International Journal of Sport, Exercise and Health Research

Systematic Review

IJSEHR 2022; 6(1): 37-42

www.sportscienceresearch.com
Received: 12-02-2022
Accepted: 19-03-2022

Aerobic Exercise in the Fasted State: The Effects on Aerobic Capacity in Healthy Adults

Muhammad Arsalan Zamir[1]

[1] Author affiliations: Consultant Family Medicine, Al Wajbah Health Centre, Primary Health Care Corporation, Doha, Qatar

Abstract

There are numerous variables that can affect energy metabolism during aerobic exercise and possibly play a role in the increase of aerobic capacity. Dependence on fat oxidation such a factor and approaches are sought to maximise adaptations in enhancing this metabolic switch. A strategy that has been explored increasingly is the dietary pattern of the fasted state. With aerobic exercise and the fasted state relying on complimentary energy metabolism pathways, this literature review aimed to investigate a pivotal interaction between aerobic exercise in the fasted state and possible benefits for aerobic capacity. The hypothesis, 'aerobic exercise in the fasted state will enhance aerobic capacity in healthy adults', was tested through exploration of implications for aerobic capacity with aerobic exercise in the fasted state. A review of the relevant literature since 2005 relating to the healthy adult population was undertaken, resulting in the critical appraisal of 41 articles. The findings from this review support metabolic switching in fasted state aerobic exercise, demonstrating preferential reliance on fat oxidation, enhanced glucose metabolism and mitochondrial activity. There appear to be benefits that can be derived for aerobic capacity, but further research is warranted to attain greater definition of the effect with fasted state aerobic exercise.

Keywords: Endurance Exercise, Ffasted State, Aerobic Capacity***.***

INTRODUCTION

Exercise activity is fuelled by adenosine triphosphate (ATP), a high-energy phosphate molecule, which is accessed differently depending on the nature of the exercise. Anaerobic exercise demands short-term energy requirements based on activities that rely on bursts of speed and strength. This depends on rapid availability and generation of ATP through metabolic pathways at the cellular level, primarily the phosphor-creatine (ATP-PCr) system and glycolysis (Figure 1). In contrast, aerobic or endurance exercise, typically lasting minutes to hours, relies on steadily drawing a greater energy yield from efficient fuel metabolism reliant on oxygen availability, referred to as oxidative phosphorylation. The production of ATP through this pathway revolves around the aerobic breakdown of carbohydrates and free fatty acids as substrates. This is influenced by mitochondrial enzymes, the electron transport chain and the function of the tricarboxylic acid cycle [1]. The main fuel of fat during this form of exercise is stored in adipose tissue and as triglycerides in skeletal muscle, with the oxidation of fat meeting the ATP energy requirements of muscular contraction during exercise [2].

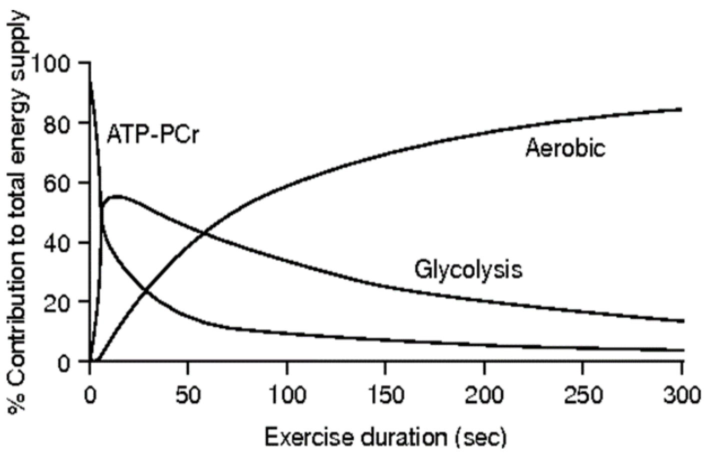

Figure 1: Relative energy system contribution to the total energy supply for any given duration of maximal exercise [3]

***Corresponding author:**
Dr. Muhammad Arsalan Zami
Author affiliations: Consultant Family Medicine, Al Wajbah Health Centre, Primary Health Care Corporation, Doha, Qatar
Email: mzamir@phcc.gov.qa

There are a number of factors that can affect energy metabolism in the context of aerobic exercise and could play a potential role in the increase of aerobic capacity. One of these is the rate and efficiency of utilising oxygen and substrates with the well-accepted role that nutritional strategies play in training regimes to support the development of aerobic capacity, whether for the general or athletic population [1].

Aerobic capacity is defined as the maximum rate at which oxygen (VO2max) can be transported from air to target tissues for use by mitochondria during high-intensity exercise. While VO2max may not be maintained for more than a few minutes, prolonged aerobic exercise requires optimal performance for longer periods that may last a few hours. The greatest percentage of VO2max that may be maintained for a prolonged duration is otherwise known as the anaerobic threshold and reflects the capability to perform sustained exercise. This capability depends on adopting strategies to maximise adaptations that ultimately promote higher rates of fat oxidation and a parallel reduction in glycolytic flux [4].

One such strategy that has been explored in recent years is the nutritional strategy of the fasted state. This is characterised by the absence of energy intake, lasting anywhere between a few hours to days. Most fasted states relate to an overnight duration without energy intake, typically around eight hours but subject to variations individually owing to patterns of sleeping and eating [5].

The effect of dietary manipulation on mitochondrial adaptations has been studied in the context of aerobic exercise training [6]. The authors noted the enhancement of mitochondrial biogenesis markers with carbohydrate restriction, specifically increases in mitochondrial size, content, number and activity. They suggested that carbohydrate restriction implicated potential beneficial implications for enhanced exercise performance.

The physiology of the fasted state and physical exercise has been the focus of interest to investigate intermediary metabolic pathways. This interaction between the fasted state and physical exercise in the context of elite sport was initially studied at the beginning of the 21st century. This resulted from the understanding amongst athletes and coaches that the fasted state may have negative connotations for sporting performance [7].

The Olympic Games of 2012 and subsequent FIFA Football World Cup (2014) attracted further interest due to being held during the annual Islamic month of Ramadan, which entails a daily fasted state (RF) that was observed by many of the participating athletes. RF has become one of the most frequently practiced dietary restriction and fasted state that has been studied [8].

With aerobic exercise and the fasted state harnessing congruent energy metabolism pathways, there appeared to be potential for augmenting gains in aerobic capacity through aerobic exercise in the fasted state. The aim of this literature review was to investigate a pivotal interaction between aerobic exercise in the fasted state and possible benefits for aerobic capacity, with potential implications for undertaking leisurely exercise in the population at large, and the training programmes of elite athletes.

METHODOLOGY

This literature review drew upon sources including an online literature search and relevant textbooks. Electronic databases included in this literature search included FINDit (University of South Wales' literature search facility), PubMed and OpenAthens. The keywords to inform the literature search included "fasted state", "aerobic exercise" and "aerobic capacity". Equivalent terms, such as "fasting state" and "endurance exercise" were also used. Using the inclusion and exclusion criteria specified below, the online literature search resulted in 646 records. After screening for duplicates and relevance to the research objectives, cross-referencing of articles that met the inclusion criteria was undertaken and the resulting cross-referenced articles were also evaluated against the inclusion criteria. 25 items in the form of academic journal articles and books were ultimately used in the literature review.

Inclusion Criteria

- Publications from year 2005 onwards in the English language.
- Human studies.
- Male and female adults of the healthy general and athlete population aged 18 years and older.

Exclusion Criteria

- Publications prior to 2005 and not in the English language.
- Animal studies.
- The child and adolescent population aged less than 18 years.

RESULTS AND DISCUSSION

General Population

Increasing aerobic capacity is a primary objective of aerobic or endurance training. Based on the approach of some athletes to perform endurance training after an overnight fast with the aim of enhancing their endurance performance, Van Proeyen *et al.* included a component of evaluating endurance performance in their study of 20 physically active young males cited in the previous chapter [9]. The endurance training programme, involving moderate-high intensity cycling up to 1.5 hours in duration at approximately 70% VO2max demonstrated that aerobic capacity was increased using FATmax as an indicative measure of aerobic capacity. FATmax was noted to have increased almost three-fold (+21% compared to +6%, P <0.05) in the fasted state compared to the carbohydrate-fed state post-tests (Figure 2).

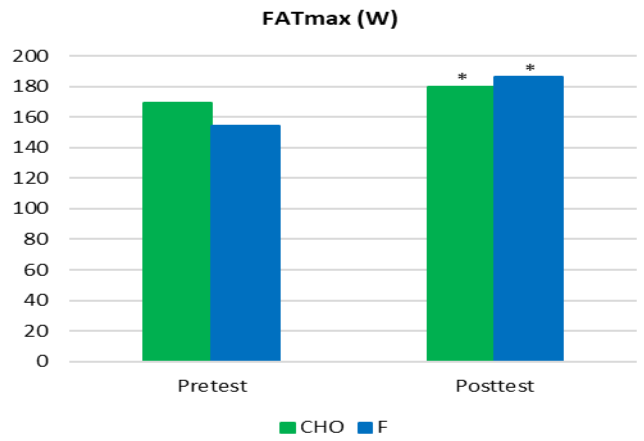

Figure 2: Effects of training in the fasted state (F) vs. training in the carbohydrate-fed state (CHO) during an incremental exercise test to exhaustion. Data provided are means + SE (F: n = 10; CHO: n = 10). An incremental exercise test and a 1-h time trial were performed on a bicycle ergometer before (pre-test) and after (post-test) in either the fasted state (F) or with ample carbohydrate intake before and during the training sessions (CHO). FATmax represents the exercise intensity estimated to correspond with the maximal rate of fat oxidation. VO2max, Maximal oxygen uptake. *P < 0.05 vs. pre-test (produced based on data from Table 1, Van Proeyen *et al.*, 2011) [9].

One-hour time trials at high intensity of approximately (85%), were also conducted for both (F and CHO), groups Both yielded a small but significant differential of (7-8%), improvement in performance following the training programme but there was not noted to be an effect for the fasted state This may have been due to the higher intensity workload or the relatively short period of training indicating that fasted state training may be a useful strategy to improve endurance exercise performance at a level of moderate-high intensity training.

Aziz *et al.* studied a cohort of 10 moderately-trained young men who ran (15-25km), weekly in the three months preceding the study period [10]. The cross-over design meant that the participants served as their own control comparing endurance running performance during (RF), and normal fed state The preceding meals were standardised and performance testing included a pre-loading run of 30 minutes at (65%), (VO2max), followed by a 30-minute time trial In comparing the control and (RF), states physiological responses including perceived exertional ratings and heart rate were not statistically different There was a small but significant difference in achieving a greater distance during the time trial of the control state, specifically (5649m), compared to (5448m), in (RF), (p=0.023), Although this study also indicated that (RF), with high intensity exercise may cause a performance decrement, the authors noted inter-individual variations with five participants demonstrating decrement four with no significant change and one with an improvement in (RF), compared to control state This could have been due to differing baseline fitness levels although these were not accurately defined beforehand in this study which would allow fitter individuals to cope better with the physical and psychological strains of training during a fasted state.

Stannard and Thompson also studied members of the general population albeit a small sample size of eight physically active men with an average of 25 years, who underwent cycle ergometer testing at three 10-minute workloads (45%, 60% and 75% VO2max), comparing pre (RF), and twice during (RF) [11]. Four of the subjects were unable to complete testing at the higher intensity of (75%), (VO2max), so comparisons were made for the lower two intensities. A reduction of (5-6%), in (VO2max), was noted during the first 20 minutes of exercise at (45% and 60% VO2max), by the end of (RF), indicating an increase in efficiency with (RF), but with suitability for low-moderate intensity exercise based on the limited results The authors did note a decline in body weight of (1.3kg), with (RF), but this was not reflected in percentage body composition and was likely due to a net energy deficit Chaouachi *et al.* also discussed the possibility of energy deficit during (RF), and consequent loss in body weight being contributory to transient decrements in performance and that these would need to be considered among fluid changes and training load variations within the athletic population [12].

Athlete Population

Chaouachi *et al.* evaluated the effect of (RF), on maximal exercise performance in 15 elite judo athletes with international competition experience [13]. The semi-longitudinal study investigated aerobic performance (pre-RF), twice during the month-long (RF), and three weeks (post-RF), Amongst power and maximal sprint testing aerobic capacity testing was undertaken through (VO2max), and (HRmax), after a multi-stage fitness test (MSFT), Although the (MSFT), was always conducted after maximal sprint testing tests were conducted at the same time on each occasion to minimise circadian influences and were effectively at around nine hours of fasted state to allow for adequate testing time prior to the completion of the total duration of [12-13]. hours' fasted state Training load and macro-nutritional intake was otherwise maintained consistently during the study period. The authors noted that (VO2max), and HRmax were not significantly changed through the study period and that the metabolic challenges of

(RF), did not affect elite endurance performance whilst maintaining their usual training load.

Chaouachi *et al.* cited a study of young club and college level team athletes who underwent a seven-week high intensity training programme with RF coinciding with weeks 3-6 of the programme [12]. The carefully-structured training programme resulted in aerobic capacity improvements in both fasted and non-fasted groups, suggesting that a well-planned and regulated training regimen can modulate for the physical challenges of training alongside (RF), (Aziz *et al.),* also emphasised the role of a well-structured training programme as a result of examining the impact of an aerobic conditioning programme which involved six sessions of high intensity interval running amongst elite young football players during (RF), demonstrating that a comparison of perceived exertional ratings and maximal aerobic performances between fasted and non-fasted control groups revealed no significant difference [14].

Careful management of elite athlete training load was also highlighted by Mirza *et al.* who studied 10 professional football players with submaximal velocity shuttle runs undertaken over a 12-week period that spanned (RF) [15]. A comparison of fasted and non-fasted players indicated that aerobic performance appeared to deteriorate with (RF), but this also coincided with a lower mean training stimulus which was adjusted for (RF), This suggests that coaches and players participating in (RF), could consider customisation of training programmes to aim for the maintenance of optimal performance.

A cohort of young football players were recruited by Kirkendall *et al.* to evaluate the effects of (RF), on performance, which included the Multi-stage Shuttle Test (MST), as a parameter of endurance performance and involves continuous (20-m), shuttle runs at steadily increasing speeds [16]. 85 players participated with (MSTs), conducted in four groups fasting am fasting pm non-fasting am non-fasting pm but only 45 continued beyond the (RF), period The results indicated a lower mean insignificant overall distance of (1576m), during (RF), compared to (1625m), (pre-RF), The mean distance in the fourth week of (RF), was significantly greater at (1761m), and greater yet at (1861m), post (RF), amongst the 45-player continuing subgroup There was not noted to be any statistical effect for post (RF), but there was a tendency for the 45-player subgroup to demonstrate increased mean distance when comparing fasted and non-fasted players (Figure 3).

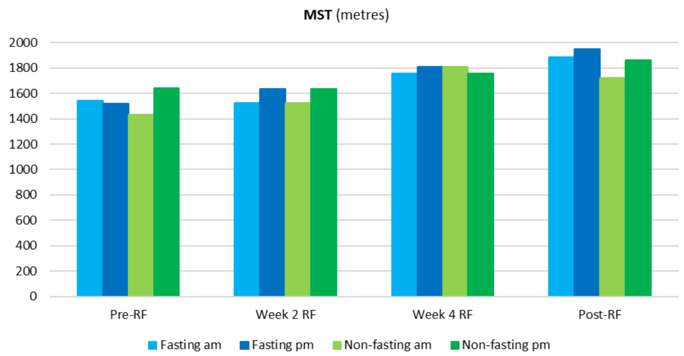

Figure 3: MST performance result by measurement occasion, fasting and time of day. Produced based on data from Table III, Kirkendall *et al.*, 2008) [16].

The players in the study trained consistently through RF and the transient indication of performance decline early in RF may be due to behavioural and lifestyle alterations, to which the players adjusted accordingly and achieved at least equivalent subsequent performances, based on the assumption that all the players did indeed provide their maximal effort during maximal effort tests. Endurance performance was of course measured in test circumstances so extrapolation to competitive match settings would need to be cautious given the multitude of other influencing variables. Zerguini *et al.* also studied a similarly-sized cohort of 100 football players with an average age of 18 years and participating in four different football teams [17]. The team's coaches were entitled to design and conduct their team's training programme, which ultimately resulted in an equivalent improvement in endurance performance measured through a bleep test for both RF and control groups. Familiarity with the testing as well as positive training effect could have explained this observation, but a well-managed and comprehensive training environment resulted in no adverse differential in performance with RF.

Considering elite cycling, Ferguson *et al.* studied the effect of caloric restriction and exercise in the fasted state within a group of 10 competitive and trained cyclists to ascertain any impact on two-hour submaximal endurance and maximal exercise performance [18]. The participants were of a similar baseline fitness level, had fixed macronutrient intake amounting to 40% less than their full daily requirements but followed their usual training regimen during the study period. Exercise testing was undertaken after an 11-hour overnight fast with water permitted ad libitum. There was no significant difference noted between baseline and final testing in either submaximal exercise performance or VO2max. The average perceived exertional ratings did decrease from baseline to final testing and, taken in conjunction with the consistent physiological parameters, suggested that adaptations to the caloric restriction and fasted state exercise may have improved metabolic efficiency, rather than any reduction in effort. This indicated that caloric deficits, 40% in this case over three weeks, can be tolerated with no decrement in moderate-high intensity exercise and can in fact facilitate body fat loss while maintaining lean muscle mass. However, the population studied was highly-trained and may be physiologically better-equipped to withstand as well as better-positioned to make use of this regimen in pre-season training or pre-competition weight management.

Middle-distance running performance during RF was investigated by Brisswalter *et al.* with 18 well-trained participants who were split in to an RF and control group. Six-minute submaximal exercise testing and a 5000m run performance was conducted before RF and a second during the fourth week of RF [19]. No significant difference was observed in running efficiency or aerobic capacity, although there were interestingly differences noted in muscle performance parameters, indicating the need for further investigation in the context of RF and resistance exercise.

Chennaoui *et al.* studied the maximal aerobic velocity (MAV) in eight middle-distance athletes pre-RF, twice through RF and post-RF [20]. They noted decremental performance through RF compared to pre and post-RF, as well as an inverse relationship with plasma interleukin-6 levels (IL-6). Along with adrenaline and noradrenaline levels, IL-6 levels were increased during RF. In line with an association of IL-6 in the mediation of sleepiness and energy availability, the decrease in endurance performance along with fatigue score increase indicates the need to temper training programmes during RF and ensure adequate energy availability and sleep strategies to optimise endurance performance.

An interesting study by Aziz *et al.* investigated the impact of RF on performance in a modified Loughborough Intermittent Shuttle Test (mLIST) undertaken by 14 university team football players with an average VO2max of 50ml/kg/min [21]. The participants acted as their own control by undertaking four mLIST sessions: familiarisation, pre-RF, during RF and post-RF. Dietary and training controls were applied in the 24 hours prior to testing sessions. The mLIST contained four blocks of 15-minute exercise components that were broken down in to 90 seconds of intermittent activities (Figure 4), which the authors calculated to include high intensity exercise for approximately 38% of the time.

Type of Movement	3 x 20m Walking at 5.5km/h	Rest	1 x 15m All-out Sprint	Rest	3 x 20m Jogging at 9.0km/h	Rest	3 x 20m Fast Running at 15.0km/h	Rest
Duration of Activity	39.0s	2.0s	4.0s	2.0s	24.0s	2.0s	15.0s	2.0s

Figure 4: The modified Loughborough Intermittent Shuttle Test (mLIST). Schematic representation of one 90 second (s) cycle of intermittent shuttle movement patterns covering a distance of 195 m. The above cycle was completed 10 times to form one exercise block of 15 min in duration (produced based on Figure 3 from Aziz *et al.*, 2017) [21].

The study found that the fasted players' sprint performances were poorer throughout the 60-minute session compared to both control sessions. This was in contrast to the consistent physiological measurements (lactate, glucose, HR and muscle fatigue indicators) between RF and control sessions. The authors suggested that this decrement in performance, without associated physiological parameter decrement, may have been due to a negative placebo ('nocebo') effect of the fasted state and a consequent pacing of efforts on the part of the players. Although a second mLIST session during RF would have been helpful in providing further insight in to this area, the study findings lend weight to the opinion that fasted state training and competition could be optimised by comprehensive physical and psychological preparation.

Nutrient & Exercise Patterns

Nutritional patterns relating to composition, timing and its GI with respect to energy metabolism in fasted state exercise was explored in the previous chapter and is considered here in the context of fasted state aerobic capacity. Bouguerra *et al.* studied the influence of timing of overnight fasted state training in 24 middle-distance runners [22]. They noted that training in the afternoon, compared to morning or late evening (shortly after the start of the fasting period), yielded better aerobic capacity indicators, including VO2max and 3000m running times. This may have been due to factors such as circadian rhythm influence on substrate metabolism or the possibility of the nocebo effect, discussed by Aziz *et al.* in their study of football players, affecting the psychological approach to training early in the fasted state [21].

Png *et al.* sought to investigate whether GI of a pre-fasting meal would have any bearing on RF endurance performance [23]. 12 healthy men took part in a randomised crossover trial to complete a 60-minute continuous run after 12 hours of RF, preceded by a control meal (GI 57) or low GI meal (GI 37). There were no significant physiological parameter differences and that ingesting a LGI meal did not provide any performance benefit for RF moderate intensity exercise.

Lane *et al.* investigated the effect of a carbohydrate (CHO) mouth rinse in 12 competitive cyclists, each completing two double-blinded time trials of 60-minute duration following and overnight fasted or fed state [24]. They were provided either 10% maltodextrin or taste-matched placebo mouth rinses at regular intervals during the time trials. The combination of CHO mouth rinse and fed state yield optimal performance, but of note was a greater increment in fasted state performance, indicating that a CHO mouth rinse could be of benefit in optimising fasted state exercise performance.

A review by Williams and Serratosa (2006) discussed the influence of nutrient type on exercise performance in the context of elite competitions and acknowledged the variability in results of studies that used differing populations and measures, such as exercise performance tests and endurance capacity tests [25]. Aird *et al.* echoed the limitations in forming any consistent conclusions [5]. The overall suggestion was to consider a HGI nutritional intake immediately before heavy and prolonged exercise while a LGI intake may be more suitable to maintain feelings of satiety and stability in blood glucose concentrations when considering fasted state exercise. However, the interaction between nutrient-timing and exercise performance needs further research.

CONCLUSION

The aim of this literature review was to investigate a pivotal interaction between aerobic exercise in the fasted state and possible benefits for aerobic capacity, with potential implications for undertaking leisurely exercise in the population at large, and the training programmes of elite athletes.

When considering implications for aerobic capacity and fasted state aerobic exercise in the general population, there were only a limited number of studies available for review. Moderate-high intensity training with an overnight IF pattern improved aerobic capacity when compared with high intensity. In the context of RF, in studies that did investigate high intensity fasted exercise, there were noted to be difficulties in undertaking this level of exercise, with trends of performance decrements in participants completing protocols. Although energy deficits during RF may have played a role in transient performance decrements, individuals with fitter baseline characteristics may have coped better with the physical and psychological demands of fasted state aerobic exercise.

The vast majority of studies in the athlete population that considered effects on aerobic capacity of fasted state aerobic exercise related to the RF pattern of fasting. The one study using an IF overnight pattern with aerobic exercise did not demonstrate any decrement in endurance performance at moderate-high intensity levels of exercise and suggested that highly-trained populations may be better-equipped physiologically to undertake this pattern of training. Physiological aerobic capacity parameters of VO2max and HRmax were not noted to have changed significantly when considering RF aerobic exercise in some studies. Highly-trained athlete populations appeared to maintain running efficiency and aerobic capacity during fasted state exercise with the RF pattern. Key factors in maintaining performance included well-structed training programmes that accounted for adjustment of training schedules as well as other lifestyle factors, such as sleep and diet patterns. This was reinforced by studies that observed decremental performance, albeit transiently early on in the RF period. This could potentially be mitigated with appropriate training stimulus and energy availability, as well as tailored sleep strategies. Performances subsequent to these adjustments matched fed compatriots with the suggestion that post-RF endurance performance may even have relatively improved. Adequate physical and psychological preparation for fasted state exercise was underlined and hinged on coordinated preparation between the coaching team and players, which could help minimise the nocebo effect in RF players.

Other strategies to optimise endurance performance with fasted state exercise included timing of training with proximity to the end of the fasted state duration, which appeared to yield better aerobic capacity indicators and endurance performance. For aerobic exercise with fasted states permitting fluid intake, carbohydrate mouth rinses may provide optimal performance. LGI meals overall may be more suited to fasted state aerobic exercise but patterns of nutrient-timing and exercise performance warrant further research.

Limitations

There were limitations that need to be factored in considering the conclusion and recommendations. The heterogeneity of populations, the range of sample size and diversity in study protocols are limiting factors in forming conclusions with wider application. Although many studies aimed to match the participating cohorts, there were

physiological and lifestyle variables that might have confounded results.

A key point of consideration was also the study context, specifically the general population compared with the athlete population, with the role in the former to improve aerobic capacity and cardiometabolic health while the latter may aim to maximise competitive performance. Another difference in context related to the pattern of fasted state, with RF exercise holding application for a highly-trained athlete population that may have no choice other than to train and compete in the fasted state. This underpinned the background to a great proportion of studies that sought to optimise athlete performance in this context of RF. As there were no studies incorporating competition settings, any patterns of effect observed in fasted state training studies would also need to be interpreted with caution if considering application to fasted state competition.

Recommendations

Aerobic exercise in the fasted state can confer potential benefits in energy metabolism and aerobic capacity to both the general untrained population as well as the highly-trained athlete population albeit with differing perspectives.

Within the athlete population, fasted state aerobic exercise may be considered in the context of training programmes, but also for athletes that observe obligatory RF and maintain participation in training and competition during this period. Fasted state exercise could be employed as part of pre-season preparation and in-season training to help maintain endurance performance while also conserving lean muscle mass. Further investigation with long-term fasted state endurance training programmes extending beyond a few weeks would help elucidate long-term metabolic and aerobic capacity effects, and whether fasted state training programmes may provide any advantages compared to fed state training programmes when considering time-efficiency or performance.

For athletes undertaking training during RF, a comprehensive and well-structured training and competition programme can help mitigate any transient decrements in performance. Structured multi-disciplinary training programmes for individual athletes can help address any physical, psychological and dietary challenges. Close monitoring of athletes and their performance may pick up variance from baseline and assist in addressing any underlying issues.

Although further research is warranted in nutrient-exercise timing patterns in the context of the fasted state, limited evidence from the current literature review indicates that LGI meals preceding the fasted state and CHO mouth rinses during fasted state exercise may optimise performance.

There are planned randomised-controlled trials to compare MICE and HIIT exercise protocols in combination with the fasted stated, but further high-quality research in both the general and athlete population, focusing on the effects of varying intensities and longer study durations of fasted state aerobic exercise, would provide additional evidence to support the wider application of this strategy.

Conflicts of interest

None declared.

Financial Support

None declared.

REFERENCES

1. MacAuley D. Oxford Handbook of Sport and Exercise Medicine. 2nd ed. Oxford: Oxford University Press. 2013;126-28.
2. Whyte G. , Loosemore M, Williams C. ABC of Sports and Exercise Medicine. 4th ed. BMJ Books. 2015;p.111.
3. Gastin P. Energy System Interaction and Relative Contribution During Maximal Exercise. Sports Medicine. 2001;31(10):725-41.
4. Burtscher M. Exercise Limitations by the Oxygen Delivery and Utilization Systems in Aging and Disease: Coordinated Adaptation and Deadaptation of

the Lung-Heart Muscle Axis - A Mini-Review. Gerontology. 2013;59(4):289-96.
5. Aird T, Davies R, Carson B. Effects of fasted vs fed-state exercise on performance and post-exercise metabolism: A systematic review and meta-analysis. Scandinavian Journal of Medicine & Science in Sports. 2018;28(5):1476-93.
6. Margolis L, Pasiakos S. Optimizing Intramuscular Adaptations to Aerobic Exercise: Effects of Carbohydrate Restriction and Protein Supplementation on Mitochondrial Biogenesis. Advances in Nutrition. 2013;4(6):657-64.
7. Zouhal H, Saedi A, Salhi A, Li H, Essop M, Laher I, *et al.* Exercise Training and Fasting: Current Insights. Open Access Journal of Sports Medicine. 2020;(11):1-28.
8. Maughan R, Fallah, J, Coyle E. The effects of fasting on metabolism and performance. British Journal of Sports Medicine. 2010;44(7):490-94.
9. Van Proeyen0 K, Szlufcik K, Nielens H, Ramaekers M, Hespel P. Beneficial metabolic adaptations due to endurance exercise training in the fasted state. Journal of Applied Physiology. 2011;110(1):236-45.
10. Aziz A, Wahid M, Png W, Jesuvadian C. Effects of Ramadan fasting on 60 min of endurance running performance in moderately trained men. British Journal of Sports Medicine2010;44(7):516-21.
11. Stannard SR. Ramadan and its effect on fuel selection during exercise and following exercise training. Asian journal of sports medicine. 2011 ;2(3):127.
12. Chaouachi A, Leiper J, Chtourou H, Aziz A, Chamari K. The effects of Ramadan intermittent fasting on athletic performance: Recommendations for the maintenance of physical fitness. Journal of Sports Sciences. 2012:53-73.
13. Chaouachi A, Coutts A, Chamari K, Wong D, Chaouachi M, Chtara M. Effect of Ramadan Intermittent Fasting on Aerobic and Anaerobic Performance and Perception of Fatigue in Male Elite Judo Athletes. Journal of Strength and Conditioning Research. 2009;23(9):2702-09.
14. Aziz A, Chia M, Singh R, Wahid M. Effects of Ramadan Fasting on Perceived Exercise Intensity during High-Intensity Interval Training in Elite Youth Soccer Players. International Journal of Sports Science & Coaching. 2011;6(1):87-98.
15. Mirza A, Aziz A, Wahid M, Chia M. Impact of Ramadan fasting on submaximal running performance of professional football players. In: 4th Asian Football Confederation Science & Football Medicine Conference. 20011.
16. Kirkendall D, Leiper J, Bartagi Z, Dvorak J, Zerguini Y. The influence of Ramadan on physical performance measures in young Muslim footballers. Journal of Sports Sciences. 2008;26:15-27.
17. Zerguini Y, Dvorak J, Maughan R, Leiper J, Bartagi Z, Kirkendall D, *et al.* Influence of Ramadan fasting on physiological and performance variables in football players: Summary of the F-MARC 2006 Ramadan fasting study. Journal of Sports Sciences. 2008;26:S3-S6.
18. Ferguson L, Rossi K, Ward E, Jadwin E, Miller T, Miller W. Effects of Caloric Restriction and Overnight Fasting on Cycling Endurance Performance. Journal of Strength and Conditioning Research. 2009;23(2):560-70.
19. Brisswalter J, Bouhlel E, Falola J, Abbiss C, Vallier J, Hauswirth C. Effects of Ramadan Intermittent Fasting on Middle-Distance Running Performance in Well-Trained Runners. Clinical Journal of Sport Medicine. 2011;21(5):422-27.
20. Chennaoui M, Desgorces F, Drogou C, Boudjemaa B, Tomaszewski A, Depiesse F, *et al.* Effects of Ramadan fasting on physical performance and metabolic, hormonal, and inflammatory parameters in middle-distance runners. Applied Physiology, Nutrition, and Metabolism. 2009;34(4):587-94.
21. Aziz A, Che Muhamad A, Roslan S, Ghulam Mohamed N, Singh R, Chia M, *et al.* Poorer Intermittent Sprints Performance in Ramadan-Fasted Muslim Footballers despite Controlling for Pre-Exercise Dietary Intake, Sleep and Training Load. Sports. 2017;5(1):4.
22. Bouguerra L, Ben Abderrahman A, Chtourou H, Zouhal H, Tabka Z, Prioux, J, *et al.* The effect of time-of-day of training during Ramadan on physiological parameters in highly trained endurance athletes. Biological Rhythm Research. 2017;48(4):541-55.
23. Png W, Bhaskaran K, Sinclair A, Aziz A. Effects of ingesting low glycemic index carbohydrate food for thesahurmeal on subjective, metabolic and physiological responses, and endurance performance in Ramadan fasted men. International Journal of Food Sciences and Nutrition. 2014;65(5):629-36.
24. Lane S, Bird S, Burke L, Hawley J. Effect of a carbohydrate mouth rinse on simulated cycling time-trial performance commenced in a fed or fasted state. Applied Physiology, Nutrition, and Metabolism. 2013;38(2):134-39.
25. Williams C, Serratosa L. Nutrition on match day. Journal of Sports Sciences. 2006;24(7):687-97.