Research Square

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Impact of Intensity-Specific Aquatic Cycling Training on Muscle Strength, Cardiorespiratory Fitness, Neurotrophic Factors, and Cognitive Function Among Older Women

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Abstract

Background

This study investigated the effects of aquatic cycling training (ACT) at varying intensities on muscle strength, cardiorespiratory fitness, brain-derived neurotrophic factor (BDNF), insulin-like growth factor-1 (IGF-1), and cognitive function among older women.

Methods

Forty women aged 65–74 years were randomly assigned to one of four groups: high-intensity interval ACT (HIIT; n = 10), moderate-intensity continuous ACT (MICT; n = 10), progressive-intensity ACT (PICT; n = 10), and control groups (n = 10). The intervention was conducted over 16 weeks, with three sessions weekly. Muscle strength (represented by isokinetic knee strength), cardiorespiratory fitness, BDNF, IGF-1, and cognitive function were measured before and after the intervention. A two-way repeated-measures (RM) analysis of variance (ANOVA) was performed to examine differences across groups and time.

Results

Knee extensor strength significantly improved across all training groups ($p < 0.01$), with between-group differences observed. Knee flexor strength significantly increased in the HIIT and PICT groups ($p < 0.01$), with partial differences between groups. Both BDNF and IGF-1 levels significantly increased across all training groups ($p < 0.01$), with confirmed group differences. Cognitive function improved significantly across all training groups, but no intensity-based differences were found.

Conclusions

Sixteen weeks of ACT produces beneficial effects on functional fitness (represented by muscle strength and cardiorespiratory fitness), BDNF, IGF-1, and cognitive function among older women, irrespective of training intensity. Improvements in muscular strength and neurotrophic factors were influenced by exercise intensity, whereas cognitive gains were independent of intensity. These findings indicate that ACT is an effective and safe intervention for enhancing physical fitness and promote neuroplasticity, thereby contributing to improved cognitive function among older women.

Trial registration

Clinical Research Information Service (CRIS), KCT0011903. Registered 27 April 2026 (Retrospectively registered).

Background

Aging induces numerous physiological changes that affect functional fitness and physical health, which ultimately increase vulnerability to chronic diseases [1]. In particular, the prevalence of sarcopenia, a key component of frailty, stands at 24% among individuals aged 65–70 years, with total muscle mass declining up to 15% at 70–80 years of age [2, 3]. Such age-related declines in muscle mass and functional fitness weaken gait and balance, elevate the risk of falls, and diminish physical and functional independence [4]. Natural aging entails peripheral muscle atrophy as well as significant neural degradation [5]. This encompasses decreased brain mass and synaptic loss, coupled with reduced blood supply and altered hippocampal integrity. Such neurological transformations ultimately lead to the deterioration of cognitive performance [6–8].

Age-related cognitive decline is a natural process; however, regular physical exercise exerts beneficial effects on neural function, supporting the maintenance and even improvement of cognitive capacity [6, 9–11]. Exercise stimulates brain-derived neurotrophic factor (BDNF) and insulin-like growth factor-1 (IGF-1), which promote neurogenesis, neuronal development, cerebrovascular integrity [12–14], and neural plasticity, ultimately improving cognitive function [13, 15–17]. Therefore, regular exercise is essential in old age to prevent and mitigate declines in physical and cognitive function.

Aerobic exercise strengthens brain plasticity and contributes to cognitive improvement [18, 19]. Additionally, compared with low-intensity exercise, high-intensity exercise produces greater benefits for the cardiovascular, metabolic, and musculoskeletal health of older adults [18]. In this context, aquatic exercise serves as a safe and effective modality for older adults, especially those with lower-limb dysfunction or those at risk of osteoporosis, because it allows high-intensity training without imposing excessive joint stress [20, 21].

Numerous studies have examined aquatic exercise among older populations. However, most have either compared aquatic exercise with land-based or combined exercise [22–26] or investigated different exercise intensities within a single aquatic exercise [27–31]. Furthermore, research focusing on neurotrophic factors and cognitive function has primarily employed aquatic aerobics or resistance training with equipment or water resistance [31, 32]. Aquatic cycling training (ACT) has been identified as an alternative that may improve cognitive function [33] as well as reduce joint load, thereby facilitating safe participation [34, 35]. Nevertheless, few studies have investigated ACT among older women [36]. Considering that the benefits for cognitive and various physical functions in older women may differ according to exercise intensity [8, 37, 38], further research is required to verify the effects of intensity on functional fitness, BDNF levels, and cognitive performance.

Therefore, this study examined the effects of ACT on muscle strength, cardiorespiratory fitness (CRF), neurotrophic factors (BDNF and IGF-1), and cognitive function among older women. With this aim, we sought to provide empirical evidence of ACT as a safe exercise prescription that prevents and improves age-related cognitive decline, thereby promoting health and independence in later life.

Methods

Participants

A total of 40 women aged 65–74 years were recruited from A Sports Center in Hanam, Gyeonggi Province, and randomly assigned to four groups: high-intensity interval ACT group (HIIT group; n = 10), moderate-intensity continuous ACT group (MICT group; n = 10), progressive-intensity ACT group (PICT group; n = 10), and control group (n = 10). To ensure unbiased allocation, a simple randomization was performed by drawing numbered lots from an opaque container. Individuals were excluded if they had engaged in regular exercise within the previous 6 months; had received pharmacological treatment for cardiovascular disease; had uncontrolled hypertension; had used sex hormones or other relevant medication; or experienced chest pain, dyspnea, arrhythmia, or musculoskeletal disorders during exercise. Table 1 lists the demographic and physical characteristics of the final sample. This study was approved by the Institutional Review Board (IRB) of Korea National Sport University (No. 20210817-116) and conducted in accordance with the ethical principles of the Declaration of Helsinki. There were no important changes to the methods after trial commencement.

Table 1
Demographic and physical characteristics of the participants

Group	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m2)	Body fat (%)
HIIT	70.30 ± 2.75	154.80 ± 6.25	53.21 ± 2.87	23.12 ± 2.06	32.80 ± 3.96
MICT	70.20 ± 2.53	155.02 ± 8.02	57.34 ± 7.15	23.78 ± 0.77	32.85 ± 0.80
PICT	69.40 ± 3.20	154.44 ± 8.13	57.60 ± 6.32	24.74 ± 1.65	31.04 ± 3.50
Control	70.00 ± 2.82	151.80 ± 6.18	54.64 ± 4.60	23.12 ± 2.06	32.80 ± 3.96
p	0.899	0.733	0.244	0.134	0.588

Values are presented as the mean ± SD

HIIT: high-intensity interval aquatic cycling training, MICT: moderate-intensity continuous aquatic cycling training, PICT: progressive-intensity aquatic cycling training

Exercise Program

Following orientation, intensity setting, and adaptation sessions, ACT was performed three times weekly for 16 weeks. All steps were conducted under controlled conditions (indoor temperature, 33–35°C; humidity, 70–75%; water temperature, 30–31°C; water depth, 1.2 m). Participants used an Aquabike V4 (AquaNess, France), with submersion between the navel and sternum. Each session comprised a 10-min warm-up, 30-min primary exercise, and 10-min cool-down. Warm-up and cool-down included slow forward/backward pedaling and static stretching. The exercise intensity was set based on the heart rate reserve (HRR) of each individual, which was derived from their maximal heart rate during a graded

exercise test. Heart rate was continuously monitored (Polar RS400sd, USA), recording peak and average values. The program was adapted from Rewald, Mesters [35]. Figure 1 shows the protocol of high-intensity interval ACT, moderate-intensity continuous ACT, and progressive-intensity ACT.

The protocol for the HIIT group was adapted from Keogh et al. [39]. We alternated 85% HRR (high) and 40% HRR (low), with 30-s bouts at up to 110 rpm, followed by 90 s at < 70 rpm, for a total of 30 min. In the MICT group, participants cycled continuously at approximately 60% HRR, with a rating of perceived exertion (RPE) of 12–14, at 60–80 rpm for a total of 30 min [39]. In the PICT group, the exercise intensity increased every 4 weeks [40]: 40–50% HRR during weeks 1–4; 50–60% HRR during weeks 5–8; 60–65% HRR during weeks 9–12; and 65–75% HRR during weeks 13–16.

Measurements

Body Composition

Weight and height were measured (Jenix, Seoul, Republic of Korea), and BMI was calculated (kg/m²). Body composition was determined using bioelectrical impedance analysis (X-Scan II, Jawon Medical, Republic of Korea).

Muscle Strength

Muscle strength was determined by assessing the isokinetic knee strength of participants (Biodex System 3, USA). After warm-up, participants were aligned with the dynamometer axis and stabilized using Velcro straps. Then, we performed three maximal extension/flexion trials at 60°/s.

Cardiorespiratory Fitness

CRF was evaluated with an automated gas-analysis system (Q4500, Quinton, Bothell, WA, USA), using a modified Balke treadmill protocol to assess maximal oxygen uptake (VO_2max). Termination criteria included a respiratory exchange ratio (RER) of > 1.15, heart rate (HR) of ≥ 90% of the age-predicted maximum (220 − age), or the request of the participant to stop.

BDNF and IGF-1

After an overnight fast of at least 8 h, venous blood was collected from the participants. BDNF was measured using Total BDNF Quantikine ELISA (R&D Systems, Minneapolis, MN, USA) and spectrophotometry (Thermo Scientific Multiskan Go). IGF-1 was measured by operating the LIAISON IGF-1 kit (DiaSorin, Saluggia, Italy) on the Liaison XL analyzer (DiaSorin, Stillwater, MN, USA) using chemiluminescent immunoassay.

Cognitive Function

Cognitive function was assessed using the Mini-Mental State Examination (MMSE). In particular, we used the standardized Korean version of the MMSE (MMSE-K), which was translated and validated by Folstein [41]. Item scoring included adjustments for illiteracy (+ 1 orientation; +2 attention/calculation; +1 language). The assessment utilizes a 30-point scale (0–30), where elevated scores are directly associated with superior cognitive performance. Scores of ≤ 23 indicate cognitive impairment.

Statistical Analysis

The required sample size was determined using G*Power 3.1.9.7. To detect a within-between interaction effect in a two-way repeated measures (RM) analysis of variance (ANOVA), the calculation was based on a medium effect size (f) of 0.25, a significance level (α) of 0.05, and a statistical power (1- β) of 0.70. Because of the four groups, two measurement points, and a correlation of 0.5 among RM, the minimum sample size was identified as 40 (n = 10 per group).

All data were analyzed using SPSS for Windows version 21.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were determined and reported as the mean ± standard deviation (SD). A two-way RM ANOVA was performed to determine group (HIIT, MICT, PICT, and control) × time (pre and post) effects. When significant primary or interaction effects were detected, post-hoc analyses were performed. Statistical significance was consistently set at $\alpha = 0.05$.

Results

Change in Muscle Strength Based on ACT Intensity

A two-way RM ANOVA of knee extensor strength showed a significant interaction effect ($p < 0.001$) and significant primary effects of both group and time (both $p < 0.001$; Table 2). Paired t-tests indicated significant pre-to-post increases in the HIIT, PICT, and MICT groups ($p < 0.01$). Between-group differences post-intervention were significant ($p < 0.01$). Regarding knee flexor strength, a significant interaction effect ($p < 0.01$) and a significant primary effect of time ($p < 0.01$) were observed. Paired t-tests showed significant gains in the HIIT and PICT groups ($p < 0.01$). Between-group differences post-intervention were significant ($p < 0.01$).

Table 2
Changes in muscle strength based on aquatic cycling training intensity

		Pre	Post‡	*Δ%*		*F*	*p*	*Post-hoc*
Knee extensor strength (%BW)	HIIT[a]	106.32 ± 5.36	151.98 ± 18.66†	42.94	G	22.400	0.001**	d < b<a, c
	MICT[b]	106.46 ± 5.28	122.80 ± 12.53†	15.34	T	138.452	0.001**	
	PICT[c]	106.28 ± 5.41	150.50 ± 10.63†	41.60	G*T	29.262	0.001**	
	Control[d]	108.02 ± 4.81	105.62 ± 9.68	-2.24				
Knee flexor strength (%BW)	HIIT[a]	53.48 ± 2.66	70.16 ± 10.85†	31.18	G	1.646	0.196	NS
	MICT[b]	55.80 ± 17.73	58.91 ± 9.58	5.57	T	18.983	0.001**	
	PICT[c]	54.98 ± 13.60	70.22 ± 13.41†	27.71	G*T	5.464	0.003**	
	Control[d]	53.55 ± 15.58	52.01 ± 12.51	-2.87				

Values are presented as the mean ± SD

G: group; T: time; G*T: group*time; Δ%=[(post - pre)/pre] × 100

HIIT: high-intensity interval aquatic cycling training, MICT: moderate-intensity continuous aquatic cycling training, PICT: progressive-intensity aquatic cycling training

† difference between pre- and post-test, ‡ difference between groups

*p < 0.05, **p < 0.01, ***p < 0.001

Changes in Cardiorespiratory Fitness based on ACT Intensity

A two-way RM ANOVA of CRF revealed no significant interaction effect (p > 0.05; Table 3).

Table 3
Changes in cardiorespiratory fitness based on aquatic cycling training intensity

	Pre	Post‡	*Δ%*		*F*	*p*	*Post-hoc*
HIIT[a]	22.68 ± 3.06	22.98 ± 2.57	1.32	*G*	0.176	0.001**	NS
MICT[b]	22.26 ± 2.11	22.56 ± 2.64	1.34	*T*	0.733	0.398	
PICT[c]	22.91 ± 2.40	23.32 ± 1.88	1.78	*G*T*	0.538	0.660	
Control[d]	22.90 ± 1.29	22.62 ± 1.82	-1.22				

Values are presented as mean ± SD

G: group; T: time; G*T: group*time; Δ%=[(post - pre)/pre] × 100

HIIT: high-intensity interval aquatic cycling training, MICT: moderate-intensity continuous aquatic cycling training, PICT: progressive-intensity aquatic cycling training

†difference between pre- and post-test, ‡ difference between groups

*p < 0.05, **p < 0.01, ***p < 0.001

Changes in BDNF Based on ACT Intensity

A two-way RM ANOVA of BDNF indicated a significant interaction effect ($p < 0.05$) and significant primary effects of both group ($p < 0.05$) and time ($p < 0.01$; Table 4). Paired t-tests showed significant pre-to-post increases in BDNF in the HIIT, MICT, and PICT groups ($p < 0.01$). Between-group differences post-intervention were significant ($p < 0.01$).

Table 4
Changes in BDNF based on aquatic cycling training intensity

	Pre	Post‡	*Δ%*		*F*	*p*	*Post-hoc*
HIIT[a]	18636.87 ± 1971.26	24266.86 ± 2656.18†	30.20	*G*	3.222	0.034*	b,d < a<c
MICT[b]	18473.27 ± 3696.37	23067.27 ± 2431.21†	24.86	*T*	45.068	0.001**	
PICT[c]	18618.97 ± 2742.43	24906.24 ± 2908.10†	33.76	*G*T*	3.462	0.026*	
Control[d]	18518.97 ± 2998.61	19406.24 ± 4135.04	4.79				

Values are presented as the mean ± SD

G: group; T: time; G*T: group*time; Δ%=[(post - pre)/pre] × 100

HIIT: high-intensity interval aquatic cycling training, MICT: moderate-intensity continuous aquatic cycling training, PICT: progressive-intensity aquatic cycling training

† difference between pre- and post-test, ‡ difference between groups

*p < 0.05, **p < 0.01, ***p < 0.001

Changes in IGF-1 Based on ACT Intensity

Two-way RM ANOVA of IGF-1 showed a significant interaction effect ($p < 0.01$) and a significant primary effect of time ($p < 0.01$; Table 5). Paired t-tests revealed significant pre-to-post increases in IGF-1 in the HIIT, MICT, and PICT groups ($p < 0.01$). Between-group differences post-intervention were significant ($p < 0.01$).

Table 5
Changes in IGF-1 based on aquatic cycling training intensity

	Pre	Post‡	*Δ%*		*F*	*p*	*Post-hoc*
HIIT[a]	115.02 ± 16.69	151.73 ± 11.12†	31.91	*G*	2.395	0.084	b,d < a,c
MICT[b]	118.44 ± 16.52	140.81 ± 17.87†	18.88	*T*	91.022	0.001**	
PICT[c]	117.68 ± 26.21	154.62 ± 16.86†	31.39	*G*T*	12.725	0.001**	
Control[d]	118.58 ± 17.07	117.72 ± 18.21	-0.72				

Values are presented as the mean ± SD

G: group; T: time; G*T: group*time; *Δ%*=[(post - pre)/pre] × 100

HIIT: high-intensity interval aquatic cycling training, MICT: moderate-intensity continuous aquatic cycling training, PICT: progressive-intensity aquatic cycling training

† difference between pre- and post-test, ‡ difference between groups

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Changes in Cognitive Function Based on ACT Intensity

A two-way RM ANOVA of MMSE scores identified a significant interaction effect ($p < 0.05$) and a significant primary effect of time ($p < 0.01$; Table 6). Paired t-tests showed that MMSE scores increased significantly in the HIIT ($p < 0.01$), PICT ($p < 0.01$), and MICT groups ($p < 0.05$). Between-group differences post-intervention were significant ($p < 0.01$).

Table 6
Changes in cognitive function based on aquatic cycling training intensity

	Pre	Post‡	Δ%		F	p	Post-hoc
HIIT[a]	24.40 ± 2.75	28.20 ± 1.31†	15.57	*G*	1.129	0.250	NS
MICT[b]	24.60 ± 2.87	27.10 ± 2.88†	10.16	*T*	35.349	0.001**	
PICT[c]	24.30 ± 3.74	28.30 ± 1.33†	16.46	*G*T*	3.675	0.006*	
Control[d]	24.35 ± 3.09	24.20 ± 2.61	-0.61				

Values are presented as the mean ± SD

G: group; T: time; G*T: group*time; $\Delta\% = [(\text{post} - \text{pre}) / \text{pre}] \times 100$

HIIT: High-intensity interval aquatic cycling training, MICT: Moderate-intensity continuous aquatic cycling training, PICT: Progressive-intensity aquatic cycling training, CG: control group

†difference between pre- and post- test, ‡difference between groups

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Discussion

This study investigated the effects of ACT at different intensities on functional fitness, BDNF, IGF-1, and cognitive function among older women. Functional fitness, encompassing muscle strength, CRF, flexibility, agility, and balance, is essential for independent living [42]; however, it declines with aging [43]. Aquatic exercise leverages buoyancy (reducing joint loading) and multidirectional resistance (increasing energy cost and heart-rate response) to improve physical function [44], thus making it suitable for insufficiently active older adults [45].

In this study, moderate-intensity continuous ACT significantly improved knee extensor strength but did not induce significant gains in knee flexor strength. Notably, progressive-intensity ACT improved both extensors and flexors. These findings align with prior reports revealing that appropriately loaded, faster-paced aquatic exercise enhances strength and functional fitness among older women [30, 46]. ACT promotes core stability and closed-kinetic-chain movement patterns, which can enhance balance, improve gait, and reduce the risk of falls.

Although no significant between-group differences were observed for CRF, all training groups showed rising statistics. Literature indicates that high-intensity interval training, dynamic, whole-body work involving upper and lower limbs, improves aerobic capacity and CRF [47]. It also reports that progressive aquatic resistance/interval training benefits cardiovascular health and fitness [48–52]. Therefore, high-

intensity interval ACT, moderate-intensity continuous ACT, and progressive-intensity ACT all appear effective for improving physical fitness among older women; however, further research is warranted to refine training intensity, frequency, duration, and modality.

BDNF increased significantly across all training groups, with some intensity-based differences. This result is consistent with the notion that BDNF responses dependent on intensity [53, 54]. Because of the central role of BDNF in neuroplasticity and cognition and its age-related decline [7, 55], regular exercise-induced increases are meaningful for cognitive health [56–60]. Similar to BDNF, IGF-1 increased significantly across all groups, with larger gains in the HIIT and PICT groups. Because IGF-1 supports muscle maintenance, metabolism, and strength but declines with age [61–63], exercise-related upregulation, especially at higher intensities, aligns with prior findings [64, 65]. The energetic demands of water-based training (arising from buoyancy and multidirectional resistance) may further stimulate IGF-1 [66], thereby supporting neural plasticity and cognitive improvement [20, 67].

MMSE scores improved significantly across all training groups, with no differences based on intensity. This finding aligns with previous research reporting that aquatic aerobics and psychomotor programs enhance cognition among older adults [32, 68–70]. In this study, ACT incorporated various upper-limb patterns in addition to pedaling, thus providing diverse, repetitive stimuli that may have supported cognitive gains. Accordingly, ACT aimed at cognitive improvement should pair sufficient repetition with varied motor challenges.

Overall, intensity-specific ACT improved muscular function, neurotrophic profiles (IGF-1 and BDNF), and cognitive function among older women. The aquatic environment minimized joint stress, while supporting strength gains. These findings reveal that ACT may be a viable strategy to prevent age-related muscle loss, maintain independence, and promote healthy aging. In addition, its multimodal sensory input may enhance cognitive outcomes.

Conclusions

Over 16 weeks, high-intensity interval ACT, moderate-intensity continuous ACT, and progressive-intensity ACT all improved isokinetic knee extensor strength. Knee flexor strength improved markedly with high-intensity interval ACT and progressive-intensity ACT (and to a lesser extent with moderate-intensity continuous ACT). BDNF and IGF-1 increased significantly across all training groups. Cognitive function improved across groups without intensity-based differences. These findings indicate that, irrespective of intensity, ACT enhances muscular fitness and promotes neuroplasticity (through increased BDNF and IGF-1), thereby contributing to improved cognitive function among older women.

Abbreviations

ACT aquatic cycling training

BDNF brain-derived neurotrophic factor

IGF-1 insulin-like growth factor-1

CRF cardiorespiratory fitness

HRR heart rate reserve

PICT progressive-intensity training

HIIT high-intensity interval training

MMSE mini-mental state examination

MICT moderate-intensity continuous

RPE rating of perceived exertion

Declarations

Ethics approval and consent to participate

Write text here Ethical approval for this study was obtained from the Institutional Review Board of Korea National Sport University (No. 20210817-116). All subjects voluntarily signed a written informed consent form before participating, having been fully briefed on the research objectives and protocols.

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Clinical trial number

Not applicable

Competing interests

The authors declare no conflicts of interest.

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Author Contributions

Conceptualization, C.Y., G.H.; methodology, C.Y., T.K.; investigation, C.Y., J.P, T.K. and G.H; data curation: J.P; writing—original draft preparation, C.Y.; writing—editing, T.K., G.H.; project administration, C.Y.

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Figures

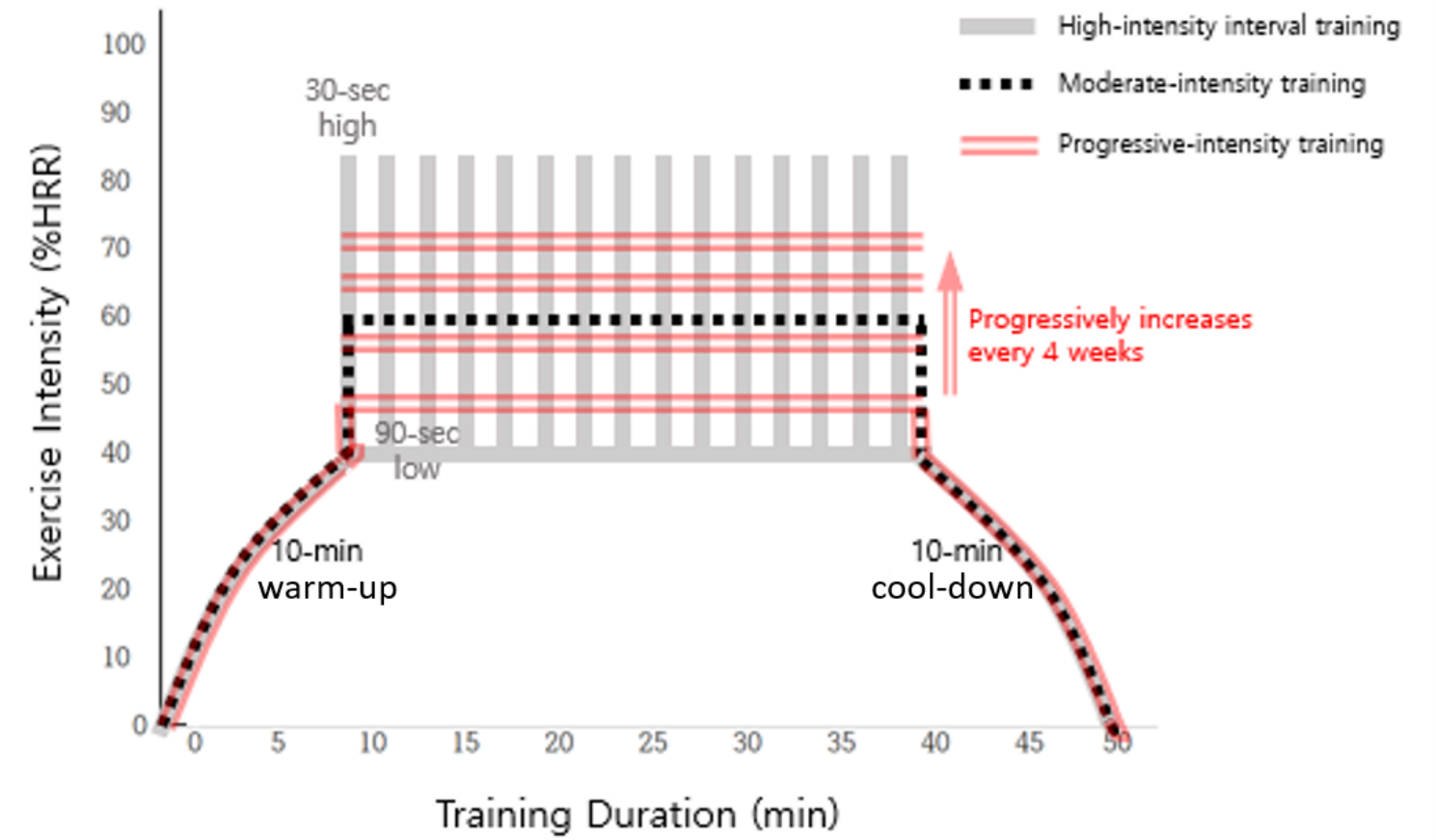


Figure 1

Protocol of the aquatic cycling training program