Normative data for maximal aerobic speed for field sport athletes: A brief review.
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Review of the Literature

NORMATIVE DATA FOR MAXIMAL AEROBIC SPEED FOR FIELD SPORT ATHLETES: A BRIEF REVIEW

Daniel Baker[1] & Nathan Heaney[2]

[1]School of Sport and Exercise Science, Edith Cowan University.
[2]Victorian Institute of Sport.

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The purpose of this short review was to provide some normative aerobic fitness data (MAS scores) for field sport athletes from a) different sports b) different levels of participation c) different ages and d) genders.

ABSTRACT

Many team field sports require the athletes to cover distances of 4 up to 14 km in a game, dictating that the aerobic energy system must provide the major energy contribution. Furthermore, the somewhat intermittent nature of these sports, with athlete's required to repeatedly accelerate, decelerate and change direction, would mean that the aerobic energy system plays a role in facilitating recovery from these actions. Accordingly, the literature overwhelmingly indicates that aerobic fitness is critical for success in team field sports. Typically the measure of Maximal Aerobic Speed (MAS) has been the aerobic variable that most overwhelmingly has been shown to differentiate between athletes participating at different levels of a sport. The purpose of this short review was to provide some normative aerobic fitness data (MAS scores) for field sport athletes in a) different sports b) different levels of participation c) different ages and d) genders. Practicing strength & conditioning coaches could use this data to benchmark where their athletes are in comparison in relation to sport, age, level of participation and gender and then to consider the direction and content of their energy system training programs.

Key Words - MAS, aerobic, soccer rugby.

INTRODUCTION

Team sports require athlete's to cover large distances with in excess of 14 kilometres per AFL game recorded consistently by midfielders (15). Team sports are intermittent in nature, with athletes required to repeatedly accelerate, decelerate and change direction, which requires the utilisation of all three energy systems (Phosphogen, Glycolitic and Aerobic systems). However, stemming from the literature it is apparent that aerobic fitness is critical for team sport success with aerobic fitness underpinning the athlete's ability to recover from the abovementioned high intensity actions (e.g. 3, 11-13, 17-21). Researchers often refer to Maximal Aerobic Speed (MAS) as a practical and time effective way to assess the aerobic energy system of team sport athletes (21) as the Velocity at VO2max (vVO2max) derived from treadmill testing with gas analysis can be impractical for team sports to administer due to cost, time and equipment required.

The purpose of this manuscript was to provide some normative data, derived from a brief review for the literature and other non-published sources, of measures of Maximal Aerobic Speed (MAS) for field sport athletes from various sports and levels of participation. It is not the scope of this manuscript to comment extensively on the validity or otherwise of the various tests of MAS that have been chosen by the researchers to measure MAS.

METHODS

A review of the literature was conducted using Google Scholar with key words such as "Maximal Aerobic Speed", "Velocity at VO2 Max" (and their acronyms MAS & VVO2 Max), "aerobic" and "athlete". Furthermore, searches were conducted in two specific journals of strength and conditioning (Journal of Strength & Conditioning Research and Australian Journal of Strength & Conditioning) in a bid to increase the elite athlete/sport relevancy of the data (as opposed to measures obtained on college aged students, non-sporting individuals etc.). From this research, a cohort of less than 40 papers were selected that identified the measures of MAS/VVO2 Max in competitive athletes. Of most interest, especially papers that encompassed elite athletes or possessed athletes of different levels of sport achievement. As a paucity of published data is available for some sports that are interest to strength & conditioning coaches, some previously unpublished data obtained by the authors in the course of their employment as strength & conditioning coaches to elite athletes was also included (2, 23). It was felt that the inclusion of some of these MAS scores for these sports of rugby league, rugby union, netball, triathlon and field hockey, would add to the robustness and depth of this review and aid strength & conditioning coaches working in those sports. It may also spur much needed research in these sports which lack comparative published data in comparison to MAS research in sports like soccer and AFL football.

The purpose of this review was to report normative data for team sport athletes from various sports and levels of participation, (and age and gender levels where possible) that strength and conditioning coaches may use to benchmark athlete progress or facilitate the design and administration of aerobic conditioning sessions.

Measuring Maximal Aerobic Speed (MAS)

There is some debate as to the most accurate way to measure aerobic fitness in team sport athletes (7). The MAS is physiologically defined as the lowest speed at which maximal oxygen uptake (VO2 max) has occurred (7, 38). In a laboratory this is measured with expensive and time consuming gas analysis systems whilst running on a treadmill, according to a number of accepted testing protocols (7, 38). However, some athletes can still run slightly faster than the first speed at which VO2 maximum has occurred without any change in VO2max so there can be a slight difference in speeds at which VO2 max is occurring (but physiologically, the lowest speed at which VO2max occurred is the definition of MAS). This is one of the many confounding factors that sometimes cloud the issue of measuring MAS in athletes for the purpose of aerobic fitness assessment and subsequent training prescription.

Table 1 - Brief description and commentary of the various tests used to determine MAS.

Name of test	Brief description	Additional comment
Laboratory (eg. 44)	Gas analysis to determine VO2 max while running on a treadmill	Considered the gold standard, but different protocols exist for treadmill running (e.g. incline). Lengthy, expensive and impractical for most situations.
Multistage Montreal Beep (29)	Field test with 2-minute stages of incrementally increasing speed around a track. Cones positioned every 20-m and audible beeps according to the speed of the stage to aid the athlete with pacing.	Good correlation with laboratory measures of MAS (r=0.96). Lengthy time for the test has led many to modify it as they believe that the buildup of fatigue precludes a true MAS.
VAMEVAL (43)	Similar to above, but 1-minute stages. Around a 200-m track with cones every 20-m and audible beeps according to the speed of the stage to aid the athlete with pacing.	
YoYoIR1 (3)	Repeated 2 × 20-m runs back and forth between the starting, turning, and finishing line at a progressively increased speed controlled by audible beeps. Between each running bout, the subjects have a 10-s active rest period, consisting of 2 × 5-m of jogging.	
Carminattis (10)	Incremental intermittent shuttle runs performed between two lines set at progressive distances apart. During the test the running pace is controlled by a constant timing every 6-s.	The test protocol starts at a speed of 9 $km \cdot h^{-1}$ and a corresponding running base of 15-m, which is increased by 1-m at every 90 s stage. Each distance stage (i.e. from 15-m to exhaustion) is composed of 5 repetitions of 12-s shuttle runs interspersed by a 6 s walk to be performed between two lines set 5-m apart from the start/finish line.
Multistage Shuttle Beep (31)	Field test with 1-minute stages of incrementally increasing speed run between two lines that are 20-m apart. Audible beeps according to the speed of the stage aid the athlete with.	Less well correlated with a laboratory assessed MAS due to the constant shuttling reducing the speed. To gain a more accurate measure of MAS, this equation is used (i.e. MSST corrected) MAS = Final shuttle speed in km/hr. x 1.34 -2.86 = MAS in km/hr. (4) Or Estimated VO2 max/3.5 = MAS in km/hr. (30)
Set Time trial (5, 14)	Tests of 5-minutes or 6-minutes, which is the typical time limit that MAS can be maintained during maximal effort aerobic running. Athletes run as far as they can in the allotted time. E.g. 1200 m in 5-minutes = 4.0 m/s.	The 5-minute version of this test correlates extremely highly to MAS assessed by the laboratory method, more so than the Montreal test (5). Simple and quick, yet is seldom used.
Set Distance trial (19, 33)	A distance that takes between 5- to 7-minutes is chosen. AFL clubs have often used 2 km TT's.	2-km TT are on the edge of MAS, even for AFL athletes as they take 6:30 to 7:30 (19). 3-km take 10-13-minutes and are more closely related to critical speed more than MAS (33).
1200-m Shuttle (27)	A shuttle based run with turns at 20-m, 40-m and 60-m x 5-reps.	A simple test taking about 4.5-6-minutes, but due to the constant shuttling, the following correction to garner a truer measure of MAS is used: 1200/(Time – 29-s (1-s for each turn) = MAS (in m/s) 1-s is used where the body mass is ~ 100 kg, however female and lighter body mass males typically require ~ .7-s per turn. Well correlated with the IFT-30:15 test (27).

For team field sports, aerobic fitness should be assessed utilising running based tests. Over the years a number of simple running-based field based tests have been developed that correlate with MAS measured utilising the treadmill/gas analysis method(s). These field tests can be continuous, intermittent, shuttle based, incremental and/or self-paced. These variables highlight the importance of the testing protocols when assessing aerobic fitness and determining MAS. Table 1 has a very brief description of the fitness tests present in this review, however it should be noted that there are advantages and disadvantages with all field tests and the specific nuances surrounding these tests is beyond the scope of this article. However, for this review, the test that was used to measure MAS is included in the tables and the Practical Implications sections makes some recommendations as which tests may be easiest to implement for strength and conditioning coaches working with team sport athletes.

Methodologies used in different studies to determine MAS

For this review, the most common tests of MAS include laboratory based VO2max testing (43), the Montreal Beep test (30), the Multistage Shuttle test (32), the YOYO IR1 test (3), time trials with set times (e.g. 5-minutes, 4, 14) or set distances (e.g. 1200-m, 1500m, 2000-m) that take the athletes between 4- to 7-minutes to complete (19, 32). Some of these tests have been further refined, such as the Montreal test being amended to include 1-minute stages (42), rather than 2-minute stages.

For the purpose of this review in instances where the MAS was not provided in the research but a field test estimate of VO2 max was described in the literature, then MAS was estimated by dividing that score by 3.5 (29). For example, a VO2max of 55 ml/kg/min developed from any test would be divided by 3.5, to derive a score of 15.71 km/hr. This is described as “corrected” in the tables.

Moreover, the Multistage Shuttle Beep test scores have been corrected by the following formula to garner a more accurate measure of MAS:

Final Shuttle speed (km) x 1.34-2.86 = MAS (in Km/hr.) (4).

This is due to the constant deceleration, change of direction and acceleration associated with the continuous Shuttle Beep test. This results in a lower and inaccurate MAS that need to be addressed via the abovementioned equation to obtain a more accurate measure of MAS (4).

Another newer test is the 1200-m shuttle (out and back x 20-m, 40-m, 60-m x 5-reps) (aka 1.2SRT, 27). To correct for the shuttles and decelerations, a correction of minus 1sec was used for each of the 29 turns. Typically, 0.7sec is used to account for the metabolic costs of completing a 180° change of direction; however the 1200-m shuttle was used with NRL players with an average body weight of 100 kg. Unpublished data by the lead author has found that the 1sec/turn correction provided a closer assessment of MAS than the 0.7sec/turn correction factor.

Finally, MAS scores are often provided in kilometers per hours in research papers, but for this manuscript they have been reported in metres per second (m/s) for a simpler comparison as (m/s) tends to be a more popular method utilised by strength & conditioning practitioners when administering MAS guided conditioning sessions in Australia (1).

RESULTS

The normative data for MAS scores for team sport athletes from various sports and levels of participation, (and age and gender levels where possible) are contained in Tables 2 to 5.

Table 2 - Comparison of MAS scores for elite male athletes from some representative field sports, compared to elite runners.

Sport	MAS (m/s)	Test	Reference
Middle Distance (1.5-3 km) runners	6.22	Montreal	6
Middle distance runner	6.11	Montreal	23
Triathletes	6.09	Montreal	23
Endurance runners (10-km)	5.79	Montreal	8
Australian Rules Football (AFL)	5.03	2 km Time Trial	19
Italian Serie A Soccer	4.91	Rampinini	37
Hockey - Australian Internationals	4.79	MSFT -corrected	26
Gaelic football	4.68	MSFT -corrected	41
Rugby League - NRL	4.36	MSFT -corrected	18
Rugby "7"'s International players	4.26	Treadmill	25

Table 3 - Comparison of MAS scores for male athletes from soccer football.

Sport	MAS (m/s)	Test	Reference
Italian Serie A	4.91	Rampinini	37
English Premier League	4.85	Unknown	39
Lille – Ligue 1	4.8	Montreal	17
French Ligue 1	4.75	VAMEVAL	16
Norwegian National team *	4.58	Laboratory	44
Norwegian 1st Division *	4.5	Laboratory	44
Norwegian 3-5th Division *	4.3	Laboratory	44
Norwegian Junior League*	4.36	Laboratory	44
Brazilian U/16 players	4.55	Carminattis	43
Brazilian U/14 players	4.11	Carminattis	43
Brazilian U/12 players	3.86	Carminattis	43
Spanish Pro Club U/16 team**	4.5	Montreal	20
Spanish Pro Club U/18 team **	4.44	Montreal	20
Spanish Pro Club U/21 team **	4.41	Montreal	20

* mean score for athletes tested between 1989 and 2012.
** This anomaly where the U/16 and U/18 players possessed greater MAS scores than U/21 players was attributed to the strength training undertaken by the U/16 and U/18 year players that led to an increase in MAS whereas the U/21 did not perform strength training and their MAS remained unchanged.

DISCUSSION

The findings will be discussed relevant to key parameters such as sport, level of participation, age and gender.

Relative importance of MAS across different sports

The greater the running demands involved in a field sport, the greater the MAS required for athletes to be successful in those sports. Higher running content in a team sport (e.g. distances covered during a game), appears to be associated with higher MAS and increased success in that sport (see Table 2). For comparison purposes, some data has been included with specialist middle distance (6) and endurance runners (8). These athletes train with larger weekly running volumes and have higher MAS scores when compared to team sport athletes, such as AFL players (14-kms a game, 15, 35), elite European soccer players (10-12 km a game, 3), NRL rugby league players (6-8 km a game, 34) and lastly rugby Sevens players (~2km a game x 3 games/day, 25).

For example, a MAS score of 4.5 m/s is considered quite high in NRL rugby league, however that level of MAS would be considered inadequate for European 1st Division soccer or AFL football, due to the greater aerobic running demands in those games. Furthermore, the higher the level of participation within a team sport, the greater the distances that are covered in a game ~ thus higher the MAS for the athletes involved (see Table 3). For example, U/20 years NYC rugby league players may only cover ~ 4km in a game (34) and exhibit MAS scores of ~ 4.16 m/s (18) compared to NRL players whom have recorded MAS scores of 4.36 m/s (18) (see Table 3).

As such, it can be clearly seen in Tables 2-5 that the greater the running demands involved in a sport, the greater the MAS required for athletes in that sport to compete, especially at the highest level.

MAS comparisons within sports and level of participation

Tables 3-5 also contain data on the MAS scores for younger athletes and sub-elite athletes from a number of different team sports. It is apparent from these results that to compete at the elite level in most team sports, a well-developed aerobic energy system and subsequently, high MAS is required. Clear differences exist in every team sport between those participating in the highest levels/leagues and the sub-elite levels irrespective of gender. Thus aspiring athletes and strength and conditioning practitioners aiming to compete and prepare athletes to compete at the highest levels in their sports can clearly see what MAS is required.

For example, examining the data in Table 5 illustrates that for female field hockey in Australia, 4.23 m/s appears to be the level of developmental or sub-elite players, whereas a MAS of >4.4 m/s has been recorded for the elite national team, which includes Olympic Gold medalists. The same trends can be seen in the Norwegian male and female soccer data (21).

Table 4 - Comparison of MAS scores for male athletes from other football codes.

Sport	MAS (m/s)	Test	Reference
Australian Rules Football (AFL)	5.03	2 km TT	19
Gaelic football	4.68	MSFT -corrected	41
Rugby League NRL > 3-Yrs in NRL	4.55	1200 ST-corrected	2
Rugby League NRL	4.36	1200 ST-corrected	2
Rugby League NRL	4.36	MSFT -corrected	18
NRL – Grand Final selected players*	4.3	MSFT -corrected	2
NRL – Not selected in Grand Final *	4.23	MSFT -corrected	2
Rugby League NYC (U/20 yrs)	4.16	MSFT -corrected	18
Rugby League NYC (U/20 yrs)	4.15	1200 ST-corrected	2
Australian Rugby Union Squad	4.32	MSFT -corrected	2
Australian Rugby Union Backs	4.41	MSFT -corrected	2
Australian Rugby Union Forwards	4.23	MSFT -corrected	2
Rugby Union “7”s Internationals	4.26	Treadmill	25
South African U/20 Rugby Union Backs **	4.23	MSFT -corrected	32
South African U/20 Rugby Union Forwards **	4.04	MSFT -corrected	32

* denotes from within the same NRL squad, players either selected or not selected to play in the NRL Grand Final
** (13-yr mean)

Table 5 - Comparison of MAS scores for male athletes from other fields sports.

Sport	MAS (m/s)	Test	Reference
Futsal Brazillian Pro	4.86		36
Futsal Brazillian Semi-Pro	4.26		36
Scottish National Hockey team	4.84	MSFT -corrected	46
Australian National Hockey team	4.79	MSFT -corrected	25
Australian level Hockey players	4.48	MSFT -corrected	26
Victorian State League Men’s Hockey	4.80	YOYO IR1	22
Victorian State League Men’s Hockey	4.79	YOYO IR1	22
Lacrosse US College 1st team	4.05	Laboratory	42
Lacrosse US College 2nd team	3.82	Laboratory	42

Trends in age related changes in MAS

The extensive data collection by researchers involved in soccer football has illustrated the changes that take place in MAS with the combination of maturation and training. Observing the data in the various Tables illustrates that MAS scores for child soccer players appear to be under 4.0 m/s (42), improving to around 4.5 m/s for elite U/16 players (20). From these levels, if athletes aspire to compete in European Leagues, they would need to improve their MAS to at least 4.7 m/s, preferably 4.8 - 4.9 m/s (see Table 3). Thus from the U/16 level, athletes may still have to improve their MAS by 8-10% to achieve the levels possessed by elite European soccer players. Presumably similar progressions in MAS would need to take place for AFL players across the teenage years ~ which could be seen as even more difficult with the larger gains in body mass that those athletes must undertake.

Gender

There is less data for female athletes across a similar time frame (see table 6); however the Norwegian data shows that elite high school soccer players exhibit MAS scores of 3.67 m/s, which increases to 3.86 m/s for the National Junior team and to 4.1 m/s for the national team, which happens to include the 2000 Olympic Gold medalists (21). This level of 8-10% change in MAS from mid-teenage years to elite performer mirrors the degree of change exhibited in male soccer players.

Table 6 - Comparison of MAS scores for female athletes from various fields sports.

Sport	MAS (m/s)	Test	Reference
Victorian Vipers, Australian Hockey National League	4.58	YOYO IR1	23
Victorian Institute of Sport Scholarship Holders	4.58	MSFT-corrected	23
Victorian Institute of Sport Scholarship Holders	4.53	YOYO IR1	23
Elite Australian Hockey	4.4	MSFT-corrected	26
Victorian Fury, Australian Netball League	4.48	YOYO IR1	23
Victorian Fury, Australian Netball League	4.43	YOYO IR1	23
Australian Hockey National Team	4.42	MSFT-corrected	45
Victorian Vipers, Australian Hockey National League	4.44	YoYo IR1	22
Australian Hockey Sub-Elite Squad	4.23	MSFT-corrected	45
Norwegian National Soccer team* (includes 2000 Olympic Gold medalists)	4.11	Laboratory	21
Norwegian 1 st Division Soccer *	4.0	Laboratory	21
Norwegian 2nd Division Soccer*	3.72	Laboratory	21
Norwegian Junior (U/20) National Soccer team *	3.86	Laboratory	21
Norwegian Elite High School Soccer Juniors*	3.67	Laboratory	21

* 19-year averages 1989-2007.

Trends in MAS and ability to tolerate large training loads

More recently, Gallo et al. reported that for every 5 seconds that AFL players were behind their team-mates in a 2 km time trial measure of MAS, they reported field tactical training sessions one full RPE point higher (19). So while other tests such as YOYO IR2 (28) may have been shown to be predictors of AFL (34) and soccer (11) playing performance (presumably because these tests also assess the anaerobic system as well as the aerobic system), the simple measure of MAS appears to be a measure of an athlete's ability to tolerate the training loads associated with professional field sports. Therefore the measure of MAS should not be seen only as a direct correlate of field sport performance, but also a determinant of the ability to perform the large and physically demanding training loads that are required for success in professional field sports.

CONCLUSIONS AND PRACTICAL IMPLICATIONS

There are a number of different field tests that are available to assess MAS in field sport athletes. In some instances, differences do exist in the scores that athletes register in different MAS tests. However, it is more apparent that there is a strong correlation between scores in a number of tests and that scores derived from different tests can be interchangeable and used for training prescription (e.g. 3, 5, 7, 10, 13, 14, 28, 32, 36, 42). Furthermore, if any single test is chosen and utilised consistently over long-term periods, then this will eradicate validity concerns. The following recommendations can be made regarding tests of MAS:

1. The simplest and quickest tests of MAS are time trials of 5-, 6 or 7-minutes. The extremely high correlation between the 5-minute test and MAS obtained in other tests validates it use (r = 0.94, ref., 5), especially when dealing with a large number of athletes who are not at the elite aerobic fitness level.
2. Equally efficient would be distance trials that take the athletes between 5- to 7-minutes to complete. Thus 1200-m distance trials for younger or most female athletes, a 1400-m distance trials for rugby league & union players as well as female elite hockey players and 1800- or 2000-m distance trials for elite/professional male soccer, field hockey or AFL players can be recommended as easy-to-administer and reliable tests of MAS.
3. If athlete pacing is a concern, then a staged test with audio signals may be a viable alternative (eg. Multistage Beep or Montreal tests). If the Multistage Beep test is used, the score must be converted with the formula described above to obtain a true MAS score.

The data detailed in this review highlights the importance of a MAS score appropriate to the athletes' gender, sport, level of participation and age. A low MAS score may also indicate a decreased ability to tolerate the training loads required to be successful at any participation level, but especially for the professional level in field sports. Therefore if an athlete possesses a MAS score that is deemed inadequate for their sport, age, gender and level of participation, then appropriate training can be undertaken to improve this physical quality. The types of training that are necessary to increase MAS scores in field sport athletes have been previously detailed by the authors (1, 22). Basically, the most efficacious training for field sport athletes occurs when using intervals at or above the 100% MAS score.

If, despite diligent training over a prolonged period, a sub-elite athlete aspiring to elite level cannot attain the MAS score deemed necessary to be competitive in a certain position, then consideration should be given to altering the sport specific position they play in. For example, if a soccer mid-fielder or AFL ruck player cannot attain a MAS score commensurate with the level of participation they wish to compete in, then the positions of striker or forward may be considered by the coaching staff.

If an adequate MAS score exists for the athlete, then the addition of other tests that include anaerobic metabolism, such as sprint speed, YOYO IR2 (28), the IFT 30-15 (9) or various repeat speed tests that may offer a greater insight into improving intermittent high-intensity running performance appropriate to success in field sport.

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