Effects of aquatic resistance training on neuromuscular performance in healthy women

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ABSTRACT

TAPANI PÖYHÖNEN, SARIANNA SIPILÄ, KARI L. KESKINEN, ARTO HAUTALA, JUKKA SAVOLAINEN, and ESKO MÄLKIÄ. Effects of aquatic resistance training on neuromuscular performance in healthy women. *Med. Sci. Sports Exerc.*, Vol. 34, No. 12, pp. 2103–2109, 2002. **Purpose:** The purpose of this study was to investigate the effects of a progressive 10-wk aquatic resistance training on neuromuscular performance and muscle mass of the knee extensors and flexors in healthy women. **Methods:** Twenty-four healthy women (34.2 ± 3.9 yr) were randomly assigned into aquatic exercise ($N = 12$) and control group ($N = 12$). Maximum knee extension and flexion torques were measured isometrically and at constant angular velocities of $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$ (isokinetic) with simultaneous electromyography (EMG) recordings of the quadriceps and hamstrings. The lean muscle mass (LCSA) of the quadriceps and hamstring muscles was determined by computed tomography scanning. **Results:** Significant interaction of group by time was observed in each of the measured parameters. The change in extension and flexion isometric/isokinetic torque varied between 8 and 13% and in EMGs between 10 and 27% in the exercise group. The change in the quadriceps LCSA of the exercise group was 4% and in hamstrings 5.5%. **Conclusions**: The results of the present study showed that 10 wk of progressive aquatic resistance training resulted in significant improvement in muscle torque of the knee extensors and flexors accompanied with proportional improvement in neural activation and with significant increase in the LCSA of the trained muscles. Aquatic training can be recommended for neuromuscular conditioning in healthy persons. **Key Words:** AQUATICS, HYPERTROPHY, MUSCLE TORQUE, SKELETAL MUSCLE, EMG

Water offers a unique exercise medium in which reduced-gravity conditions decrease the impact forces on joints, while the water itself creates resistance to movement. Aquatics may be an alternative training mode to improve overall fitness especially in persons with low levels of physical fitness. It may also be used for the fit athletes as a part of the early rehabilitation process after injury and to facilitate recovery process of the neuromuscular system after training, leading back to full sport participation. Aquatic rehabilitation has been also shown to improve muscle performance and endurance in elderly people (21), in patients suffering from rheumatoid arthritis and fibromyalgia syndrome (5,14,26), knee disorders (27), and poliomyelitis-related disabilities (8,18,28). However, none of the previous studies have examined the underlying neuromuscular mechanisms behind the improvements in muscle performance, and only one study attempted to estimate resistance produced by water during exercises.

There is scientific evidence that shows that aquatic aerobic training such as water running can elicit improvements in fitness similar to that of land-based training (7). The neuromuscular responses to aquatic exercises are largely unknown, as research interest in resistance-type aquatic training in healthy persons has been scant. To our knowledge, only one study compared quadriceps muscle strengthening on land and in water in young healthy women and found nonsignificant differences in strength improvement between the water and land exercise groups after 8 wk of training (17). However, more data are needed to answer the question of whether water offers sufficient resistance to overload healthy or pathological neuromuscular system.

A scientific knowledge of the basic neuromuscular function, intensity, and resistance of the exercises in healthy persons provide the framework for progressive hydrotherapy program to be safely applied for rehabilitation purposes. Furthermore, information is needed about aquatic training responses and the underlying mechanisms leading to an improvement in muscle performance. Therefore, this randomized and controlled study was accomplished to clarify the effects of a pro-

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gressive 10-wk aquatic resistance-training program on isometric and isokinetic torque, neural activation, and muscle cross-sectional area in healthy women.

METHODS

Subjects. After obtaining approval from the Ethical Committee of the Central Hospital of Kymenlaakso, 24 female health care professionals signed written informed consent forms and participated as subjects in the present study. They were randomly assigned into two groups: an exercise group ($N = 12$), mean (SD) age 33.8 (3.9) yr, body mass 60.6 (4.9) kg, height 165.8 (3.4) cm; and a control group ($N = 12$), age 34.7 (3.9) yr, body mass 64.8 (4.9) kg, height 168.1 (4.6) cm. All the participants were healthy with no contraindications for participation in an intensive training program. The subjects were habitually active participating in regular weekly physical activity (2–3 times a week, 35–60 min per session). Walking and aerobics were the principal activities reported by subjects. The exercise and the control group did not differ with respect to the level of physical activity, which remained constant throughout the experiment. One subject had to withdraw from the training group after 2 wk because of an acute respiratory infection. In addition, one other subject was excluded from the control group due to a significant increase in the level of physical activity from 3–4 times a week (baseline) to 7–8 times a week, as reported in the subject's physical activity diary.

Experimental design. The measurements of neuromuscular performance including electromyography (EMG), isometric and isokinetic torques, and muscle mass were performed 3–4 d before and after the training period. In addition, the women in the exercise group underwent additional measurements at the beginning of the fifth training week. The exercise group participated in a 10-wk aquatic resistance-training program. The subjects in the exercise and control groups were asked to maintain their current level of physical activity throughout the 10-wk period. To ensure that this was achieved, the participants in both groups were instructed to keep physical activity diaries that included information on the types and duration of the physical activities performed.

Isometric and isokinetic torque measurements. The maximum isometric and isokinetic torque production of the knee extensors and flexors were measured using an isokinetic dynamometer with a sampling frequency of 100 Hz (Biodex Corp., Shirley, NY). The dynamometer was calibrated before each measurement session according to the standard procedure recommended by the manufacturer. For isometric and isokinetic measurements, the day-to-day reproducibility was determined by calculating the intraclass correlation coefficient (ICC). The ICC varied between 0.94 and 0.98 (19). Before the measurement session, the subjects were carefully familiarized with the testing procedure and received instruction in the performance of maximal isometric and isokinetic efforts using the left leg. After the warm-up period, which included 8 min of stationary cycling and 4 min of stretching of the lower leg musculature, the subjects were positioned on the dynamometer, and their position was fixed firmly using straps in 90° of hip flexion and 60° of knee flexion. After a few submaximal repetitions, the subjects were instructed to perform two maximal isometric extension and flexion efforts (4 s) as explosively as possible. The recovery time between the two successive efforts for both extension and flexion was 60 s, with a recovery period of 2 min between the extension and flexion efforts. Verbal encouragement was used to motivate the subjects in the achievement of a maximal effort. Thereafter, as a pretest warm-up for the isokinetic test measurements, the subjects performed four submaximal and two maximal concentric knee extension-flexion efforts on the isokinetic dynamometer. The actual testing protocol consisted of four and six maximal extension-flexion repetitions at constant angular velocities of $60° \cdot s^{-1}$ and $180° \cdot s^{-1}$, respectively. The measurements with the slower contraction velocity represent maximal torque production, whereas the faster velocity measurements represented power-type torque production. The range of motion (ROM) of the knee was limited to a ROM from 115° of knee flexion to full extension (0°). The best repetitions were selected for further analysis. In addition, the isometric knee extension-flexion force-time curve was produced using 50-ms intervals over the first 500 ms.

Electromyography recordings. The surface EMGs of the quadriceps (vastus medialis, vastus lateralis) and hamstring muscles (biceps femoris, semitendinosus) were recorded using an eight-channel EMG system (Mespec 4000 telemetry system, Mega Electronics, Kuopio, Finland). Oval shaped bipolar pregelled silver chloride surface electrodes (Medicotest N-OO-S, Olstykke, Denmark), 2.1 cm wide and 2.9 cm long, were positioned longitudinally along the muscle fibers between the center of the innervation zone and the distal tendon of each muscle. The inter-electrode distance was 2.0 cm. The reference electrode was positioned on the lateral condyle of the tibia. To keep the inter-electrode resistance low (< 2 kΩ), the skin was shaved, rubbed with sandpaper, and cleaned with 60% alcohol. The position of the electrodes was marked on the skin with indelible ink to ensure the same electrode position for each session.

The measured EMG signals were preamplified using a gain of 1000. The preamplifier was located in the telemeter transmitter. The signals were carried out with a different amplifier with an input impedance of 10 GΩ, a common mode rejection ratio $>$ 100 dB, and a signal-to noise ratio 72 dB. The filtering of the raw EMG was performed with low- and high-pass filters (Butterworth type), with the bandwidth between 20 Hz and 500 Hz. The raw EMG signal was passed through a 12-bit A-D converter with a 1000-Hz sampling frequency and then transferred to a computer for further analysis. Background noise in the filtered signal was less than 1 μV. During the maximal isometric contraction (MVC), the EMG signal was full-wave rectified, and average amplitude of the signal (aEMG) was calculated with a window width of 500–1500 ms or 1000–2000 ms from the starting point of the force curve, depending on the timing of the peak force. In the isokinetic measurements, the average of the EMG signal was calculated in the range between 50

TABLE 1. The summary of the 10-wk aquatic training program used in the present study (rep, repetition).

Wk	Sessions/wk	Sets/session	Reps/set	Work/rep (s)	Rest/rep (s)	Time/wk (min)	Boot Size	Drag Force (N)
1	2	2	20–25	20	30	24	Small	65 ± 20
2	2	2	20–25	25	35	30	Small	65 ± 20
3	2	2	14–20	20	35	28	Medium	112 ± 24
4	3	3	14–20	20	35	43	Medium	112 ± 24
5	3	3	14–20	25	40	50	Medium	112 ± 24
6	3	3	14–20	30	50	58	Medium	112 ± 24
7	3	3	12–15	25	45	52	Large	160 ± 32
8	3	3	12–15	30	50	58	Large	160 ± 32
9	3	3	12–15	35	50	66	Large	160 ± 32
10	3	3	12–15	35	50	66	Large	160 ± 32

ms before and 50 ms after the peak torque. According to our previous study (20), the ICC coefficients varied between 0.90 and 0.96 for the EMG measurements.

Computed tomography (CT). The measurements of muscle mass were performed 3–4 d before and after the training period. CT scans were obtained from the left mid-thigh using a Siemens Somatom DR scanner (Siemens AG, Erlangen, Germany). Mid-thigh was defined as the midpoint between the greater trochanter and the lateral joint line of the knee. The distance from the floor to the measuring sites was recorded and used for the follow-up measurements. Lean tissue cross-sectional area (LCSA) and mean density of the lean tissue (Houndsfield unit, HU) were measured for the quadriceps femoris and hamstrings by a measurer not aware of the subject's group. In the previous study, the coefficient of variation between two consecutive measurements varied between 1 and 2% for the LCSA and was less than 1% for the mean HU of the lean muscle tissue (24).

Training protocol. The 10-wk aquatic training was specifically directed to improve the neuromuscular performance of the quadriceps and hamstring muscle groups. All training sessions for 10 wk were conducted in small groups including four to five persons and were supervised by an experienced instructor. Each session started with a 6- to 8-min warm-up including aqua jogging using floating belts (Aqua Jogger, Eugene, OR) and stretching exercises for the lower-extremity muscles. This was by followed by 30–45 min of resistance training and then a 5-min cooling-down period. The exercises used in this training program were selected on the basis of the current knowledge on muscle function and water resistance (drag) for knee exercises under water (19,20). Each training session consisted of four primary exercises for both legs: 1) repeated one leg knee extension-flexion movements in sitting position, 2) repeated one leg knee extension-flexion in standing positions, 3) reciprocal knee extension-flexion movements in a sitting position, and 4) either a hip extension-flexion movement with extended knee in a standing position or " water kicking" in which the knee was extended during hip flexion and flexed during hip extension. These two movements in exercise 4 were alternated each training session. According to the EMG studies (19,20), the concentric-eccentric ratio of the trained muscle groups was approximately 1:1 during exercise cycles. In water, the effect of the movement velocity on the resistance produced by water is emphasized. When the velocity doubles, the drag produced by water quadruples. Therefore, the subjects in the exercise group were instructed to perform each repetition during exercise sessions with maximal effort in order to achieve the highest possible movement velocity and subsequent resistance. Verbal encouragement by the instructor was provided.

Table 1 summarizes the training program including the weekly sessions, sets, duration of work and rest, training time a week (work + rest of each set/repetition), and resistance produced by the resistance boots. The progression of the training program was ensured by using three different sized resistance-boots (small, medium, and large) and by varying the amounts of sets and duration of the exercises, which were equal for each subject. The small Aqua Runners Zero Impact Footwear (Aqua Jogger) attached around the foot of the subject were used during the initial 2 wk of training in order to technically practice the exercises. Thereafter, the actual strength training in water was conducted using the medium and large resistance boots (Hydro-Tone hydro-boots, Hydro-Tone Fitness Systems, Inc., Huntington Beach, CA) with frontal areas of 0.045 and 0.075 m^2, respectively. These resistance boots were attached around the lower leg and foot.

To estimate the intensity of the training, the water resistance was calculated, and velocity of the movements and heart rate responses during exercises were measured. The peak drag of water was determined using the general fluid equation (1):

$$F_d = 0.5 \cdot \rho \cdot A \cdot v^2 \cdot C_d$$

where F_d is the drag force (N), ρ is the density of water (998.6 $kg \cdot m^{-3}$), A is the projected frontal area of the leg (m^2), ν is the velocity of the shank of the subject ($m \cdot s^{-1}$), and C_d is the coefficient of drag. In this study, the projected area for each subject was measured by manually drawing the silhouette outlines of the leg while wearing the resistance boots. The velocity of the shank of each subject was determined from underwater motion analyses. A sagittal view of the lateral side of the lower leg was videotaped by an underwater video camera (Hitachi VK-C180E, 50-Hz field rate). Markers were painted on three bony landmarks: the lateral greater trochanter, the lateral femoral epicondyle, and the lateral malleolus. Video images of knee extension and flexion were digitized automatically and corrected manually to further determine range of motion and angular velocity.

TABLE 2. The effects of aquatic training on isometric and isokinetic torque, corresponding EMGs (vastus lateralis + vastus medialis/2) and muscle mass (mean SD) for knee extensors (IA, interaction).

Variable	Exercise		Control		ANOVA (P)		
	Baseline	10-wk	Baseline	10-wk	Group	Time	IA
Isometric torque (N·m)	169 (26)	183 (22)	170 (36)	163 (29)	0.669	0.374	0.020
EMG (μV)	276 (63)	346 (108)	342 (75)	334 (81)	0.732	0.052	0.022
Isokinetic torque (N·m) (60°·s^{-1})	135 (17)	145 (15)	148 (19)	142 (18)	0.569	0.327	0.001
EMG (μV)	157 (38)	217 (66)	175 (48)	187 (46)	0.803	0.006	0.010
Isokinetic torque (N·m) (180°·s^{-1})	94 (10)	100 (8)	100 (9)	98 (8)	0.465	0.460	0.001
EMG (μV)	160 (34)	198 (51)	212 (56)	211 (49)	0.192	0.117	0.090
LCSA (cm^2)	55.4 (2.8)	57.4 (3.0)	57.9 (4.2)	57.8 (3.7)	0.417	0.050	0.028
Density (HU)	53.8 (1.9)	54.9 (2.1)	53.8 (1.5)	52.9 (2.2)	0.274	0.676	0.003

In addition, the coefficients of drag determined by Pöyhönen et al. (19) were used in the drag calculations. The drag values of each subject were determined during the third training week. The average peak drag for extension and flexion for the small, medium, and large resistance boots are presented in Table 1. The mean of the peak angular velocities with small, medium, and large resistance boots were 420 ± 22, 315 ± 26, and 162 ± 20°·s^{-1} during extension and flexion. The heart rate responses of the subjects were monitored continuously during the training sessions using heart rate monitors (Polar Sport Tester, Polar Electro, Kempele, Finland) to control the level of work and recovery. The average heart rates during the exertion period of the sessions with the medium and large resistance boots were 127 ± 11 and 125 ± 12 beats·min^{-1}, respectively.

Statistical analyses. Standard procedures were used to calculate means and standard deviations (SD). The statistical differences in the physical characteristics and in the baseline measurements between the exercise group and the control group were determined using *t*-tests for independent samples. The effects of the aquatic training program were assessed using ANOVA for repeated measures. Within-exercise group differences from the baseline to the mid- and post-training measurements were also assessed using ANOVA for repeated measures. The level of significance was set at $P < 0.05$. The statistical power was from 79 to 92% for isometric/isokinetic torque measurements, from 70 to 72% for the EMG measurements, and from 85 to 92% for the CT measurements.

RESULTS

There were no significant differences between the exercise group and the control group in age, height, and body mass. In the baseline measurements, no significant differences in muscle torque, EMG values, LCSA, or mean density of LCSA were found between the study groups (Tables 2 and 3).

The exercise group trained on average 24.8 times (22–26) during the 10-wk training period. Significant interactions of group by time were observed in each main outcome variable (Tables 2 and 3) except in EMG measured during isokinetic extension at 180°·s^{-1}. The isometric and isokinetic torque of the extensors and flexors of the subjects in the exercise group increased significantly compared with control group subjects. The individual percentage changes in isometric torque are presented in Figure 1. The aquatic training improved the EMGs of the maximal isometric extension and flexion efforts by 26.4% and 10%, while the changes in the control group were −1% and −2%, respectively. In the exercise group, the mean changes in the EMGs of the quadriceps/hamstring during peak isokinetic torque production were 27.7/19.9% (60°·s^{-1}) and 19.2/10.2% (180°·s^{-1}). In the control group, the changes in the EMG activities of the quadriceps/hamstrings during the peak isokinetic efforts were 6.5/−1.8% (60°·s^{-1}) and −0.4/−9.9% (180°·s^{-1}), respectively.

No changes were observed in the exercise group after 5 wk of training in the peak isometric and dynamic torque values and corresponding EMGs. However, each neuromuscular parameter improved significantly (P = 0.05–0.001) between the 5- and 10-wk measurements. The knee extension and flexion force-time curves both showed that the exercise group subjects improved significantly ($P = 0.025$) their force production during the first 150 ms after 5 wk of training compared with the baseline measurements. During the 200- to 500-ms interval of the force-time curves, no differences were found between the baseline and 5 wk measurements.

After 10 wk of aquatic training, the LCSA and mean density of the quadriceps and hamstring muscles of the

TABLE 3. The effects of aquatic training on isometric and isokinetic torque, corresponding EMGs (biceps femoris + semitendinosus/2) and muscle mass (mean, SD) for knee flexors (IA, interaction).

Variable	Exercise		Control		ANOVA (P)		
	Baseline	10-wk	Baseline	10-wk	Group	Time	IA
Isometric torque (N·m)	82 (7)	91 (9)	83 (12)	82 (13)	0.399	0.078	0.008
EMG (μV)	200 (57)	238 (44)	195 (37)	190 (41)	0.441	0.568	0.048
Isokinetic torque (N·m) (60°·s^{-1})	75 (8)	81 (14)	72 (13)	71 (13)	0.263	0.121	0.009
EMG (μV)	210 (47)	257 (66)	167 (42)	164 (29)	0.662	0.086	0.006
Isokinetic torque (N·m) (180°·s^{-1})	53 (6)	60 (7)	53 (11)	54 (10)	0.279	0.012	0.001
EMG (μV)	194 (67)	202 (53)	213 (47)	178 (43)	0.663	0.626	0.013
LCSA (cm^2)	26.8 (2.8)	28.1 (3.0)	27.4 (2.2)	26.7 (3.0)	0.758	0.684	0.009
Density (HU)	48.8 (2.4)	49.8 (2.4)	49.1 (2.0)	47.9 (2.4)	0.501	0.374	0.002

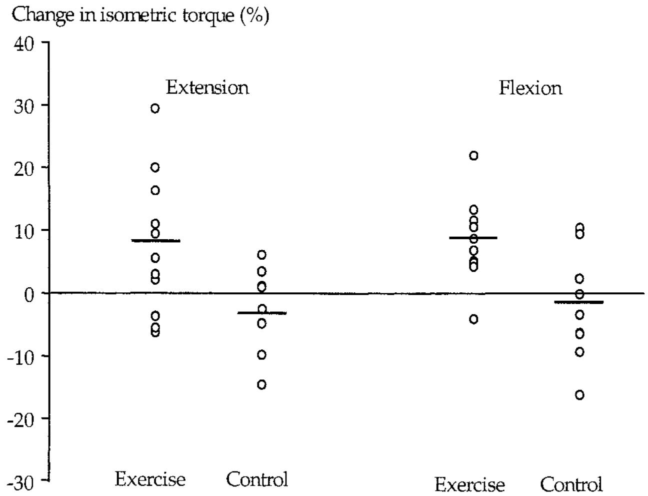

FIGURE 1—Individual percentage changes in maximal isometric torque production during extension and flexion between baseline and 10-wk measurements; — indicates means.

subjects in the exercise group increased significantly compared to control group subjects (Fig. 2).

DISCUSSION

The results of the present study indicated that 10 wk of progressive resistance-type aquatic training can result in increases in the maximal isometric and isokinetic torques of the knee extensors and flexors in healthy women. The torque gains are accompanied with proportional improvement in neural activation and with a significant increase in the lean muscle mass of the quadriceps and hamstring muscles. Thus, progressive resistance-type aquatic training leads to both functional and hypertrophic adaptations in the healthy neuromuscular system.

In this study, the mean percentage changes of 5–13% in the isometric and isokinetic extension torques were smaller than the changes of 13–35% reported in dry land studies (2,4,9,13,29). The mean increase of 19–28% in the EMG of the quadriceps was comparable to the 19% increase reported by Häkkinen et al. (10) and the gain of 4% in the LCSA of the quadriceps was in line with the changes of 3–6% reported by previous studies (2,4,29). With respect to the knee flexor muscles, the torque improved by 9–13% and was accompanied by a 10–19% increase in EMGs and by a 6% gain in the LCSA after training in this study. Cureton et al. (4) reported that strength of the knee flexors increased by 24%, but no hypertrophy was observed after 16 wk of strength training. Sipilä and Suominen (24,25) found no training effects on the isometric strength and muscle mass of the knee flexors in older women after 18 wk of strength training.

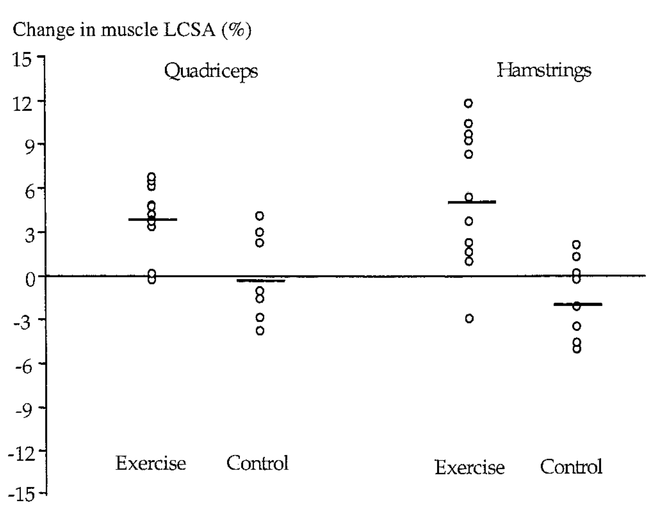

FIGURE 2—Individual percentage changes in the LCSA of the quadriceps and hamstring muscles between baseline and 10-wk measurements; — indicates means.

The comparisons between the different strength training studies should be made with a caution. It is notable that some of the reviewed studies did not use randomized controlled study designs. In addition, the results of the refereed studies showed relatively large ranges of percentage changes in the torque values. This may be due to the variety of training programs and measurement methods used. Test mode specificity was also observed, and therefore changes in muscle strength were greatest when measured during the muscle action and conditions used in training. In this study, torque was tested on dry-land conditions instead of in water, and this may partly explain the lower percentage changes in the torque values obtained in our study compared with the respective changes on dry land. Finally, the majority of the previous studies have emphasized the group mean values whereas only few have paid attention to the individual changes. Our study shows that the variability in training response is quite large, which is in line with other studies reporting individual changes.

There is one dry-land experiment (11) in which the study design and results are somewhat comparable to that used in the present study. Higbie et al. (11) Showed that 10 wk of concentric isokinetic training in untrained women (age 18–35) resulted in an increase of 18% in the maximum unilateral torque of the quadriceps, which was accompanied by an improvement of 22% in EMG activity and a 6% gain in the CSA of the quadriceps obtained using magnetic resonance imaging. The training sessions of their study were conducted 3 $d \cdot wk^{-1}$ for a total of 30 sessions in which the subjects performed three sets of 10 maximal knee extension-flexion repetitions at an angular velocity of $60° \cdot s^{-1}$. The similarity between isokinetic and aquatic training is that no external gravity loads were applied to the extremity and speed was the controlling factor for the resistance in the movements.

It is well established that the underlying mechanisms behind the increases in torque after the initial weeks of strength training are mostly attributed to adaptive changes in neural activation and, thereafter, due to muscular hypertrophy (15,23). The rates of the changes in the EMG measurements increased rapidly in the early conditioning period and decreased during the later training period (15). Conversely, in the present study, the EMG and torque outputs within the exercise group were unchanged when measured after 5 wk of training. This suggests that the initial 5 wk seemed to be mostly power-type strength training, which was supported by the significant increase in isometric force production during the initial 150-ms interval in the extension and flexion force-time curves. This indicates that due to the small frontal areas of the first two resistance boots, the drag produced by the water remained low and the subsequent mean peak angular velocities reached the relatively high values of 420 and $315°\cdot s^{-1}$, respectively. Therefore, the velocity of the exercises during the early training was high enough to improve explosive torque but not maximal torque output. It should be noted, however, that the control croup was not measured after 5 wk of training.

During the last 5 wk, the peak drag with the large resistance boots in extension was 160 ± 32 N and 154 ± 26 N in flexion. To concretize these peak drag forces expressed as the percentage of the maximal isometric torque measured on dry land, the values corresponded on the average of 40–45% in extension and even 65–70% in flexion. However, these percentage values should be considered with a caution due to different exercise conditions.

As is commonly expected, the movements in water are purely concentric. However, our earlier EMG study (20) demonstrated that a reduction of agonist activity occurred concurrently during the final ROM with eccentric activity of the antagonists in repeated knee extension-flexion. This is partly because of the flow patterns of water, deceleration of the moving leg, and preactivation before the change in the direction of the movement (19). Therefore, underwater knee extension-flexion seems to be a stretch-shortening cycle type of exercise in which the subsequent muscle actions have an influence on each other (12). According to several studies, training with combined eccentric/concentric muscle actions seems to result in greater gains in strength and power (3,6,16) and in muscle mass (11) than pure concentric training. In addition, the aquatic exercises, which are typically nonweight-bearing single-joint movements, may partly explain the training induced changes. These "simple" exercises seem to result in earlier hypertrophy than training involving multi-joint exercises, which may need a longer period of initial neural adaptation and, thereby, delayed hypertrophy (2,22).

The encouraging effects of aquatic training on the hamstrings can be explained by hydrodynamic principles. To optimally utilize water resistance, the leg movement should oppose the upward force of buoyancy during the major part of the ROM. Therefore, the seated starting position allowed water to resist the flexion movement effectively, which is clearly seen from the extension-flexion EMG curve showing high activity of the hamstrings in the beginning of flexion when the orientation of the leg is perpendicular to the direction of the buoyant forces (19). The results of this study also suggest that the frontal area of the external devices, and thus the level of resistance, could be easily changed to accommodate the needs and force levels of each individual. This enables the determination of the optimal relationship between the velocity increments and the frontal area of the moving extremity for training purposes.

In conclusion, the results of this study showed that, in healthy women, 10 wk of aquatic training resulted in significant improvements in the static and dynamic torques of the knee extensors and flexors in conjunction with increases in muscle activity and gains in the LCSAs of the quadriceps and hamstring muscles. Consequently, aquatic resistance training can be recommended for neuromuscular conditioning in healthy persons, and it may offer an effective tool for training for those with limited capacity to exercise on dry land.

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