 ± 166	49 ± 4	51 ± 7	194 ± 6	197 ± 13

	Range of motion (°)		Reaction time (ms)		Muscle stiffness			
					Calf		Thigh	
	Control	Aqua	Control	Aqua	Control	Aqua	Control	Aqua
Day 0	68 ± 10	70 ± 7	293.9 ± 43.2	316.4 ± 24.5	57 ± 5	60 ± 4	53 ± 3	55 ± 2
Day 1	65 ± 12	65 ± 6	300.3 ± 46.6	315.7 ± 26.6	59 ± 5	59 ± 3	54 ± 3	54 ± 2
Day 2	65 ± 12	68 ± 8	307.7 ± 31.4	315.7 ± 26.6	58 ± 6	58 ± 3	54 ± 3	54 ± 2
Day 3	66 ± 9	67 ± 7	305.4 ± 40.7	315.3 ± 20.1	57 ± 5	58 ± 3	53 ± 3	53 ± 2

*Significant difference (time main effect: $P < 0.05$).

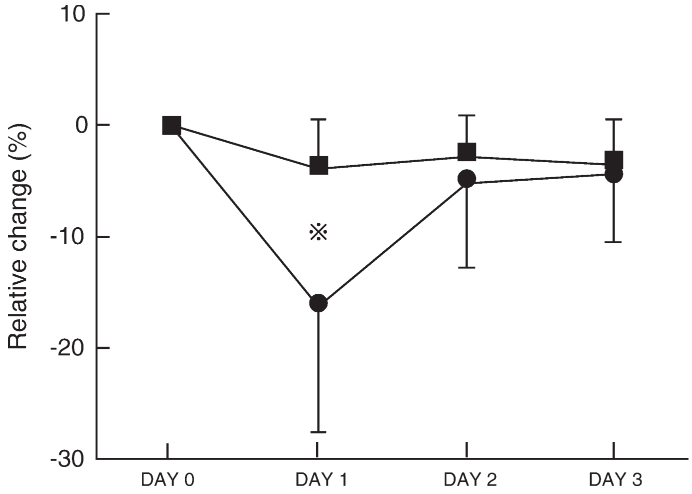

Figure 1. Relative change in leg muscle power. The values are the adjusted mean ($\pm s$) from analysis of variance. ■, aqua exercise ($n = 5$); ●, control ($n = 5$). ※ Significant difference between the two groups (power × time interaction: $P < 0.05$).

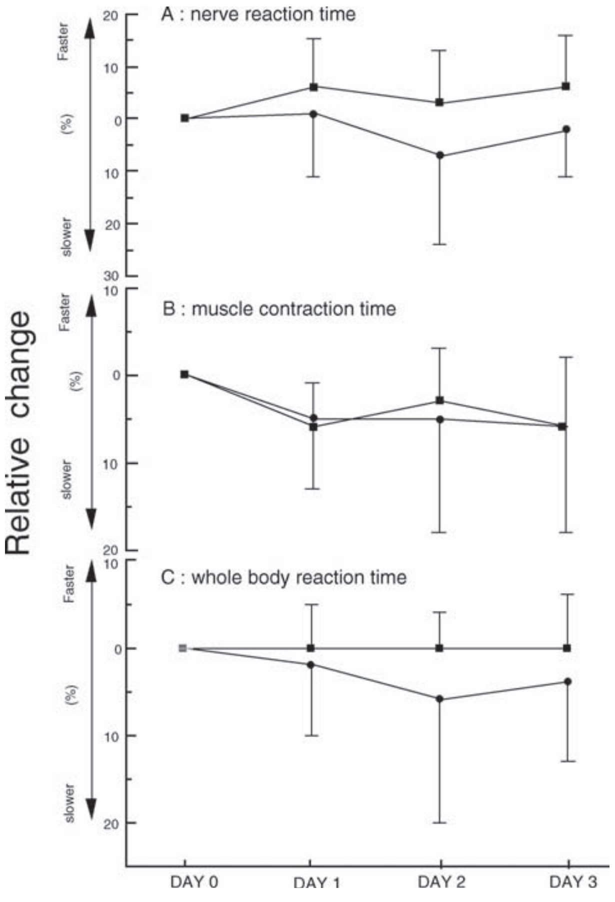

Figure 2. Relative change in nerve reaction time (top panel), muscle contraction time (middle panel) and whole-body reaction time (bottom panel). The values are the adjusted mean ($\pm s$) from analysis of variance. ■, aqua exercise ($n = 5$); ●, control ($n = 5$).

reaction time of the aqua exercise group did not change (both time main effect and group × time interaction: N.S.).

Since the participants did not report significant soreness of the abdomen, back, hip, posterior region of the thigh or anterior region of the calf, we compared the change in muscle soreness of the posterior region of the calf (calf) and the anterior region of the thigh (thigh).

For muscle soreness of the calf, on Day 0 two participants reported "2: somewhat sore" in both groups. On Day 1, two participants reported "5: very, very sore" in both groups and this was the peak muscle soreness over the 4 days. On Day 2, one participant in the control group still reported "5: very, very sore"; the remaining controls reported "4: very sore". Two participants in the aqua exercise group reported "2: somewhat sore" on Day 2, but one participant reported "5: very, very sore." On Day 3, one participant in the control group reported "4: very sore", with the rest reporting "3: sore"; three participants in the aqua exercise group reported "1: not at all", with the rest reporting "2: somewhat sore" and "3: sore". These changes in the two groups over 4 days were statistically significant (time main effect: $P < 0.05$). Also, the soreness experienced by the aqua exercise group showed a statistically significant recovery in comparison to that of the control group (group × time interaction: $P < 0.05$) (see Figure 3A).

For muscle soreness of the thigh, on Day 0 two participants in the aqua exercise group reported "2: somewhat sore", while all those in the control group reported "1: not at all". On Day 1, two participants in the control group and one participant in the aqua exercise group reported "4: very sore"; the remaining participants reported "3: sore". On Day 2, only one participant had recovered from Day 1, and those two days (Days 1 and 2) were considered to be the peak of muscle soreness of the thigh. On Day 3,

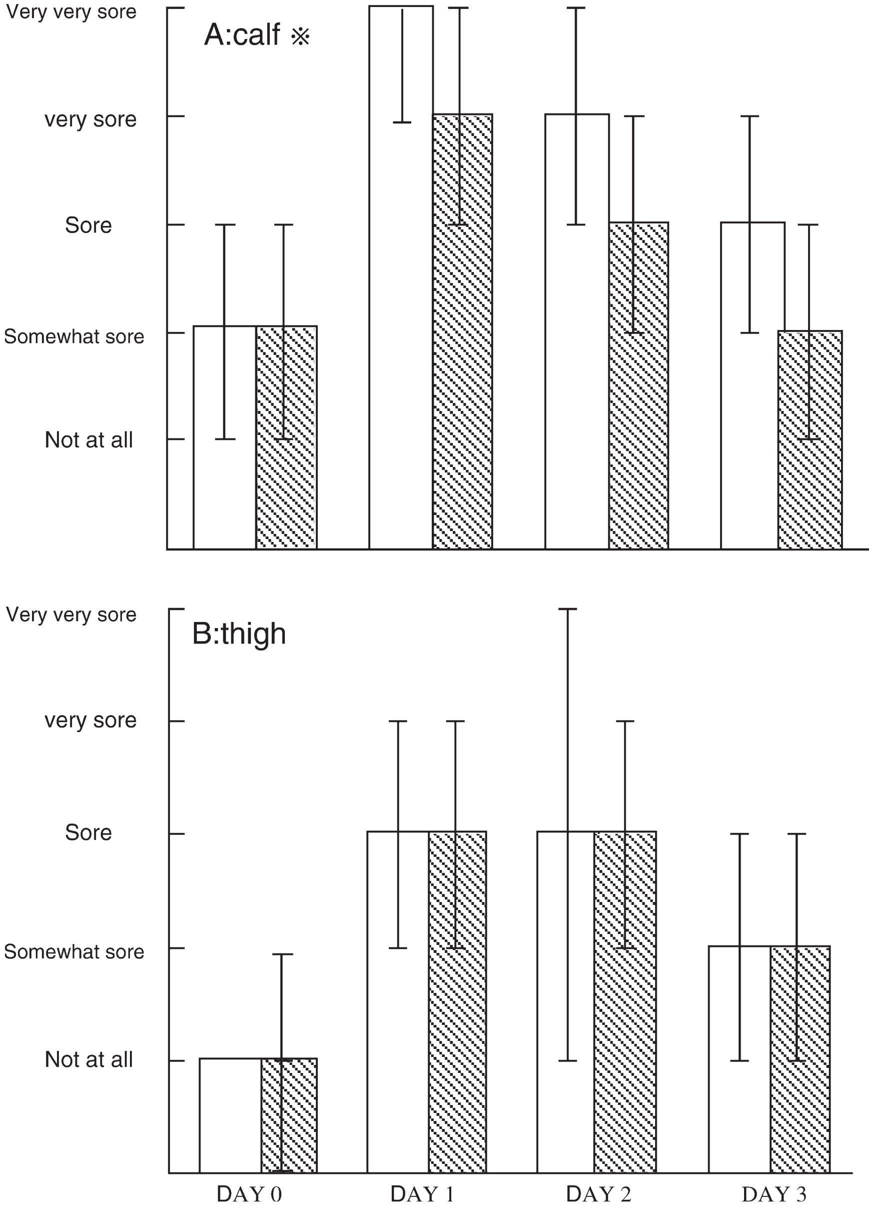

Figure 3. Assessment of calf (top panel) and thigh (bottom panel) muscle soreness. The values are the adjusted mean ($\pm s$) from analysis of variance. ▨, aqua exercise ($n = 5$); ☐, control ($n = 5$). ※ Significant difference between the two groups (soreness × time interaction: $P < 0.05$).

all participants in both groups reported "2: somewhat sore" or "1: not at all". Though the changes in both groups over 4 days were statistically significant, there was no statistically significant difference between the two groups (time main effect: $P < 0.05$; group × time interaction: n.s.) (see Figure 3B).

Since there were no changes in the posterior region of the thigh and the anterior region of the calf, we compared the change in muscle stiffness of the posterior region of the calf (calf) and the anterior region of the thigh (thigh).

Figure 4A shows the rate of change in muscle stiffness of the calf from Day 1 to Day 3 compared with Day 0. While stiffness in the control group peaked on Day 1 and had begun to return to baseline values by Day 3, the stiffness in the aqua exercise group showed a continuous downward trend over 4 days. The changes between the two groups over 4 days differed significantly (time main effect: $P < 0.05$; group × time interaction: $P < 0.05$).

Although there was no statistically significant change in muscle stiffness of the thigh between the two groups, the control group showed increased muscle stiffness of the thigh as well as calf on Day 1, which had returned to baseline values by Day 3. The aqua exercise group showed a continuous downward trend from Day 0 to Day 3 (time main effect: $P < 0.05$; group × time interaction: n.s.) (see Figure 4B).

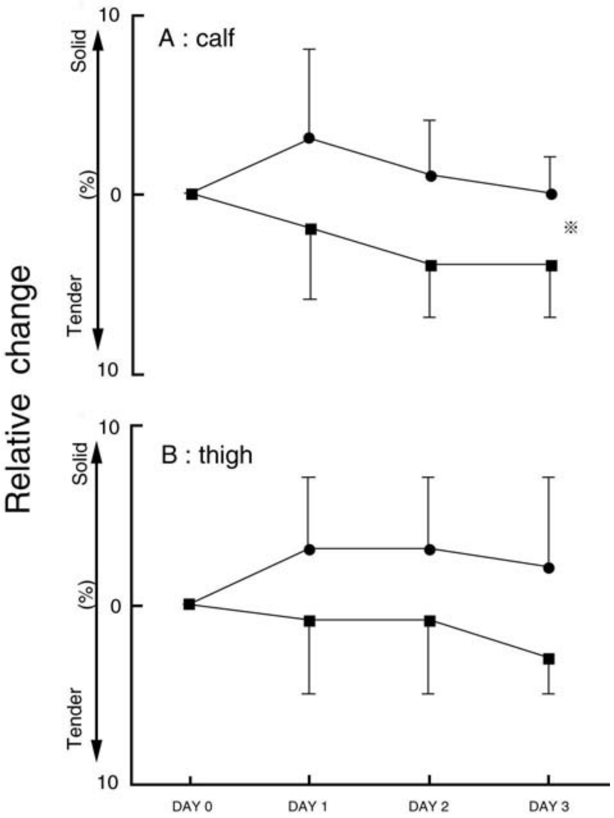

Figure 4. Relative change in calf (top panel) and thigh (bottom panel) muscle stiffness. The values are the adjusted mean (±*s*) from analysis of variance. ■, aqua exercise ($n = 5$); •, control ($n = 5$). ※ Significant difference between the two groups (stiffness × time interaction: $P < 0.05$).

Discussion

The main finding in this study was that aqua exercise facilitated the recovery of physiological functioning of the leg muscles after high-intensity eccentric exercise – running on a downhill slope – that caused DOMS. Muscle power, muscle stiffness and muscle soreness were shown to recover more quickly after aqua exercise compared with just resting.

An increase in serum creatine kinase activity is used as a marker of muscle damage (Clark & Eston, 1992; Newham, Jones, Ghosh, & Aurora, 1998; Sargeant & Dolan, 1987). Serum creatine kinase activity increased mainly on Day 1 in this study, which shows that the participants in both groups had muscle damage after downhill running. However, the increase in activity was not as great as reported in other studies, possibly because the long-distance runners were partially habituated to downhill running (Armstrong, 1984; Wales, Tonkonogi, Malm, Ekblom, & Sahlin, 2001). As the aqua exercise did not attenuate the increase in creatine kinase activity more than that in the control group, aqua exercise may not be effective in reducing muscle damage.

Muscle power in the control group was at its lowest on Day 1 and recovered to baseline values by Day 4. In the aqua exercise group, there was no change in muscle power over the 4 days and there was a statistically significant difference between the aqua exercise group and the control group (see Figure 1). This decline in power in the control group may be due to morphological alterations such as decay of the sarcomeres (Clarkson & Tremblay, 1988; Ebbeling & Clarkson, 1989; Newham, Jones, & Clarkson, 1987). Since it is considered that this morphological alteration is related to increased serum creatine kinase activity (Nosaka & Clarkson, 1994), we can assume that the decline in power is caused by the muscle damage that results from downhill running. However, the aqua exercise group did not show a decline of muscle power, despite showing the same change in serum creatine kinase activity. Viitasalo *et al.* (1995) reported that water jet massage after highly intensive muscle training prevented declining muscle strength. Moreover, Lambert, Marcus, Burgess and Noakes (2002) reported that they were able to reduce muscle strength loss by applying micro-current therapy, where the muscle had been damaged by eccentric contractions. Both mechanisms have yet to be clarified, but it can be assumed that a massage effect with mild water flow inhibited the decline of muscle power in this study.

Although sit-and-reach flexibility, stride length and range of motion of the ankle tended to be reduced by downhill running on Day 1, only the value for stride length was statistically significant. The value for sit and reach measured in this study represents flexibility of the posterior region of the thigh. Also, for range of motion of the ankle, the muscles in the posterior region of the calf are stretched during dorsiflexion. In this study, downhill running caused great soreness in the anterior region of the thigh and posterior region of the calf. Therefore, it is assumed that only stride length changed significantly because stretching a leg backward caused tension of the anterior region of the thigh.

Whole-body reaction time in the control group tended to be negatively affected until Day 2, while there were no changes in the aqua exercise group. Although there were no statistically significant differences between the two groups, this tendency for a slower rewcovery of whole-body reaction time depended on nerve reaction time rather than muscle contraction time. In this study, we classified nerve reaction time and muscle contraction time by strains on a force plate. Since excitation – contraction coupling of damaged muscle is delayed due to decay of sarcomeres caused by eccentric contractions and changing levels of calcium in muscle cells, in conjunction with alternation of the non-contractile element (Belcastro, Shewchuk, & Raj, 1998), it is presumed that the difference between the two groups reflects the time-lag at the end point of nerve reaction time; in other words, the starting point of muscle contraction time. This finding requires further study by electromyographic analysis.

In aqua exercise, vestibular stimulation improves static reaction due to the spurring of anti-gravity muscles in the limbs and trunk (Ebbeling & Clarkson, 1989). As a result, neurotransmitters can be smoothly sent along nerves to muscles, and neuromuscular cooperation can be improved. Thus, it is considered that these factors were also reflected in the results.

Muscle soreness of the calf peaked on Day 1 in both groups, while muscle soreness of the thigh continued to peak over 2 days (Days 1 and 2). Furthermore, the soreness of the calf in the control group was significantly greater than that in the aqua exercise group (see Figure 3). In contrast, the soreness of the thigh showed a similar trend in both groups. Soreness of the thigh for both groups was experienced in the anterior region, which is consistent with the stride length (see Figure 3B). There was no difference in soreness of the thigh between the two groups, as was the case for stride length.

For the calf (posterior region), while the control group reported "5: very, very sore" on Day 1, the aqua exercise group had less soreness than the control group over the 3 days of recovery. In this study, flexibility of the ankle did not reflect muscle soreness of the lower thigh. However, the aqua exercise was more effective in reducing muscle soreness of the calf than of the thigh. Also, the participants reported more soreness in their calves, which indicates that the calf tends to experience more reaction force from the ground. This can be explained by the fact that the calf is closer to the ground and has fewer elements to absorb shock caused by gravity (Pierrynowski, Tiiddus, & Plyley, 1987). Moreover, as the muscle soreness increased to "very, very sore", the muscular power decreased significantly and the stiffness was more severe in the control group. These variations may have a negative influence on muscle soreness at the onset of muscular power, and increased muscular stiffness may have been caused by the decay of muscular tissue and damage to the soft tissue after downhill running (Newham *et al*., 1998). With aqua exercise, soaking in water results in an increase of peripheral blood flow volume and an increase of tissue fluid flow in damaged areas, which promotes the healing process. Moreover, it has been reported that increasing hydrostatic pressure on the body in water also promotes blood circulation (Hall, Bisson, & O'Hare, 1990). Therefore, aqua exercise can help the lower thigh to recover quickly from pain brought on by downhill running.

Muscle stiffness was greater in the control group than in the aqua exercise group on Day 1 in both the calf and the thigh. In addition, the muscle stiffness had been improving slowly for 3 days, even after downhill running in the aqua exercise group (see Figure 4). It is presumed that mechanical factors, such as decay of muscular tissue and damage of soft tissue caused by eccentric contractions, and oedema caused by acute muscle fatigue, may result in stiffening of the muscles (Newham *et al*., 1998). The muscle stiffness meter used in this study measured the hardness of soft tissues of a body that has both viscous and elastic elements and it was proved that we could objectively assess the factors that cause muscle stiffening (Yamamoto *et al*., 1999).

In this study, there was a remarkable downward (softening) trend of muscle stiffness of the thigh and calf in the aqua exercise group. It is believed that the load on the anti-gravity muscles is reduced to 25–30% of body mass when a human body is immersed in water up to the xiphisternum, and it is reduced to 10% when the body is immersed up to the shoulders (Bates & Hanson, 1996). Because the depth of the swimming pool we used in this study was about 1.3 m and all participants were immersed in water up to a level midway between their xiphisternum and shoulders, it was sufficiently deep to reduce the load supported by the legs. Moreover, the participants may have experienced mild massage effects from water resistance (wave, form and viscous resistance) when they moved in water. In addition to the results for muscle soreness, increasing hydrostatic pressure on the body in water with increasing peripheral blood flow volume and increasing tissue fluid flow in the damaged area may eliminate the oedema that causes stiffening of the muscles, and this may explain why the stiffness of the thigh/calf muscles in the aqua exercise group was reduced more than in the control group.

The results of this study showed that aqua exercise after downhill running promoted recovery of muscle power, muscle soreness and muscle stiffness, and tended to promote recovery of whole-body reaction time more quickly than in conditions without the aqua exercise (control group), because of the benefits of water resistance, buoyancy and exercising. We conclude that aqua exercise helps recover physiological functioning of the leg muscles after downhill running.

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