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Original Article

Supramaximal vs Functional High-Intensity Interval Training Effects on Macrovascular Reactivity in Young Male Athletes

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Abstract

To investigate the effects of supramaximal high-intensity interval training (SIT) vs functional high-intensity interval training (FIT) on sports performance, oxidative stress, and acute and chronic flow-mediated dilatation (FMD) were observed. Forty-five young male athletes were randomly allocated to control (CON), SIT, and FIT groups. The SIT program consisted of 10 sets of 30 s of cycle ergometry at 170 % of VO_{2peak} alternating with 30 s rest periods. The FIT program consisted of 10 training postures of 30 s alternating with 30 s rest periods, matching the SIT in energy expenditure and duration of training session. Both SIT and FIT groups underwent training 3 times per week for 10 weeks. Maximal oxygen consumption increased significantly in both SIT and FIT groups relative to pre-test status and the CON group (P<0.05), while the height of counter movement jump increased only in the FIT group. FMD increased significantly with 10 weeks of training in both groups relative to pre-test and the CON group. Only the FIT group had increased FMD at 5 min after training in post-test (P<0.05). Plasma malondialdehyde decreased significantly only in the FIT group (P<0.05). In conclusion, both SIT and FIT programs exerted beneficial effects on health-related physical fitness and FMD. However, the FIT program generated superior results in counter movement jump and acute FMD.

Keywords: flow-mediated dilatation, supramaximal high-intensity interval training, functional high-intensity interval training, oxidative stress

1. Introduction

The aim of this study was to examine the effects of SIT and FIT programs on sport performance, oxidative stress, and acute and chronic FMD in young male athletes. These two programs were designed to have similar energy expenditure and duration per training session. We believe that the FIT program was superior and should be practical for athletes.

Endothelial dysfunction takes place in the early development of atherosclerotic process, and increases cardiovascular risk (Endermann & Schiffrin, 2004). The pathophysiology of endothelial dysfunction is complex and relates to impairment of nitric oxide (NO) availability, and oxidative excess (Endermann & Schiffrin, 2004; Virdis, Ghiadoni, Giannarelli, & Taddei, 2010). Aerobic exercise is a potent strategy to enhance vascular endothelial function through several pathways, such as 1) the improvement of brachial artery flow-mediated dilatation (FMD), which is a non-invasive evaluation of endothelial function and NO dependent vasodilatation response (Betik, Luckham, & Hughson, 2003), 2) decreased level of malondialdehyde, an indicator of lipid peroxidation and oxidative stress (Mitranun, Deerochanawong, Tanaka, & Suksom, 2014), and 3) increased NO, a marker of endothelium-dependent vasodilatation (Ribeiro, Alves, Duarte, & Oliveira, 2010).

Traditional aerobic exercise training with moderate continuous intensity and 30-47 min/session has been reported to favorably affect vascular reactivity in several studies (DeSouza *et al*., 2000; Mitranun *et al*., 2014; Wisloff

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et al., 2007). The American College of Sports Medicine additionally recommends for most individuals to accumulate at least 150 minutes of aerobic exercise per week for optimal cardiovascular risk reduction (American College of Sports Medicine, 2013). However, high intensity aerobic exercise training has given superior results in cardiovascular risk reduction over low or moderate intensity (Lee, Sesso, Oguma, & Paffenbarger, 2003; Tanasescu *et al*., 2002). In fact, it would be difficult to maintain high intensity throughout an exercise period. Thus, interval aerobic training, repeated bouts of high intensity alternating with periods of recovery, has emerged in the recent years , and has shown notable results on endothelial function in patients with heart failure (Wisloff *et al*., 2007), metabolic syndrome (Tjonna *et al*., 2008), and type 2 diabetes (Mitranun *et al*., 2014).

Supramaximal high-intensity interval training (SIT) relates to interval training exceeding some maximal sustainable point , which can be VO2 peak (Tabata *et al*., 1996) or average speed (Cicioni-Kolsky, Lorenzen, Williams, & Kemp, 2013). SIT has shorter duration training sessions than ordinary interval training (Brestoff *et al*., 2009; Chuensiri, Tanaka, & Suksom, 2015; Tabata *et al*., 1996). A recent study on the acute effects of SIT at 170 % of VO2 max in obese prepubescent boys demonstrated greater improvement in vascular function (higher FMD) than SIT at 130 % of VO2 peak (Cheunsiri *et al*., 2015). Habitual SIT at 170 % for 6 weeks in young males promoted both anaerobic capacity and VO2max (Tabata *et al.*, 1996). However, the training effects of SIT on both acute and chronic FMD, oxidative stress, and its underlying mechanisms are unclear in young athletes.

Functional high-intensity interval training (FIT), our novel training program, consisted of 10 training postures in each set, with 10 sets and 30 s per set, alternating with 30 s rest periods; this simulated the bouts and pattern of SIT. Each training posture in the FIT program was selected to improve sport performance. In addition, a study of the local vascular function in acute training demonstrated significantly reduced FMD following slow contraction, but no such change following fast contraction in inactive persons (Gonzales, Thompson, Thistlethwaite, & Scheuermann, 2011). FIT generates more intense muscle contractions than SIT, and may have more favorable effects on FMD in young athletes as well.

2. Material and Methods

2.1 Participants

A total of 48 young male athletes were recruited from three sports teams in Srinakharinwirot University, Nakhon Nayok, Thailand. They consisted of 15 futsal athletes, 16 soccer athletes, and 17 Rugby athletes. The inclusion criteria included being well-trained and non-smoking males who were 18-22 years of age. The body mass index (BMI) of these athletes was from 18.5 to 24.9 kg/m^2. All participants usually had regular exercise on 5-6 days a week (for at least 3 years) and were free from cardiovascular disease, cerebrovascular disease, and any recent serious injury. The present study was approved by the Ethics Committee of Srinakharinwirot University, Thailand, and was conducted according to the Helsinki Declaration. Informed consent was obtained from all participants.

The eligible participants were stratified by type of sports and randomly allocated into three groups: control (CON), supramaximal high-intensity interval training (SIT), and functional high-intensity interval training (FIT). Participants were excluded if they dropped out or completed less than 80% of the training schedule. By the end of the study, one subject had dropped out from each exercise group. Thus, the remaining athletes were 15 participants in the CON group (5 futsal athletes, 5 soccer athletes, rugby athletes), 15 participants in the SIT group (5 futsal athletes, 5 soccer athletes, 5 rugby athletes), and 15 participants in the FIT group (4 futsal athletes, 5 soccer athletes, 6 rugby athletes).

2.2 Training intervention

All participants were advised to maintain their routine sport activity. In addition, both trained groups, SIT and FIT, were assigned to undergo training programs for 20 min/day, 3 times a week for 10 weeks. The SIT and FIT training programs were designed to have the same energy expenditure/oxygen consumption and duration per training session. Gas analyzer system (Oxycon Mobile, Jaeger®, CareFusion GmbH, Hoechberg, Germany) was used to control that equality. To ensure that the participants performed at the target training intensity and target heart rate, both programs were observed in every exercise session and total oxygen consumption was measured every two weeks.

The SIT program: In the training session, the participants were asked to perform on an Ergomedic 894E cycle ergometer (Monark, Vansbro, Sweden). They warmed up gradually to achieve 50% of the peak oxygen consumption (VO2 peak) within 5 min, then performed in intervals ten 30-sec high-intensity training bouts at 170% of their VO2 peak with 30-sec rest period, and a 5-min cool-down period. The total training duration was 20 min and the oxygen consumption was 28.5 ± 0.6 L.

The FIT program: In the training session, participants were asked to perform 10 sport specific training postures as follows:

Lunge with medicine ball: Participants started with standing position and held a 5-kg medicine ball with both hands at horizontal level of the chest and stepped forward with their left leg. They maintained the upper body in a vertical position and stepped back to the starting position. The participants repeated this posture with their right leg and then alternated between the legs for 30 s. The distance of the step was approximately the range from greater trochanter to the ground, which was measured in the standing position.

Squat jump with medicine ball: Participants started with a standing position and held a 5-kg medicine ball with both hands at horizontal level of the chest. The whole body was engaged in the regular squat position, both knees and hips underwent flexion until both thighs were parallel to the ground. Explosively, they jumped forcefully off the ground into the air. On landing, they turned back to the squat position and repeated the jump for 30 s.

Burpee: Participants started with standing position and then dropped the whole body into a squat position with both hands on the ground. Kicking both feet back into a plank position and keeping both arms extended. Immediately returning both feet to the squat position they jumped up forcefully off the ground into the air with both upper extremities extended over the head. On landing, they turned back to a squat position, then standing position, and repeated the Burpee for 30 s.

Three cone agility: Three cones were placed in a straight line with 50 cm spacing. Participants started to run rapidly to the left side of the first cone, turned to the right side of the second cone, and then turned to the left side of the third cone. Participants immediately turned around and faced the third cone, then started to run to the left side of the third cone, turned to the right side of the second cone and started to the left side of the first cone, and turned around to the starting position. Participants repeated this posture for 30 s.

Jump squat twist with medicine ball: Participants started in a squat position with a 5-kg medicine ball held with both hands at horizontal level of the chest. They jumped rapidly on the right side, rotated the whole body in the opposite direction (180 degrees from starting position), and landed in squat position. Instantly, participants jumped and rotated again to the starting position. This posture was repeated for 30 s.

Side jump: A small cone of 15 cm height was placed on the ground. Participants stood at the right side of the cone and then jumped over the cone to the left side. Immediately they jumped over again to the starting position. The feet were kept close together throughout this training. Participants repeated this posture for 30 s.

Lunge twist with medicine ball: Participants started in standing position and held a 5-kg medicine ball with both hands at horizontal level of the chest. They stepped forward with their left leg and rotated their trunk to the right side. Participants maintained the upper body in a vertical position and stepped back to the starting position. Immediately they did the same but on the opposite side, and repeated this for 30 s. The distance of the step was approximately the range from the greater trochanter to the ground, which was measured in the standing position.

Depth jump: A small box, 30 cm x 30 cm x 45 cm (width x length x height), was placed on the ground. Participants stood on the box close to the front edge, stepped off the box, and landed in a squatting position. Rapidly, they jumped forcefully off the ground into the air stretching both upper extremities over their head. On landing, they turned back to squatting and standing positions respectively. Participants then returned back behind the box, stepped on it, and repeated this posture for 30 s.

Knee tuck jump: Participants started in standing position with both knees slightly bent, holding both hands out with palms downward at the level of chest height. Rapidly they dipped dow into squat position and immediately exploded upward. Driving both knees towards the chest (hip flexion) they attempted to touch up to the palms of their hands by jumping as high as possible and raising both knees up. On landing, they returned back to the squat position and repeated the jump for 30 s.

Pattern-X on 3-by-3 grid: A 75 cm x 75 cm grid of 9 squares was drawn on the ground. Participants were assigned to stand in the middle of the grid. They started to step forward to the right upper square with the right foot and step forward to the left upper square with the left foot respectively. Then, they returned the right foot to the middle of the table and followed by the left foot afterwards. Immediately, participants stepped back to the right lower square with the right foot and stepped back to the left lower square with the left foot. Finally, they returned the right and the left foot to the middle of the table to the starting position. This posture was repeated for 30 s.

The participants in the FIT group warmed up gradually to achieve 50% of VO2 peak within 5 min by jogging, then performed intervals of ten 30-sec high-intensity training postures with 30-sec rest periods. The exercise session was concluded with a 5-mincool-down. The participants were instructed to perform training near the maximal exertion. The total training duration was 20 min and the total oxygen consumption was 28.1 ± 0.1 L.

2.3 Measurements

All participants were asked to allow measurements of health and skill-related physical fitness data, blood biochemistry data, and brachial artery flow-mediated dilatation data. On the first day, after 8 hours of overnight fasting, venous blood samples were collected from the antecubital vein. Blood samplings was performed at the same time of the day (e.g., 7:30 AM) for the baseline and after training, in order to avoid diurnal variations of blood chemistry. Two hours after breakfast the participants were subjected to collection of biological data, and health and skill-related physical fitness assessments. On the second day, flow-mediated dilatation data were assessed before and immediately after performing SIT or FIT programs. After 10 weeks, all the measurements were repeated 72 after the last bout of exercise training, in order to avoid the acute effects of training.

2.4 Health and skill-related physical fitness measures

Body fat was determined with a body composition analyzer (Omron BF511, Omron Healthcare Europe B.V., Hoofddorp, Netherlands). All participants were asked to remain in supine position for at least 5 minutes as a rest period prior to the measurement. Heart rate and blood pressure were measured using a digital blood pressure monitor (Omron M2, Omron Healthcare Europe B.V., Hoofddorp, Netherlands) and the mean arterial pressure (MAP) was calculated by the formula MAP=1/3 x [systolic blood pressure – diastolic blood pressure] + diastolic blood pressure.

To determine the VO2 peak, all participants were subjected to a standard graded exercise protocol on an Ergomedic 894E cycle ergometer (Monark, Vansbro, Sweden) at least 7 days before the 1st day of exercise training intervention. The participants warmed up at 50 W for 5 min, power started at 100 W, and 50 W increments were applied every 2 min until volitional exhaustion. Pedaling frequency was controlled in range of 70-90 rpm and was terminated when below 70 rpm for longer than 30 s. VO2 peak was measured with the gas analyzer system throughout the exercise test. Heart rate was measured with a Polar heart rate monitor (Polar Team 2 Pro, Polar Electro Inc., Lake Success, NY, USA).

Agility T-test was recorded by using an electronic timing system (Smartspeed, Fusion Sport, Australia) two hours after the completion of VO2 peak measurements. At the starting line, both electronic timing system sensors were set 0.75 cm above the ground with 3 m distance between them. The test was based on the modified agility T-test protocol (Sassi *et al*., 2009) and the time (s) of test recorded was the lower value from two trials.

Counter movement jump (CMJ) and squat jump (SJ) leg power measurements. The CMJ was performed on a jump mat (Smartjump, Fusion Sport, Australia). The participants started in standing position with hands on the waist without arms swinging, dropped the whole body into a semi-squat position and suddenly jumped in the air. The SJ was started in semi-squat position and hands on the waist without arms swinging. They performed maximal vertical jumps in the CMJ. The peak height recorded was the higher value from two trials, both in CMJ and SJ.

Trunk flexibility was assessed using a sit-and-reach box. Participants placed the left hand on top of the right, then bended the trunk forward and reached along the straight line of a sit-and-reach box, holding the position for 3 seconds. The largest distance from 3 trials was recorded.

2.5 Flow-mediated dilatation (FMD) measures

Brachial artery flow-mediated dilatation was measured with a portable ultrasound system (Vivid i-GE Healthcare, Cardiovascular Ultrasound System; GE Medical Systems, Tirat Carmel, Israel). All participants were asked to rest in supine position comfortably for 20 min and blood pressure cuff was placed around the right forearm throughout the measurement. The brachial artery was imaged above the antecubital fossa at 1 min baseline, 5 min occlusion and 5 min deflation (Corretti *et al*., 2002; Dhindsa *et al*., 2008). At the occlusion period, the cuff was inflated rapidly to 50 mmHg above systolic blood pressure. In all periods, brachial artery diameters were recorded by using B-mode, and a computer-based analysis program (Brachial Analyzer, Medical Imaging Applications, Coralville, IA, USA) was used for analyzing changes in brachial artery diameter. FMD was calculated using the formula FMD = (maximum diameter – baseline diameter) x 100/baseline diameter. FMD was determined 2 times in the CON group (weeks 1 and 11). For the SIT and FIT groups, FMD determination was performed 4 times. These included pre-test and within five minutes after the training on the first day of week 1, and three days (72 hours) after the last training on week 10 in a post-test, and within five minutes after the training (SIT or FIT) interventions.

2.6 Malondialdehyde (MDA) measures

Blood samples were collected to EDTA in a tube as whole blood samples. MDA concentration in the blood plasma was measured with high-performance liquid chromatography (HPLC) at a clinical laboratory (National Healthcare System Co. Ltd, Bangkok, Thailand).

2.7 Statistical analysis

The data are expressed as mean ± standard deviation. The significant differences between CON, SIT, and FIT groups were analyzed using two-way (group x time) analysis of variance with repeated measures, followed by Tukey's multiple comparison test. Differences with $P<0.05$ were considered statistically significant. Pearson correlations were assessed.

3. Results

The baseline data on participant characteristics are shown in Table 1. The three groups; CON, SIT, and FIT were well balanced regarding total number, age, height, body mass, body mass index, body fat, heart rate at rest, systolic blood pressure, diastolic blood pressure, and mean arterial pressure.

Table 1. Baseline data on participant characteristics

	CON	SIT	FIT
Total Number (n)	15	15	15
Age (years)	20.5 ± 1.0	20.2 ± 0.9	20.6 ± 1.0
Height (cm)	175.5 ± 5.8	173.3 ± 6.4	175.3 ± 5.9
Body mass (kg)	70.0 ± 7.1	72.7 ± 8.8	73.0 ± 7.2
Body mass index (kg/m^2)	22.4 ± 2.0	23.6 ± 2.9	23.7 ± 1.6
Body fat (%)	12.3 ± 1.1	11.9 ± 0.8	11.8 ± 1.0
Heart rate at rest	58.3 ± 6.0	56.0 ± 5.7	57.4 ± 4.9
Systolic blood pressure (mmHg)	115.3 ± 8.7	117.4 ± 7.9	118.9 ± 8.3
Diastolic blood pressure (mmHg)	71.4 ± 5.5	73.7 ± 4.9	72.9 ± 5.0
Mean arterial pressure (mmHg)	85.5 ± 5.9	88.2 ± 6.1	88.4 ± 5.7

Data are mean ± SD
CON = Control group; SIT = Supramaximal high-intensity interval training group;
FIT = Functional high-intensity interval training group

The changes in health and skill-related physical fitness data are shown in Table 2. Maximal O_2 consumption increased significantly in both SIT and FIT when compared to pre-test or the CON group (*P*<0.05). Counter movement jump (CMJ) increased significantly (*P*<0.05) only in the FIT group from pre-test. There were no significant changes in body mass, body mass index, percentage of body fat, heart rate at rest, systolic blood pressure, diastolic blood pressure, mean arterial pressure, trunk flexibility, agility t-test, or squat jump.

As illustrated in Figure 1, FMD increased significantly from baseline pre-test in both SIT and FIT groups, and also relative to the CON group (*P*<0.05). Both SIT and FIT groups showed increased FMD at 5 min after training from the pre-test (*P*<0.05). However, only the FIT group experienced increased FMD at 5 min after training in the post-test (*P*<0.05).

Significant reduction of plasma malondialdehyde (MDA) (*P*<0.05) was observed only for the FIT group (Figure 2), and the change of plasma MDA in post-test correlated negatively with the change in FMD from baseline (*r*= -0.69).

4. Discussion

The major findings of this study are that both SIT and FIT training were beneficial in improving health and skill-related physical fitness and FMD, and that FIT gave superior results in counter movement jump (CMJ), oxidative stress, and acute FMD after 10 weeks of training, despite SIT matching it in exercise session duration and energy expenditure. Our findings suggest FIT training with short exercise sessions as an additional training program for athletes that could enhance sport performance, oxidative stress, and vascular function.

The effects of high-intensity interval training have been investigated in several studies of specific populations, and it appears to givein many aspects better results than ordinary aerobic training (Mitranun *et al.*, 2014; Tjonna *et al.*, 2008; Wisløff *et al.*, 2007). The previous studies had exercise duration varied from 30 min to 40 min. However, the metabolic changes might not differ in active subjects between low volume high-intensity interval training (long duration of resting period = 4.5 min/rest) and 40-60 min aerobic training with cycling (Burgomaster *et al.*, 2008). To our knowledge, no previous design of short duration training with a very high intensity for improving sport performance has been matched for exercise session duration and energy expenditure with the SIT program. The FIT program is such novel high-intensity interval training, and was designed for comparing its outcomes with the SIT program at 170 % of VO_2 peak. Both SIT and FIT groups in our study showed large changes in VO_2 peak from pre-test status and relative to the control group (VO_2 peak changes were 7.93 % in SIT group and 10.17 % in FIT group). In a previous study, five-weeks of high-intensity interval training (total training time 28.8 ± 1.7 min) of fourteen aged soccer players also showed improved oxygen consumption (VO_2 peak change 6.90%) (Sperlich *et al.*, 2011) despite the short 10 min training sessions. Thus, the SIT and FIT programs are important when training duration is restricted. Considering the potential mechanisms activated by both programs, the change in maximal oxygen consumption may be triggered by mitochondrial function in the metabolic pathway, i.e. PGC-1 alpha, a critical coordinator activating metabolic genes required for substrate utilization and mitochondrial biogenesis (Earnest, 2008). In high-intensity interval training, high correlation between VO_2 peak and PGC-1 alpha (*r*=0.71) has been reported (Wisløff et al., 2007).

Table 2. Health and skill-related physical fitness data

	CON (n = 15)		SIT (n = 15)		FIT (n = 15)	
	Pre	Post	Pre	Post	Pre	Post
Body mass (kg)	70.0 ± 7.1	70.4 ± 7.7	72.7 ± 8.8	72.3 ± 8.0	73.0 ± 7.2	72.7± 8.5
Body mass index (kg/m^2)	22.4 ± 2.0	22.7 ± 1.5	23.6 ± 2.9	23.1 ± 1.9	23.7 ± 1.6	23.4 ± 1.2
Body fat (%)	12.3 ± 1.1	12.6 ± 1.4	11.9 ± 0.8	11.5 ± 0.9	11.8 ± 1.0	11.6 ± 1.0
Heart rate at rest (bpm)	58.3 ± 6.0	56.4 ± 5.2	56.0 ± 5.7	55.2 ± 6.7	57.4 ± 4.9	56.6 ± 6.0
Systolic blood pressure (mmHg)	115.3 ± 8.7	114.7 ± 9.4	117.4 ± 7.9	118.3 ± 8.2	118.9 ± 8.3	116.9 ± 7.2
Diastolic blood pressure (mmHg)	71.4 ± 5.5	73.2 ± 5.8	73.7 ± 4.9	72.4 ± 6.2	72.9 ± 5.0	71.8 ± 6.6
Mean arterial pressure (mmHg)	85.5 ± 5.9	85.2 ± 7.1	88.2 ± 6.1	87.9 ± 8.0	88.4 ± 5.7	87.0 ± 7.3
Maximal O_2 consumption (VO_2 peak) (mL/kg/min)	45.0 ± 5.1	46.5 ± 4.6	47.9 ± 4.7	51.7 ± 4.1*†	47.2 ± 4.3	52.0 ± 4.2*†
Trunk flexibility (cm)	11.3 ± 4.9	9.9 ± 4.5	10.8 ± 4.0	10.7 ± 5.2	10.4 ± 4.3	10.8 ± 5.7
Agility T-test (s)	11.17 ± 1.16	10.6 ± 0.73	11.08 ± 1.04	10.71 ± 0.90	11.32 ± 0.81	10.66 ± 0.50
Counter movement jump (CMJ) (cm)	46.5 ± 6.5	48.1 ± 8.5	44.4 ± 5.1	43.4 ± 5.5	45.4 ± 5.6	48.4 ± 6.0*
Squat jump (SJ) (cm)	40.2 ± 5.6	40.6 ± 5.9	37.0 ± 4.4	38.0 ± 4.4	39.2 ± 3.4	40.2 ± 4.2

Data are given as mean ± SD
CON = Control group; SIT = Supramaximal high-intensity interval training group; FIT = Functional high-intensity interval training group
* *P* < 0.05 vs. Pre; † *P* < 0.05 vs. CON

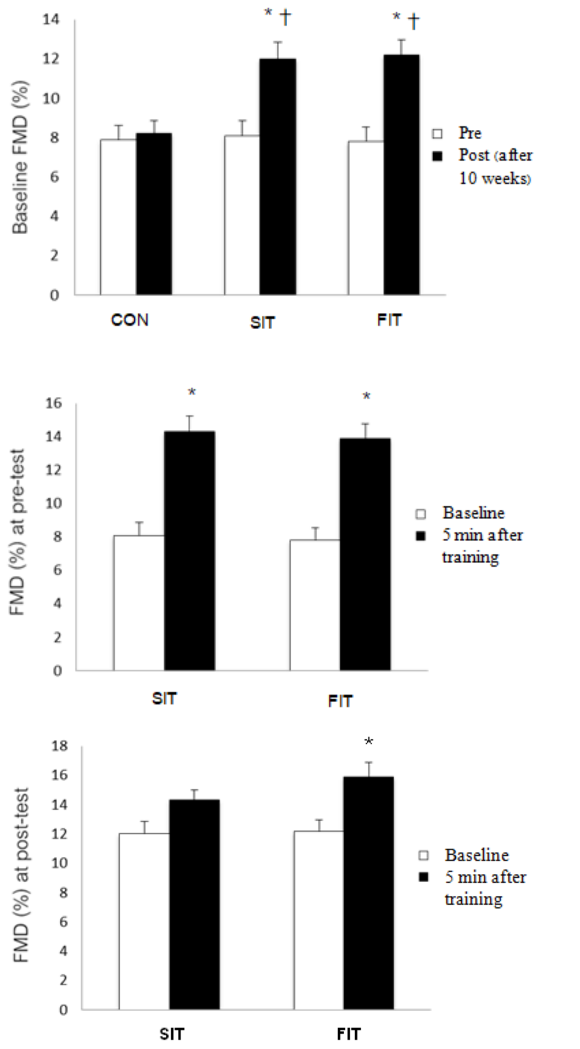

Figure 1. The Flow-mediated dilatation (FMD) in pre-test and post-test, FMD in pre-test (baseline and 5 min after training), FMD in post-test (baseline and 5 min after training). CON = Control group; SIT = Supramaximal high-intensity interval training group; FIT = Functional high-intensity interval training group. * $P < 0.05$ vs. Pre, † $P < 0.05$ vs. CON

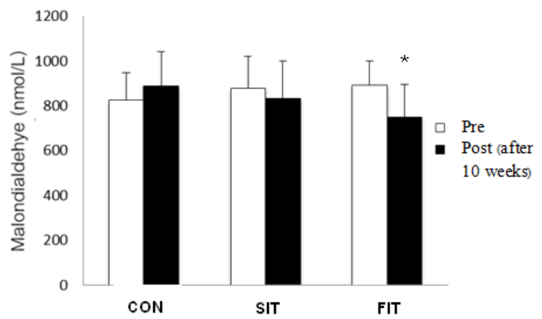

Figure 2. The plasma malondialdehyde (MDA) levels. CON = Control group; SIT = Supramaximal high-intensity interval training group; FIT = Functional high-intensity interval training group. * $P < 0.05$ vs. Pre

The FIT program in this study consisted of ten training postures that each were designed to improve sport performance (Markovic, Mirkov, Knezevic, & Jaric, 2013; Thomas, French, & Hayes, 2009). This combination of training postures in FIT induced improved CMJ (by 6.61%), which was not observed in the SIT group. In a previous study, depth jump, one of the postures in our FIT program, was shown to improve CMJ after 6 weeks of training in young soccer players (by 8%) (Thomas *et al*., 2009). The increased height of vertical jump may also result from squat jumps with medicine ball, which is supported by a previous study of jump training with different loads (Markovic *et al*., 2013). Consequently, the combination effects of these training postures might have caused the changes in CMJ.

FMD has emerged as a non-invasively determined indicator of endothelial function and nitric oxide dependent vasodilatation (Betik *et al*., 2003; Tinken *et al*., 2010). Increased FMD reflects increased shear stress, which activates endothelial nitric oxide synthase that releases nitric oxide (Deanfield *et al*., 2005). On seeking to improve vascular function, moderate intensity training might not increase the FMD in athletes due to unchanged peripheral vascular conductance (Carrick-Ranson *et al*., 2014; Fleg *et al*., 1994). In this study, FMD increased significantly with 10 weeks of training in both SIT and FIT groups from pre-test baseline and relative to the CON group. Both SIT and FIT groups showed increased FMD at 5 min after training in pre-test. Interestingly, the higher FMD at 5 min after training in post-test was observed only in FIT group.

In a recent study, the acute effects of high-intensity interval training at 170% VO_2 peak gave elevated FMD immediately after training (Chuensiri *et al*., 2015), while another report showed the opposite result (Rognmo *et al*., 2008). The shear stress pattern during training in both SIT and FIT groups might be of intermittent type. In a previous study of osteogenic differentiation of human mesenchymal stem cells, intermittent fluid shear stress gave stronger results than continuous shear stress (Liu *et al*., 2011). In this study significantly increased FMD at 5 min after training in post-test was observed only in the FIT group. This might be due to the different muscle contraction pathways that acute exercise affects; local vascular function showed significantly reduced FMD following slow contraction but no change following fast contractions, in active persons (Gonzales *et al*., 2011). In our study, the FIT group was exposed to more rapid contractions than the SIT group. Moreover, MDA level, a marker for oxidative stress and endothelial dysfunction (Kelishadi, Hashemi, Mohammadifard, Asgary, & Khavarian, 2008; Nielsen, Mikkelsen, Nielsen, Andersen, & Grandjean, 1997), was clearly diminished only in the FIT group. We also found that the change of FMD between baseline in pre-test and post-test was inversely correlated with the changes in MDA (r= -0.69). Consequently, the lower level of basal MDA after 10 weeks of training triggered a change in acute FMD in the post-test only in the FIT group. Even though acute FMD is related to oxidative stress reductin, further studies will could investigate the underlying mechanisms by which the FIT program affected acute FMD.

In summary, both supramaximal and functional high-intensity interval training programs have beneficial effects on health and skill-related physical fitness and on flow-mediated dilatation. However, the functional high-intensity interval training (FIT) gave superior results on counter movement jump, oxidative stress, and acute FMD after 10 weeks of training. With 20 min training sessions over 10 weeks, functional high-intensity interval training could improve sport performance, oxidative stress, and vascular function, and FIT should be recommended as an additional program for young male athletes to improve these parameters.

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