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The Role of Aerobic Capacity and Strength Levels on Wingate Performance and Lactate Concentrations

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ABSTRACT

Background: Blood lactate (La$^-$) is commonly assessed in tests of sport performance. Sports that utilize intermittent high intensity effort, monitoring of La$^-$ from previous exercise can be useful to document intensity of effort. **Objective:** The purpose of this study was to investigate the role La$^-$ played during successive Wingate (Win) tests and subsequent anaerobic exercise performance. **Method:** Well-trained, national team athletes from Jordan (n = 31) volunteered to participate. A quasi-experimental design was utilized to test Win performance and La$^-$ concentration. All participants engage in two Win tests with one minute rest between sets. La$^-$ was collected at four time points (prior to Win test 1, immediately after Win 1, after Win 2 and after a 10 minute recovery period). **Results:** Findings from a multiple linear regression model ($p = 0.032$) showed increased levels of La$^-$ accumulation as a predictor to higher power and strength ($p = 0.046$). Conversely, peak aerobic capacity was a predictor for decreasing La$^-$ accumulation over time ($p = 0.039$), which may suggest faster recovery. **Conclusion:** Anaerobic athletes who participate in short, high intense bouts of exercise may require high intensity training programs to increase aerobic fitness, power output, and optimal performance. Practical applications include optimizing training programs to reflect competition.

Key words: Athletic Performance, Exercise, Lactic Acid, Physical Exertion, Sports

INTRODUCTION

Success in sports rely on the ability to perform intermittent bouts of high-intensity exercise and regulate physiological changes. High intensity interval training (HIIT) is defined as any bout of exercise between one second and two minutes where the energy is derived from anaerobic processes (Wells & Norris, 2009). La$^-$ is positively correlated to fatigue and decreases in performance during physical exertion (Fitts, 1994; Gladden, 2004; Green, 1997; Klausen et al., 1972; Sahlin, 1986). Anaerobic threshold (AT) typically occurs when La$^-$ accumulation exceeds removal between 50% to 70% of maximal oxygen uptake (Chmura & Nazar, 2010; Figueira et al., 2008). Once intensity exceeds the AT, changes occur including depletion of high energy phosphates and accumulation of metabolites H^+ and P_i (Jones et al., 2008). The change in the condition of muscular cells indicates a transition from a sustainable workload to one that is exhaustive resulting in a shorter duration of performance (Chmura & Nazar, 2010).

One key predictor of performance is the speed at which La$^-$ accumulation exceeds 4mmol/l (Heck et al., 1985; Weltman, 1995). La$^-$ accumulation is associated with pH below the normal physiological level (Gollnick et al., 1986). Sahlin (1986) found that H^+ production may be due to H^+ production from the glycolytic reactions involving ATP hydrolysis. Cairns (2006) supports that La$^-$ accumulation may provide an ergogenic aid to performance and suggest that a deeper understanding of La$^-$ production in humans is needed. Supramaximal exercise lasting at least 30 seconds has been found to increase La$^-$ concentration until the 8th minute of recovery while decreasing after 10 minutes of rest (Ozturk et al., 1998). Further, Coco et al. (2022) found increases in lactate above 4mmol/l after a five minute Sambo match. The results showed lactate levels returning to baseline after 15 minutes post exercise with maximal and submaximal conditions. Thus, it is beneficial for coaches and athletes to understand the La$^-$ accumulation and removal speeds during a particular paradigm, particularly those short, intense repeated bouts of activity.

The Wingate (Win) test is a valid measure to predict and track aerobic capacity and power performance over time (Zagatto et al., 2009). The 30 second maximum effort test

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measures peak aerobic performance and power (Feito et al., 2019; Fitts, 1994). Coco et al. (2022) investigated sixteen male Sambo athletes' lactate levels, fatigue, and attentional ability pre- and post-fifteen minute training session. Sambo is comparable to Judo, and the athletes in this study played competitively for at least five years. Results from this study showed increases in lactate across the two conditions (i.e., Sport Sambo vs. Combat Sambo) throughout time points and evidence of fatigue and worsening of attentional processes in the Combat Sambo condition. Coco et al. (2022) suggests that increases in lactate above anaerobic threshold (4 mmol/L) can impact aspects of performance like physical/mental fatigue and attention.

The impact of accumulated muscular strength and aerobic fitness from training on repeat bouts of high intensity training need to be evaluated more within our specific population. Specifically, the purpose of this study was to investigate how the role of training background impacted performance and lactate accumulation during successive Win tests.

METHOD

Study Design

The present study was quasi-experimental and used within subject repeated measures to perform Win tests in a controlled laboratory setting. The study was approved by the PI's Institutional Review Board prior to any data collection and conducted in line with the Declaration of Helsinki. Necessary sample size was determined using G*Power 3.1 software assuming a moderate effect size, and to achieve sufficient power (0.95) a sample size greater than 29 was required. As noted in de Lira et al. (2013), sample sizes tend to be smaller when participants are elite athletes. Considering our population of National team members, the sample size reflects and is greater than the sample sizes of other research in this line of work (de Lira et al., 2013; $n = 10$; Feito et al., 2015; $n = 29$).

Participants

A convenience sample of subjects were recruited from an available pool of national team athletes from Jordan. Thirty-one anaerobically conditioned athletes (VO_2 max 52.7 ± 1.53ml/kg/min; National Team Boxing, Taekwondo, Judo and Futsal athletes) volunteered to take part in this study. All participants were from Jordan and trained in their specialty sport for 6 ± 1.8 years (mass = 66.4 + 7.27 kg, height = 172.58 + 6.46 cm, and BMI = 22.29 + 2.21). To qualify for the study, subjects needed to be a national team athlete, be able to participate in maximum effort aerobic and anaerobic exercise and be free from current musculoskeletal injuries limiting exercise. All subjects were cleared to participate by the team physician. Exclusion criterion included the occurrence or presence of injury. Though Futsal and Judo are considered anaerobic sports, it is important to note the dynamics are different. Futsal is played with five players on each side with unlimited substitutions being permitted during competitions. Judo competitions tend to encompass a higher frequency of short bouts of intense exercise.

Study Procedure

On the first visit to the laboratory, informed consent was signed, and participant's descriptive data was obtained. Two days later, a maximal VO_2 test was performed using a metabolic system (Quark PFT, Cosmed, Rome, Italy) to evaluate the participant's cardiovascular fitness. Three days later, a warm-up, Win1, and Win 2 were performed and power measures peak power (Peak PWR), average power (Avg PWR), minimum power (Min PWR) and power drop (PWR Drop) were collected using a standardized Win protocol (McLester et al., 2008). Rest time between Win 1 and Win 2 was one minute, which was chosen based upon published reports that shorter recovery periods significantly impacted peak and mean power during Win tests (Harbili, 2015).

Lactate concentration was determined at four points: prior to Win test 1, immediately after Win 1, after Win 2 and after a 10 minute recovery. Quality control was performed periodically during the study as the lactate analyzer was periodically tested with high and low control solutions.

Test Protocols

Maximum aerobic capacity was determined using a calibrated metabolic system (Quark PFT, Cosmed, Rome). Subjects were instructed to run on the treadmill until volitional failure. Initial speed was set at 6 km/h and increased by 1 km/min every stage. For the Wingate test, subjects were fitted to a cycle ergometer and received instructions regarding the nature of the test. The flywheel resistance was set at the standard 7.5% of body mass in kilograms for all subjects. The subjects warmed up briefly by pedaling against light resistance, then were instructed to pedal as fast as possible, at which point the weight was released and the subject pedaled at maximum effort for 30 seconds. Peak PWR, Avg. PWR, Min PWR and PWR Drop were calculated using a computerized ergometer (Monark 894E, Monark Exercise AB, Vansboro, Sweden). For blood lactate, blood samples were drawn from fingertips by a certified lab technician and analyzed for La^- using a calibrated hand-held lactate analyzer (Lactate Pro; Arkray KDK, Kyoto, Japan).

Strength was determined using a leg and back dynamometer (Takei 5001, Takei Scientific Instruments Co., Ltd, Tokyo, Japan). For the leg strength assessment (quadriceps strength), chain length was adjusted with the subject in a standing position to approximately the mid-thigh pull position. Participants were then instructed to pull up on the handle connected to the chain with maximum effort, the results were recorded on the analogue force gauge attached to the device in kilograms.

Statistical Analysis

Differences in Win performance measures (peak, average, power drop) were assessed using pair-samples *t*-test analysis. Bivariate associations between variables were undertaken using Pearson correlations. Changes in lactate concentration across time were assessed with repeated measures ANOVA with Tukey HSD used for post hoc analysis. Examination of the associations between strength (isokinetic quadriceps), maximum aerobic power (VO_2 max), and changes in Win test performance and lactate were undertaken using multiple linear regression. A modern statistical software package (JMP Pro 16.0) was used for all analyses and statistical significance was set a priori at alpha < 0.05.

RESULTS

Significant and non-significant differences were found for the dependent variables assessed in this study. Participants' baseline characteristics are presented in in Table 1. All participants complied with the study procedures and completed the exercise-testing protocol safely. No athletes have been injured in their sport exercises between their familiarization visit to the human performance lab and official testing session.

Wingate Peak Power

Analysis of change in Win peak power revealed significant differences between Win trial 1 and 2 (t = 3.07, p = 0.004, 1st Win peak power = 8.92 ± 1.89 watts/kg, 2nd Win peak power = 8.92 ± 1.89 watts/kg). Average peak power across trails was not associated with either maximum aerobic capacity or quadriceps strength (p > 0.10). Subsequent analysis of the change in Win peak power using multiple linear regression revealed a significant model (r^2 = 0.52, p < 0.001) with VO_2 max (Standard β = 0.375, p = 0.017) and quadriceps strength (Standard β = -0.671, p < 0.001) as significant predictors. Increased strength was associated with larger changes in peak power with repeated Win tests (Figure 1), whereas increased aerobic capacity was associated reduced peak power deficit (Figure 2).

Wingate Average Power

Analysis of change in Win peak power revealed differences between trial 1 and 2 (t = 5.57, p < 0.001, 1st Win average power = 6.65 ± 1.13 watts/kg, 2nd average power = 5.71 ± 0.68 watts/kg). Mean average power across trails was positively associated with maximum aerobic capacity (r = 0.393, p = 0.028), but not quadricep strength (p = 0.323). Subsequent analysis of the change in Win average power using multiple linear regression revealed a significant model (r^2 = 0.42, p = 0.002) with both VO_2 max (Standard β = 0.38, p = 0.028) and quadriceps strength (Standard β = -0.58, p = 0.002) as significant predictors. Increased strength was associated with larger changes in average power with repeated Win tests, whereas increased aerobic capacity was associated with reduced average power deficit.

Wingate Power Drop

Analysis of change in Win power drop did not reveal a difference between trial 1 and 2 (t = 0.03, p = 0.974, 1st Win power drop = 4.74 ± 1.68 watts/kg, 2nd Win power drop = 4.73 ± 1.41 watts/kg).

Table 1. Participants' baseline characteristics (n = 31)

	M	*SD*
Age (Years)	24.9	4.3
Weight (Kg)	73.0	11.9
Height (cm)	176.0	7.4
BMI (Kg/m2)	23.4	2.7
Body Fat Percent	16.3	6.4
Fat Free Mass (Kg)	61.1	11.0
VO2 max (ml/kg/min)	52.3	5.5
Systolic Blood Pressure (mmHg)	121.3	8.6
Diastolic Blood Pressure (mmHg)	75.7	5.6
Resting Heart Rate (bpm)	59.3	7.8

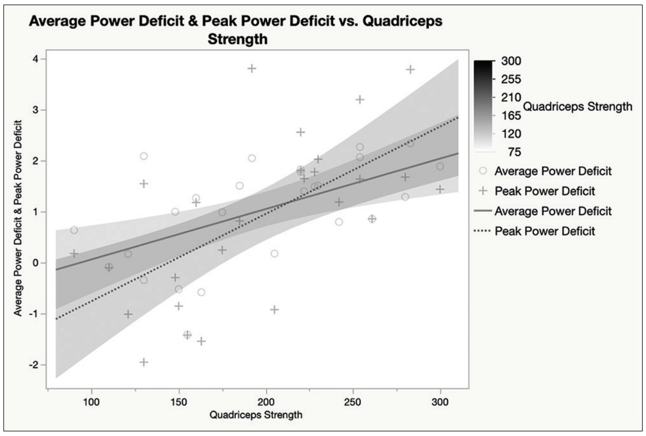

Figure 1. Increased strength was associated with larger changes in peak power with repeated Wingate tests

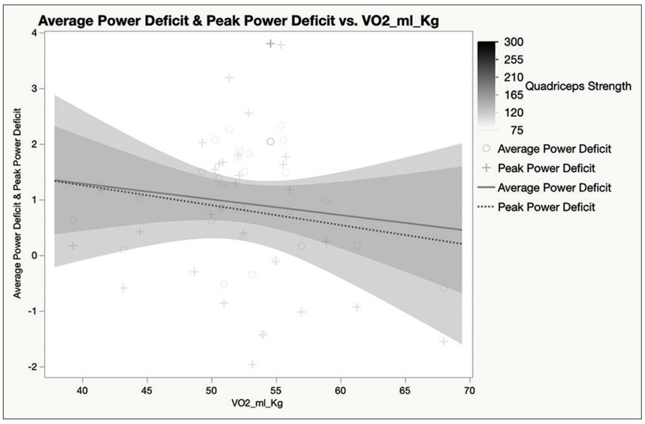

Figure 2. Increased aerobic capacity was associated reduced peak power deficit

Lactate

A repeated measures ANOVA examining La^- concentration by time (baseline, Win 1, Win 2, 10 minute post Win 2) revealed a main effect for time ($F_{3,8}$ = 50.58, p < 0.001). Post hoc testing with Tukey HSD revealed that all time points were significantly different than one another with the sole exception of 2nd Win and 10 minute post ($p < 0.05$). Subsequent analysis of the 10 minute post La^- measure using multiple linear regression revealed a significant model ($r^2 = 0.26$, $p = 0.032$) with both VO_2 max (Standard $\beta = -0.39$, $p = 0.039$) and quadriceps strength (Standard $\beta = 0.39$, $p = 0.046$) were significant predictors. Increased strength was associated with increased 10 minute post La^-, whereas increased aerobic capacity was associated with decreased 10 minute post La^- (Figure 3).

DISCUSSION

This study investigated the effects of anaerobic exercise-induced La^- accumulation on subsequent Win trials using National team Boxing, Taekwondo, Judo and Futsal athletes. The present study adds to the literature in the novelty of the findings and addition of La^- accumulation studies for those with a HIIT type exercise or high anaerobic background (e.g., CrossFit, Futsal, Sambo, Taekwondo; Coco et al., 2022; Feito et al., 2019). Feito et al. (2019) concludes that aerobic fitness is a major predictor on La^- accumulation, fatigue, and decreased power output on Win test over time. We anticipated that La^- accumulation is related to increased power and strength, while aerobic capacity is related to decreases in La^- accumulation after a 10 minute recovery period. Ozturk et al. (1998) suggest that after the 10th minute of recovery La^- concentration decreases. Coco et al. (2022) also found increases in lactate pre to post five minute Sambo match with decreases to normal lactate levels post fifteen minutes after exercise. Our study strengthens the literature with elite level anaerobic athletes in that they may recover faster between bouts of intense exercise if they are more aerobically fit. Interestingly, de Lira et al. (2013) investigated ten Olympic level boxers' VO_2 Max capactity and heart rate during a simulated match to capture anaerobic atheltes' performance profiles. Findings highlighted the use of anaerboic and aerobic metabolic pathways such that high aerobic capacity is associated with greater strength outputs and faster recovery. This study did not consider the impact of training background or measure lactate levels. However, they suggested that the training programs for anaerobic athletes should incorporate exercises to develop the areobic and anaerobic metabolic pathways (de Lira, 2013).

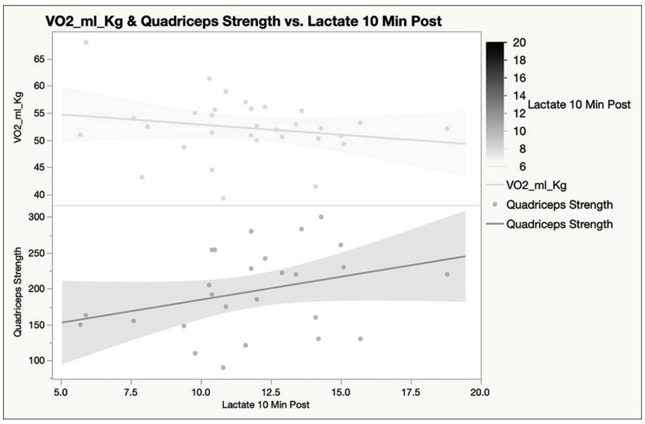

Figure 3. Increased aerobic capacity was associated with decreased 10 minute post Lactate

Wingate Peak Power

Analysis of change in Win peak power revealed significant differences between trial 1 and 2. Subsequent analysis of the change in Win peak power using multiple linear regression revealed a significant model with both VO_2 max and quadriceps strength as significant predictors in the model. Increased strength was associated with larger changes in peak power with repeated Win tests, whereas increased aerobic capacity was associated reduced peak power deficit. This finding illustrates a basic key point of exercise performance suggesting that the level of La^- accumulation during an anaerobic bout (30s) would be associated to the level of maximal power that can be produced (Ozturk et al., 1998).

Wingate Average power

Results suggest that increased strength was associated with larger changes in average power with repeated Win tests, whereas increased aerobic capacity was associated with reduced average power deficit and greater overall average power. Analysis of change in Win power drop did not reveal a difference between trial 1 and 2. This finding might be partially explained by the fact that the recovery time was enough to restore some of the depleted phosphocreatine (PCr) and clearance of inorganic phosphate (Figueira et al., 2008; Jones et al., 2008). Ozturk et al. (1998) recommend a recovery period of at least 10 minutes after a supramaximal bout of at least 30s for maximum recovery to see decreases of La^- in a non-fit sample ($n = 11$). They support that recovery rate may be dependent on aerobic capacity. Exercise experience and competency levels may also influence aerobic endurance and power performance, specifically in CrossFit or HIIT type training (Bellar et al., 2015).

Furthermore, the decrease in average power and minimum power in trial two as compared to trial one supports the idea that peak power was related to PCr stores. As rate of ATP production was likely lower during the second trial, implied by the drop in average and peak power, this coincides with a shift into glycolytic ATP production. After 90 seconds of high intensity exercise, Schumacher et al. (2005) showed full replenishment of PCr after 40 and 60 seconds of recovery in elite athletes and healthy controls, respectively. The levels of PCr measured using "phosphorus magnetic resonance spectroscopy" were depleted to 67% and 56 % of resting values for elite athletes and healthy controls, respectively. In the present investigation, our findings support this notion in terms of the ability to reproduce Peak power.

Lactate

The 10 minute post lactate measure using multiple linear regression revealed a significant model with both VO_2 max and quadriceps strength as significant predictors. Increased strength was associated with increased 10 minute post lactate, whereas increased aerobic capacity was associated with decreased 10 minute post lactate. Although La^- accumulation results from the difference between production and removal, some athletes can remove La^- more quickly than others. Results from the ANOVA with post hoc testing led us to conclude that lactate levels increased significantly from Win 1 to Win 2 tests but did not show signs of significant accumulation immediately after Win 2 to post 10 minutes of rest after Win 2. This is in line with Ozturk et al. (1998) and Coco et al. (2022). Coco et al. found increases in lactate greater than 4mmol/l after a five minute Combat Sambo match. Lactate levels returned to baseline after a 15 minute rest period. The current study's trials lasted approximately three minutes compared to five minutes. Differences in our findings compared to Coco et al. could be due to the intensity and duration of tests (i.e., Wingate test vs. Combat Sambo match). Consequently, La^- accumulation following exercise may only be partly related to the production of the working muscle (Bishop & Martino, 1993). Therefore, it is possible that La^-accumulation does not always accurately reflect muscle conditions. It is speculated that the rate of La^- accumulation may be attributed to various factors such as: capillary density, muscle fiber type, training background, and lactate removal rates. Aerobic capacity and strength are differentially related to some of these factors which may explain the La^- pattern observed in this study.

Practical Application

Athletes with anaerobic performance profiles may consider training programs that optimize their performance profile (de Lira et al., 2013; Nalbandian et al., 2018). One suggestion for coaches and athletes is to use HIIT to improve strength, power, and aerobic fitness (Aravena Tapia et al., 2020; de Lira et al., 2013). For example, Aravena Tapia et al. (2020) randomly assigned 12 National Taekwondo athletes to either a control or treatment group. Both groups were given the same Taekwondo technical training for four weeks, while the treatment group also received HIIT three times a week. This investigation of HIIT specific for Taekwondo athletes revealed improvements on a frequency of speed kick test and anaerobic performance pre/post treatment. However, HITT in this study did not improve fatigue. This finding could be due to the specificity and differences of the HITT compared to the Wingate test. Another explanation is that Aravena Tapia et al. did not collect blood lactate levels. This example demonstrates that training background is an important factor in anaerobic performance, although further research on training background is needed. Further, there is evidence that La^- accumulation during HIIT type exercises may be beneficial for power movements (Cairns, 2006). Lastly, in a sample of 32 health adult male CrossFit athletes, Bellar et al. (2015) found experience with sport (i.e., CrossFit) to be a significant positive predictor for aerobic capacity and anaerobic power. Such that as athletes mature in their sport, their aerobic/anaerobic fitness and recovery rates may improve. Coaches and athletes should be aware of these considerations during training to get the most efficient and effective workouts as they prepare for competitions.

Limitations

While the current sample is adequate to present the findings of the study, a larger sample would have served to increase the statistical power for this research and provide comparative results by sport type. After conducting the second bout of anaerobic Win test, lactate concentration was tested immediately after the test and after 10 minutes of recovery, lactate levels were not measured during the 10 minute period which may have explained when lactate values have peaked. Ozturk et al. (1998) found peak lactate at 8 minuets post Win 2 test. Despite these limitations, this study contributes to the literature regarding lactate accumulation and recovery. Future directions should include comparative examinations of sport type (i.e., Boxing, Futsal, Taekwondo, and Judo) and type of training background (i.e., HIIT type or traditional cardio workouts). Additionally, this study did not compare anaerobic to aerobic sports, which may provide interesting differences in performance profiles. Lastly, future research should measure lactate levels every minute post final Win trail to measure the occurrence of peak lactate levels and recovery periods.

CONCLUSION

The findings in the present study are beneficial for anaerobic athletes who must perform multiple bouts of maximal intensity exercise within a short timeframe. Anerobic athletes with higher quadricep strength may have larger changes in peak and average power on subsequent Win tests. Those with higher strength also may accumulate more lactate during bouts of intense exercise. Their performance on Win test may translate to their performance in matches. Additionally, anerobic athletes with higher aerobic fitness may have faster rates of recovery between high intense bouts of exercise. Our findings provide new information on athletes with anaerobic performance profiles, which can be used to optimize training programs. Those in Futsal, Taekwondo, Boxing, and Judo with lower aerobic capacity may consider using HIIT type workouts to increase aerobic fitness and subsequent average power.

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