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Original article

HIGH-INTENSITY INTERVAL TRAINING: THE EFFECTS OF ACTIVE AND PASSIVE RECOVERY BOUTS ON PHYSIOLOGICAL INDICES IN VARSITY SOCCER PLAYERS

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ABSTRACT

This study aimed to compare the effects of high-intensity interval training with active or passive recovery on changes in physiological and performance indices in soccer players. **Methods:** A total of 22 male varsity soccer players were randomly allocated to either an active or passive recovery high-intensity interval training group. The participants in the active group completed5 x 30-sec treadmill running at 105% velocity of peak oxygen consumption with 30 seconds recovery at 60% ventilatory threshold interspersed between bouts. The participants in the passive group completed the same treadmill running protocol but with 30-secpassive recovery (rest) between bouts. Each group repeated their assigned protocol after 180-sec rest (i.e., inter-set rest). All participants performed the protocol twice per week over 6 weeks. Peak oxygen consumption, ventilatory threshold, and running anaerobic sprint test measures were recorded pre- and post-6 weeks of training. **Results:** There were no significant between-group differences in the change in peak oxygen consumption (difference = 1.40 $ml·kg^{-1}·min^{-1}$,*P*=0.319),ventilatory threshold (VT_1)(difference = 0.54 $ml·kg·min^{-1}$,*P*=0.786), or%HR_{max} at VT_1(difference = 2.19%, *P*=0.416,*d*=0.37) after 6 weeks of training. There were also no between-group differences in the change in peak power (difference = 36 W, *P*=0.271)fatigue index(difference =0.89 W/sec^{-1},*P*=0.274) or anaerobic capacity (difference = 274W, *P*=0.137).A significant difference in the change in average power was noted in the passive versus active group(52 W,*P*=0.044) during the running anaerobic sprint test. **Conclusion**: Performing active recovery after high-intensity work bouts result in similar improvements in physiological and performance indices compared with passive recovery in soccer players. However, as the practical significance of outcome measures was not determined, the absence of an effect cannot be completely excluded.

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KEYWORDS: HIIT/ RAST/ Aerobic capacity/ Anaerobic capacity/ Ventilatory threshold

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INTRODUCTION

High-intensity running is a valid measure of soccer performance with more intensive running observed in players at a higher level of competition[1].Accordingly, the ability to perform repeated bouts of high-intensity exercise is emphasized in strength and conditioning programs to maintain and/or improve the necessary physiological adaptations to enhance performance outcomes. However, in season, the time allocated to technical, tactical, and recovery training aspects reduces the ability to develop specific components of fitness[2]. Therefore, consideration must be given to which methods provide the greatest return for the time invested in developing targeted physiological attributes.

High-intensity interval training (HIIT) is widely applied in team sports due to its ability to induce training effects in a time-efficient manner. In regards to high-intensity exercise, there are several programming variables (work Interval intensity, work duration, relief interval intensity, relief intensity duration, exercise modality, number of repetitions, number of series, and between series recovery and duration), which can be manipulated to alter the physiological response upon the body and result in specific adaptations[3].The most important factors are related to the intensity and duration of the work intervals and relief intervals, respectively[2,4].If work bout intervals are too long in duration and/or intense, or if too little recovery is provided after completion of a work bout, it reduces the ability to complete a programmed HIIT session. Indeed, anaerobic work capacity can be affected when exercising above critical power/speed with too little recovery[5] due to failure in completing all prescribed work bouts in series; effectively reducing targeted training adaptations. Alternatively, accelerating clearance of blood lactate after intense exercise, in part due to oxidation of accumulated lactate (particularly in type 1 skeletal muscle fibers)[6], may impact the cascade of metabolic signaling processes that play an important role in attaining HIIT adaptations[7,8].

There has been a limited number of studies attempting to examine different HIIT recovery approaches, however, passive recovery during a single HIIT exercise session has been demonstrated to prolong the time to exhaustion and slow the rate of decrease in oxyhemoglobin compared with active recovery[9]. The lower metabolic power with passive recovery proposed to result in a higher reoxygenation of myoglobin and phosphocreatine resynthesis[9]. Similarly, Kriel et al[10] reported that passive recovery can lead to lower deoxyhemoglobin levels in the thigh and a higher mean power output during cycling. In contrast, Wiewelhove et al[8] investigated the effects of 4 weeks (12 sessions with passive recovery) of long-interval (>60 sec) treadmill HIIT sessions on blood lactate levels with either active or passive recovery applied at the end of the final HIIT bout (15 min as a cool down). It was found that active recovery did not attenuate training adaptations and led to a higher anaerobic threshold at the end of the training program. Therefore, facilitating the removal of accumulated lactate via active recovery did not appear to attenuate training adaptation. The continuation of training at low intensity was proposed to activate specific adaptive mechanisms not produced with passive recovery. Despite the aforementioned findings, only a limited number of longitudinal studies have examined active and passive recovery on physiological and performance indices; thus, the optimal HIIT recovery method to use between work bouts remains to be substantiated.

We aimed to compare the effects of 6 weeks of HIIT training with active or passive recovery on changes in key physiological and performance indices in soccer players. We hypothesized that performing active recovery between HIIT work bouts would result in greater improvements in physiological and performance measures compared to passive recovery after 6 weeks of training.

METHODS

Participants: Twenty-two varsity soccer players (mean±SD: age,19.68±1.52yrs; height,1.75±0.06 m; mass,66.28±7.49kg; VO_{2peak},48.36±3.52 ml·kg^{-1}·min^{-1}) free from cardiovascular, respiratory and metabolic disease were randomly allocated to active (ACT, *n*=11) and passive (PAS, *n*=11) experimental groups. The participants were familiarized (1 session) with the experimental procedure and associated risks and gave their written informed consent to participate. This study was performed in compliance with the Ethics Committee for Human Research at Mahidol University (MU-CIRB 2020/049.1902). A flowchart of the experimental procedure is provided in Figure 1.

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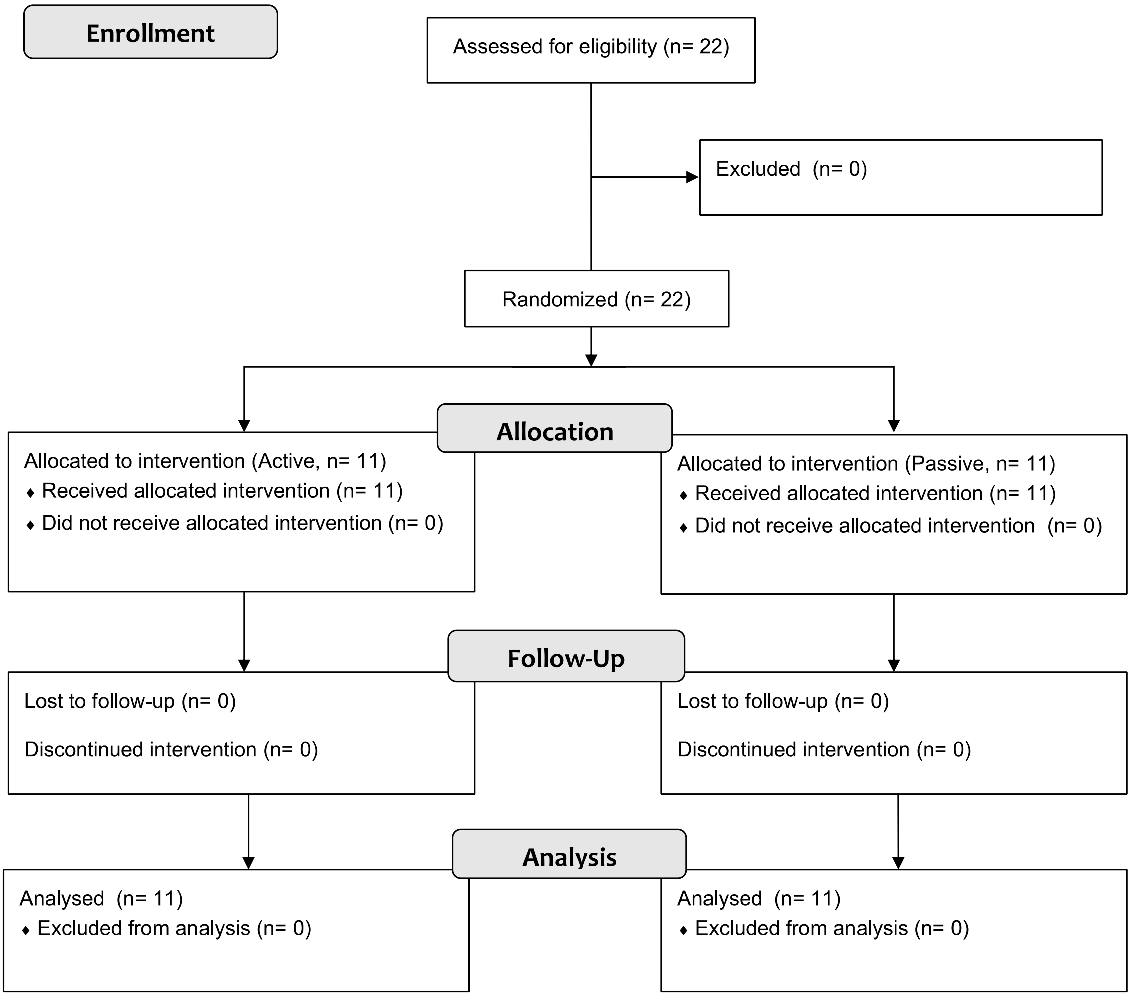

Figure 1. Experimental procedure

Procedure: After being familiarized with the test procedures, the participants were asked to attend the laboratory to perform physiological assessments and performance tests. ***First visit:*** The participants arrived at the laboratory (8.00-11.00 am)and were asked to complete a maximal incremental running protocol on a treadmill (Valiant CPET, Lode, Netherlands) while simultaneous breath by breath (VO_2) measurements were recorded (Metalyzer 3B, Cortex, Germany). The treadmill protocol commenced at a speed of 7 $km{\cdot}h^{-1}$and was increased by 1 $km{\cdot}h^{-1}$ every minute until the participant reached voluntary exhaustion. Peak oxygen uptake (VO_{2peak}, $ml{\cdot}kg^{-1}{\cdot}min^{-1}$) was recorded as the highest 15-secaverage recorded before volitional exhaustion. The treadmill velocity at VO_{2peak} (vVO_{2peak}) was determined as the highest treadmill speed attained at this point. The first ventilatory threshold breakpoint (VT_1),used as a proxy for anaerobic threshold[11], was obtained for each participant upon completion of the incremental exercise test via exporting VO_2 and VCO_2 data to excel. VT_1 breakpoint was subsequently determined using the V-slope method[12]by assuming the threshold corresponds to the break in the linear VCO_2-VO_2 relationship. The VT_1breakpoint was independently assessed by two researchers and a consensus on the threshold was attained. During the incremental exercise test, heart rate was continuously recorded using a telemetry chest strap and wrist monitor (Polar H10, Finland).Each participant's percentage of maximum heart rate corresponding with VT_1(%HR_{max} at VT_1) and percentage of VO2peak at VT1 (%VO_{2peak} at VT_1) was subsequently recorded upon completion of the test. In the afternoon of the first visit (13.00-16.00 pm).***Running Anaerobic Sprint Test (RAST):***After a 5 min standardized warm-up (inc.,stretches), each participant was asked to sprint as quickly as possible over a marked distance of 35 m for a total of 6 repetitions separated by 10-sec recovery. Sprint times were recorded using timing gates (Multi Choice Reaction Timer, Thailand)and used to calculate peak power (Equation I), average power (Equation II),anaerobic capacity(Equation III), and fatigue index (Equation IV), respectively[13].The morning and afternoon test sessions were separated by at least 2 hours to limit the carry over of residual fatigue.

Equation I:

Peak power output (W) = body mass (kg) x distance (m)^2 ÷ time (sec)^3

Equation II:

Average power output (W) = sum of peak power from all sprints÷ 6

Equation III:

Anaerobic capacity (W): Sum of all 6 peak power outputs

EquationIV:

Fatigue index (W / sec) = (Maximum power – Minimum power)÷ *total time for 6 sprints (sec)*

Second visit: HIIT protocol: upon completing a 5 min standardized warm-up, each participant ran on a treadmill (Valiant CPET, Lode, Netherlands) at a speed equivalent to 105% of individual vVO_{2peak} for 30 sec[3]before either resting passively in a standing position for 30 sec (PAS) or continuing to run at a speed equivalent to 60% of individualized VT_1 (ACT)[14,15].This work bout: recovery prescription was repeated for a total of 5 repetitions and repeated (2nd set) after 180 sec of passive inter-set rest. All participants completed their assigned HIIT protocol twice a week for 6 weeks which was undertaken alongside the participants' standardized routine soccer training program (inc., tactical and technical training sessions, and small-sided games) All participants completed a similar routine due to being affiliated to the same University soccer team. On the participants' final visit to the laboratory (Post; ~1 week after completing the HIIT program), baseline physiological measures (VO_{2peak}, VT_1,

%VO_{2peak} at VT_1, %HRmax at VT_1) and performance indices (peak power, average power, anaerobic capacity, fatigue index) were reassessed.

Participants were instructed to avoid consuming a meal within 2 hours before attending the laboratory and to refrain from caffeine intake 24 hours before pre- and post-HIIT assessments. Participants completed the assessment sessions at approximately the same time of day and all experimental procedures were supervised by the same researcher.

DATA ANALYSES

An analysis of covariance (ANCOVA) model was employed, with the change score (posttest – pretest) used as the dependent variable and pre-test values used as a covariate to control for any between-group imbalances at baseline[16].All data were checked for normality by performing Shapiro-Wilk tests and examining quantile-quantile (Q-Q) plots. Levene's test was used to test the assumption of homogeneity of variances. The least significant difference (LSD) test was used for post hoc pair wise comparisons of the fixed effects (i.e., the effect of the group upon variable outcome measures). The ANCOVA adjusted change scores (estimated marginal means) are reported in the text. While we purposively placed less emphasis upon within-group changes (i.e., pre to post-test change), statistical significance is interpreted if the95% confidence interval (CI)did not include zero. The αlevel for evaluation of statistical significance was set a $P<0.05$. Effect sizes (*d*) are reported to determine the magnitude of difference between groups (ACT vs PAS) and assessed against Cohen's *d* definitions of: <0.2, 0.3, 0.5, and 0.8 for trivial, small, moderate, and large, respectively[17] (95% CI's included). The freely available jamovi statistical software, version 1.6.23.0 (https://www.jamovi.org) was employed for all statistical analysis. All data are presented as the adjusted mean and 95%CI(controlling for covariate pre-values) unless otherwise stated.

RESULTS

It was estimated that anANCOVA design with a total sample size of 22 participants across 2 groups with 80% power (α = 0.05)would be sensitive to effects of$\eta^2 p$ = 0.53. Therefore, this experimental study would not be able to reliably detect effects smaller than $\eta^2 p$ = 0.53.Our sample size approach was based on utilizing aconvenience sample (University soccer team players) and time constraints for collecting data. Pre and post absolute data for physiological and performance variables are displayed in Table 1.

Table 1. Pre and post absolute data for physiological and performance variables (Mean ±SD).

	Active			Passive		
	Pre	Post	*d*	Pre	Post	*d*
Physiological variables						
VO_{2peak} (ml·kg·min^{-1})	50.27 ± 2.28	55.27 ± 3.13	2.56	51.64 ± 3.17	54.73 ± 3.82	0.76
VT_1 (ml·kg·min^{-1})	32.67 ± 1.71	35.76 ± 3.87	0.76	34.23 ± 3.67	38.10 ± 6.64	0.85
%VO_{2peak} at VT_1 (%)	66 + 4	67 ± 6	0.22	66 ± 5	67 ± 4	-0.26
%HR_{max} at VT_1 (%)	78 ± 4	80 ± 7	0.22	81 ± 4	79 ± 6	-0.41
Performance Variables						
Peak power (W)	729 ± 135	681 ± 72	-0.33	635 ± 113	700 ± 70	0.69
Average power (W)	562 ± 48	545 ± 60	-0.31	513 ± 81	561 ± 80	0.87
Fatigue Index (W·sec^{-1})	729 ± 135	681 ± 72	-0.33	635 ± 113	700 ± 70	0.87
Anaerobic capacity (W)	3339 ± 319	3335 ± 426	-0.01	3010 ± 632	3342 ± 662	0.82

Within-group effect sizes (*d*) not adjusted for covariate in the ANCOVA model.

Physiological Assessment

Peak Oxygen Consumption (VO_{2peak}).There was a significant improvement in VO_{2peak}over the 6-week HIIT program in both the ACT (4.75 ml·kg·min^{-1}, 95%CI[2.75 to6.74]) and PAS (3.34 ml·kg·min^{-1},95%CI[1.35 to 5.34]) groups (Figure 2A). However, there was no significant difference in the magnitude of change in VO_{2peak} ($F_{(1,19)}$=1.05, *P*=0.319, mean difference = 1.40 ml·kg·min^{-1}, *d*= 0.45, 95%CI [-0.48 to 1.39])between groups (Figure 2A).

Ventilatory Threshold (VT_1).After completion of the HIIT training program,VT1significantly improved in both the ACT(3.21 ml·kg·min^{-1}, 95%CI [0.37 to 6.06])and PAS(3.75 ml·kg·min^{-1}, 95%CI [0.91 to 6.60])groups (Figure 2B).However, there was no significant difference in the magnitude of change in $VT_1F_{(1,19)}$=0.08, *P*=0.786, mean difference = -0.54 ml·kg·min^{-1},*d*= -0.12, 95%CI [-1.05 to 0.81])between groups (Figure 2B).

Percentage ofVO_{2peak}at Ventilatory Threshold (VT_1). The %*VO_{2peak}* at which VT_1occurred remained similar to pre-value safter 6 weeks of training with no significant change noted within the ACT (1.28%, 95%CI [-1.63 to 4.18]) or PAS groups (1.36%, 95%CI [-1.54 to 4.26]), respectively (Figure 2C). There was also no significant difference in the magnitude of change in %VO_{2peak}atVT$_1$($F_{(1,19)}$=0.00, P=0.966, mean difference = -0.09%,d= -0.02, 95%CI [-0.91 to 0.87]) between groups (Figure 2C).

Percentage HR$_{max}$at Ventilatory Threshold (VT$_1$). Despite VT$_1$improving after 6 weeks of training in both groups, %HR$_{max}$at VT$_1$ did not significantly change in either the ACT(1.19%,95%CI [-2.63 to 5.00]) or PAS(-1.00%,95%CI [-4.82 to 2.81])groups (Figure 2D).There was also no significant difference in the magnitude of change in %HR$_{max}$at VT$_1$($F_{(1,19)}$= 0.69, P=0.416, mean difference = 2.19%, d=0.37, 95%CI [-1, 2])between groups (Figure 2D).

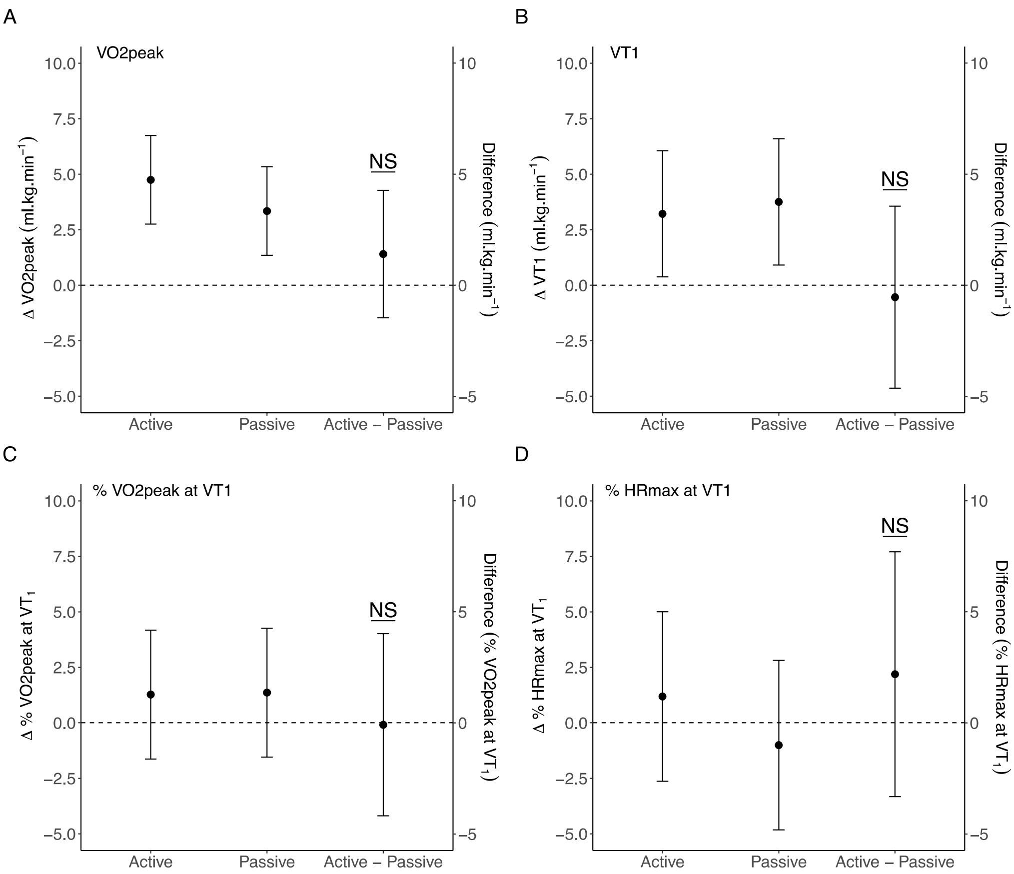

Figure 2. The within and between-group change in physiological measures:A) VO_{2peak}, B) Ventilatory threshold (VT$_1$),C) %VO_{2peak} at VT$_1$ andD)%HR at VT1within the Active (n=11) and Passive (n=11) recovery groups. Data displays the adjusted means and 95% CI's.* = a significant between-group difference; NS = non-significant between-group difference. Significant within-group differences are determined by non-overlap of the 95%CI with the zero line of no effect.

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Performance Assessment

RAST: Peak power. Peak power during the RAST remained unchanged post 6 weeks of HIIT training in the ACT (-10 W,95%CI [-55 to 36]) and PAS (-26W,95%CI [-19 to 71]) groups (Figure 3A).There was also no significant difference in the magnitude of change in peak power($F_{(1,19)}$= 0.69, *P*=0.271, mean difference = -36 W, *d*=-0.52, 95%CI [-1.5 to0.4]) between groups (Figure 3A).

RAST: Average Power. Average power during the RAST increased over the 6-week HIIT training program in the PAS group (42 W,95%CI [-7 to 76]), however average power values remained unchanged in the ACT group (-10 W,95%CI [-45 to 24]). This led to a significant difference being observed in the magnitude of change in average power($F_{(1,19)}$= 1.27, *P*=0.044, mean difference = -52 W, *d*=-0.99, 95%CI [-1.97, -0.01])between groups (Figure 3B).

RAST: Anaerobic Capacity. There was no significant change in anaerobic capacity over the 6-week HIIT training program in either the ACT (27 W, 95%CI [-227 to 281]) or PAS (301 W, 95% CI [47 to 555]) groups. There was also no significant difference in the change in anaerobic capacity [F(1,19)= 2.41, *P*=0.137, mean difference = -274 W, *d*=-0.70, 95%CI [-1.67 to -0.27]])between groups (Figure 2C).

RAST: Fatigue Index. There was no significant change in fatigue index observed after 6 weeks of HIIT training in either the ACT (-0.88 W/sec^{-1},95%CI [-2.01 to 0.26]) or PAS (0.01 W/sec^{-1}, 95%CI [-1.12to 1.15]) groups (Figure 3D). There was also no significant difference in the change in fatigue index ($F_{(1,19)}$= 1.27, *P*=0.274, mean difference = -0.89 W/sec^{-1}, *d*=-0.51, 95%CI [-1.47 to0.45])between groups (Figure 3D).

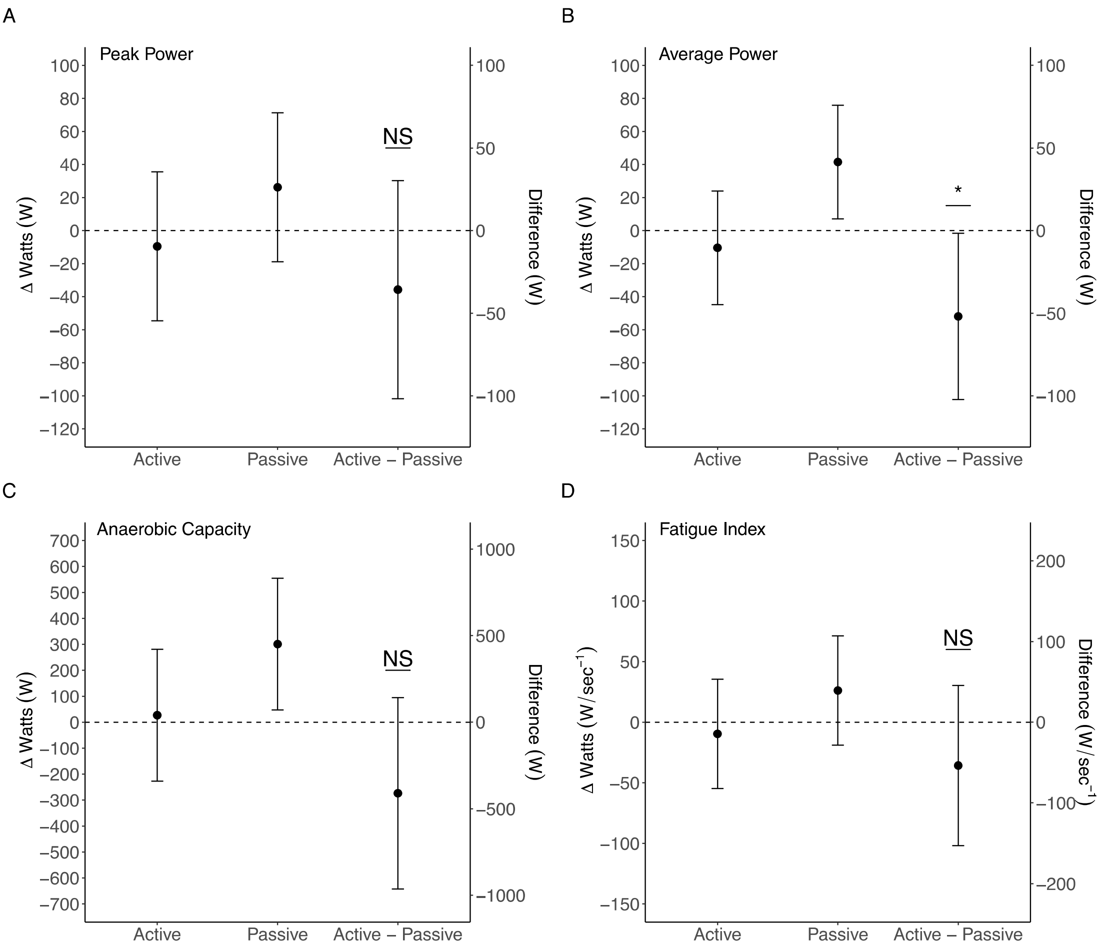

Figure 3. The within and between-group changes in physiological measures: A) Peak Power, B) Average Power, C) Fatigue Index, and D) Anaerobic Capacity within the Active (*n*=11) and Passive (*n*=11) recovery groups. Data displays the adjusted means and 95% CI's. * = a significant between-group difference; NS = non-significant between-group difference. Significant within-group differences are determined by non-overlap of the 95%CI with the zero line of no effect.

DISCUSSION

The main findings in this study showed that performing active or passive recovery between short duration (30 sec) HIIT work bouts generally resulted in similar between-group changes in physiological and performance outcomes after 6-weeks of training. The only between-group difference was observed for average power during the RAST, with the PAS group demonstrating a greater improvement over the 6 weeks. Nevertheless, VO_{2peak} and VT_1 were observed to markedly improve within both recovery groups upon completion of the training program.

In the present study, there was a marked increase in VO_{2peak} and VT_1 (Figure 2A&B) in both the ACT and PAS groups over the 6-week HIIT training period. Our data are consistent with previous work, which has reported improvements in maximal aerobic capacity and anaerobic threshold after various HIIT configurations[18,19,20]. The observed improvement in VO_{2peak} was likely facilitated by the work bouts at an intensity above >90% VO_{2peak} to drive central (i.e., cardiac output and blood volume)[21] and peripheral adaptations (i.e., mitochondrial content and capillary density)[22]. The improvement in ventilatory threshold across both groups at the end of the training period may be attributed to metabolic stimuli, in particular blood lactate and hydrogen ion (H+) accumulation, from the intense work bouts[9,23,24]. It is reported that active recovery can enhance blood lactate removal compared with passive recovery[8]. However, as we presently observed no marked differences in the magnitude of change in VT_1 between groups (Figure 2B), our data do not provide support for this hypothesis. It is unknown whether selecting higher intensity work bouts would have resulted in a difference in VT_1 between the ACT and PAS groups. Despite the aforementioned findings, we did not find any change in the percentage of VO_{2peak} or HR_{max} at the first ventilatory breakpoint at the end of the 6-week program in either recovery group (Figure 2C&D). These findings suggest that fractional utilization, the percentage of VO_{2peak} that can be sustained for a period of time[21], was not improved over the 6-week HIIT training program.

Although we observed within-group improvements in aerobic and anaerobic thresholds (i.e., VO_{2peak} & VT_1), these improvements in physiological indices generally did not transfer over to enhancing anaerobic performance. Despite RAST average power and anaerobic capacity improving in the PAS group (Figure 3B & C), a between-group difference was only observable for average power. Alternatively, RAST peak power and fatigue index were not influenced by increases in physiological capacity across groups (Figure 3A & D). Our findings contrast with past work, which found passive recovery improved peak power (Wingate test) over 15 interval sessions performed over a 2-week shock microcycle[7]. Nevertheless, Wahl et al[7] employed longer interval bouts (4-min work: 3-min recovery) compared with our implemented HIIT program.

In the present study, the larger magnitude of change in average power in the PAS group was likely related to better maintenance of run times across the six RAST sprints (see Equation II). It is difficult to ascertain the underlying mechanisms explaining the between-group differences in post-test average power in the absence of additional physiological measures (i.e., blood biomarkers). However, active recovery is reported to enhance the clearance of lactate accumulated during intense exercise[14,15]. This removal of the lactate stimulus during HIIT sessions may have reduced buffering capacity (as indicated by a greater change in anaerobic capacity in the PAS group; Figure 3C) and lessened adaptive response in the ACT versus PAS group[7]. Thus, it may be speculated that the decreased ability to buffer lactate during the RAST partly explains the between-group difference in average power. Alternatively, an adaptive response associated with the relationship of phosphocreatine (PCr) resynthesis in the presence of oxygen availability (i.e., dependent upon ATP derived from O_2 metabolism)[25,26]may also explain in combination, or independently with lactate kinetics, the greater change in average power in the PAS group.

The practical implications of our findings to incorporating HIIT training into a soccer-conditioning regimen, suggest that adopting either active or passive recovery intervals may have equal efficacy when employing HIIT bouts of similar intensity and duration. While it may be inferred that both types of recovery can lead to comparable improvements in aerobic capacity and anaerobic threshold, there appears little transfer to improving anaerobic peak power or capacity over 6 weeks. Nevertheless, the greater change in average power in the PAS group suggests this type of HIIT may facilitate the maintenance of power output when performing repeated sprints of short duration in training and competition.

While we observed no marked differences between the ACT and PAS groups across several measured variables, the absence of a significant effect is not necessarily evidence of an effect not being present[27]. Therefore, future work should determine the practical significance (smallest effect size of interest) in key physiological and performance parameters to facilitate inferences to applied soccer practice. In addition, our relatively small sample size did not render the width of uncertainty (i.e., wide confidence interval) around the mean differences within and between groups, potentially leading to sampling error. It is recommended that future work investigate various HIIT work : rest durations and intensities (using both active and passive recovery) to address whether different physiological and performance outcomes would be consistent compared with our current observations.

In summary, university soccer players performed 6-weeks of HIIT training, incorporating either active or passive recovery bouts, and had physiological and performance-related outcomes measured. The main findings demonstrated that the HIIT training program was effective to improve within-group changes in aerobic capacity and ventilatory threshold throughout the 6-week program. However, the improvements in physiological indices only transferred to markedly improve average power and anaerobic capacity within the PAS group. Nevertheless, no marked between-group differences (except average power) were observed in physiological or performance parameters. Therefore, it is concluded that both active and passive recovery may be considered equally effective for application in short-interval (30 sec) HIIT training programs in soccer players.

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