The Maximal Accumulated Oxygen Deficit Method
A Valid and Reliable Measure of Anaerobic Capacity?

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Abstract

The maximal accumulated oxygen deficit (MAOD) method has been extensively, but unfortunately not very methodically, used; the procedure used to determine the MAOD varies considerably. Therefore, this review evaluates the effect of different numbers and durations of submaximal exercise bouts on the linear power output (PO)-oxygen uptake (VO2) relationship and thus the MAOD. Changing the number and duration of the submaximal exercise bouts substantially influences the calculated MAOD when relatively long submaximal exercise bouts are used and no fixed value of the y-intercept is forced into the linear regression line. This is most likely due to non-linearity of the PO-VO2 relationship for exercise intensities above the lactate threshold (LT). Non-linearity of the PO-VO2 relationship is probably caused by the development of a slow component in VO2 during submaximal exercise at intensities above the LT. Thus, it is important to standardize the number, duration and intensity of submaximal exercise bouts necessary to establish...
A number of studies have been performed trying to define a practical measure of anaerobic capacity. Anaerobic capacity is defined as the maximal amount of adenosine triphosphate (ATP) that can be resynthesized by anaerobic metabolism; that is, mainly phosphocreatine (PCr) hydrolysis and glycolysis. Over the last 20 years, the gold standard to determine anaerobic capacity has been the maximal accumulated oxygen deficit (MAOD). Krogh and Lindhard\(^1\) introduced the term ‘oxygen deficit’ in 1920, Hermansen\(^2\) reintroduced the term in 1969 and Medbo et al.\(^3\) suggested in 1988 that the MAOD was a quantitative expression of anaerobic capacity. A number of studies published since the original report of Medbo et al.\(^3\) have accepted the MAOD as the best practical measure of anaerobic capacity.\(^4-49\)

In the original protocol used by Medbo et al.\(^3\) a linear relationship between treadmill speed and oxygen uptake (\(\dot{V}O_2\)) or between power output (PO) and \(\dot{V}O_2\)\(^{50,51}\) is established for each individual. This relationship is extrapolated to supramaximal exercise intensities and the \(\dot{V}O_2\) demand corresponding to supramaximal workloads is predicted. When this \(\dot{V}O_2\) demand is multiplied by the duration of the exercise bout, the accumulated \(\dot{V}O_2\) demand is estimated. The MAOD is calculated by subtracting the accumulated \(\dot{V}O_2\) measured during the exercise bout, from the estimated accumulated \(\dot{V}O_2\) demand.

Medbo et al.\(^3\) and Medbo and Tabata\(^{50,51}\) used at least ten submaximal exercise bouts with a duration of 10 minutes for the determination of the individual linear PO-\(\dot{V}O_2\) relationship. In the literature, the number, duration and intensity of the submaximal exercise bouts has varied considerably. One goal of this review is to evaluate the effect of different numbers and durations of submaximal exercise bouts on the linear PO-\(\dot{V}O_2\) relationship.

In the original study of Medbo et al.\(^3\) and in more recent publications,\(^{40-42,44,46,47,52-56}\) a supramaximal constant intensity work bout to fatigue was used to determine the MAOD. If anaerobic capacity is a well defined individual entity,\(^3\) then it can be hypothesized that if every protocol ends when the subject is totally exhausted, the anaerobic capacity would be the same for different
exercise protocols. More recently, supramaximal all-out protocols, ramp exercise protocols, intermittent exercise protocols and differently paced supramaximal cycling protocols have been used to determine the MAOD. Therefore, the second goal of this review is to compare the effect of different exercise protocols on the computed value of anaerobic capacity.

There is also a lack of clear evidence about the validity of the MAOD method. Medbo et al. concluded that the MAOD is a quantitative expression of anaerobic capacity and Medbo and Tabata found a strong relationship between muscle characteristics and oxygen deficit, from which they concluded that the MAOD is indeed a valid measure of anaerobic capacity. However, Bangsbo questioned the methodology of the MAOD method as described by Medbo et al. Thus, the last goal of this review is to evaluate the validity and the reliability of the MAOD method.

1. Anaerobic Energy Production: the Time Course of the Different Components

In order to perform exercise, ATP has to be continuously re-synthesized by aerobic and anaerobic ATP-forming processes. During steady-state submaximal exercise ATP re-synthesis is largely accomplished by aerobic processes. However, when exercise is performed at high intensities or during the onset of even submaximal exercise, the ATP-turnover rate exceeds the momentary aerobically attributable energy production and relies on both aerobic and anaerobic processes.

Several studies used maximal intermittent cycling exercise to study anaerobic ATP re-synthesis. Short-term supramaximal sprint-type exercise is highly suitable to study anaerobic energy production, because the POs elicited by the cyclists are far in excess of the PO at VO_{2max} (PVO_{2max}). To meet the high ATP demand of supramaximal exercise, substrate (e.g. adenosine diphosphate [ADP]) phosphorylation from PCr hydrolysis and glycolysis is necessary to overcome the oxygen deficit at the onset of exercise.

The upper limit of glycolysis and pyruvate production is determined by glycogen phosphorylase (Phos) which catalyzes the rate-limiting step in glycolenogenesis. Pyruvate dehydrogenase (PDH), which catalyzes the oxidative decarboxylation of pyruvate to acetyl-CoA, controls the entry of pyruvate into the tricarboxylic acid cycle. Therefore, the time course of the activation of Phos and PDH has been extensively studied in order to get more insight into anaerobic energy production.

Subjects in the study of Parolin et al. had to perform three 30-second bouts of maximal isokinetic cycling, separated by 4-minute rest periods, in order to study the metabolic responses during sprint-type exercise. Muscle biopsy data revealed that the primary source of ATP re-synthesis during the initial 6 seconds of supramaximal exercise was substrate phosphorylation from PCr hydrolysis. The active form of Phos increased significantly during the first 6 seconds and continued to be elevated during the remaining exercise time, which resulted in significant pyruvate production. During the last 15 seconds of the exercise bout, the PCr stores became depleted and glycogenolysis became inhibited, probably by the high [H^+] which diminished the effect of substrate level phosphorylation to ATP re-synthesis. The active form of PDH became fully active throughout the second part of the sprint bout, most likely stimulated by the enhanced pyruvate production and high [H^+], resulting in the oxidation of pyruvate and minimal further lactate production. During the initial seconds of the third supramaximal exercise bout, phosphorylation from PCr hydrolysis was less than during bout one, but still contributed a large amount to ATP re-synthesis. However, inhibition of Phos excluded a large contribution of substrate level phosphorylation to ATP re-synthesis. PDH was completely activated before the start of the third sprint which resulted in close agreement between pyruvate production and oxidation. Thus, the inability to maintain a high level of substrate phosphorylation from PCr hydrolysis and glycolysis during each supramaximal exercise bout and during successive exercise bouts was accounted for by an increased level of oxidative
phosphorylation. It has to be mentioned that besides substrate level phosphorylation, the myokinase reaction also contributes to ATP re-synthesis; however, the resultant amount of free adenosine monophosphate (AMP) is relatively small and therefore contributes only slightly to ATP re-synthesis.

The time course of substrate phosphorylation from PCr hydrolysis and glycolysis is relatively the same during supramaximal constant PO protocols. González-Alonso et al. studied heat production of the quadriceps muscles and the Musculus tensor fasciae latae during intense dynamic knee-extensor exercise to compute the energy liberation of the anaerobic and aerobic energy producing systems. During the initial 30 seconds of the 180 seconds of knee-extensor exercise, the contribution of the aerobic system was only 32%, which increased to >82% after 60 seconds. The increase in oxidative phosphorylation was accompanied by a significant increase (107%) in heat production, without any significant change in PO. The most likely explanation for this finding is that substrate phosphorylation from PCr hydrolysis and glycolysis results in lesser heat liberation per ATP produced than oxidative phosphorylation. These results are confirmed by the study of Krustrup et al., who found a decrease in mechanical efficiency from 56±5% to 32±3% during low intensity knee-extensor exercise and a decrease from 47±4% to 36±3% during a 90-second high intensity bout. The studies of González-Alonso et al. and Krustrup et al. supported the hypothesis that the mechanical efficiency is higher for anaerobic ATP re-synthesis than for aerobic ATP-resynthesis. This important finding of a higher anaerobic mechanical efficiency than aerobic mechanical efficiency has to be taken into account when the MAOD values expressed in mL O₂ eq (oxygen equivalent) per kg body mass (mL O₂ eq kg⁻¹) are converted to concentrations of the different anaerobic components in mmol kg⁻¹. Thus, as long as we speak about the anaerobic capacity in oxygen equivalents or in mechanical work performed, the difference in anaerobic and aerobic mechanical efficiency is of no hindrance.

2. The Construction of a Linear Relationship Between Exercise Intensity and Oxygen Uptake

2.1 Exercise Modality

In the original study of Medbo et al., the chosen exercise modality was treadmill running. Besides treadmill running, Medbo and Tabata also used bicycle exercise to determine anaerobic capacity with the MAOD method. Since these early studies of Medbo et al. and Medbo and Tabata, the MAOD has also been determined for supramaximal rowing, arm cranking, arm cranking, swimming and one-legged, dynamic, knee-extensor exercise. We will only discuss the concerns that come along with the estimation of anaerobic capacity during running and bicycling exercise, as those exercise modalities are most often used.

2.1.1 Running

Several studies investigated the effect of different treadmill inclinations on the MAOD attained during running, from which it can be concluded that uphill running results in significantly higher anaerobic capacities than horizontal running. Olesen found that the MAOD increased from 39.5±10.7 and 56.9±8.0 mL O₂ eq kg⁻¹ at a 1% grade to 69.4±8.3 and 99.8±7.1 mL O₂ eq kg⁻¹ at a 20% grade in anaerobically untrained and anaerobically trained runners, respectively. The results of the study of Craig and Morgan supported the findings of Olesen but they did not find a correlation between the treadmill belt inclination and the MAOD attained during treadmill running (r = -0.15), which suggests that certain subjects show a higher running economy during horizontal running while other subjects show a higher running economy during uphill running. The finding that the percentage inclination and the MAOD are unrelated is in contrast with the finding of Olesen. The oxygen deficit reached a maximum value at a 15% gradient and a further increase to a 20% gradient did not result in an additional increase in oxygen deficit, which suggests the attainment of the anaerobic capacity for running.
Medbo et al. concluded that the MAOD is heavily dependent on the active muscle mass, which suggests that during uphill running a larger muscle mass is activated than during horizontal running. Sloniger et al. used exercise-induced contrast shifts in magnetic resonance images to determine the pattern and intensity of muscle activation during treadmill running. A significant 9% increase in the active muscle mass was found during uphill running as compared with horizontal running, which was achieved by an altered pattern of muscle activation, i.e. the percentage of muscle volume increased significantly (p<0.004) for the Musculus vastus group [i.e. the M. vastus lateralis, M. vastus medialis and the M. vastus intermedius] (23%) and the Musculus soleus (14%), and decreased significantly (p<0.004) for the Musculus rectus femoris (29%), the Musculus gracilis (18%) and the Musculus semitendinosus (17%) from horizontal to uphill running. However, they only found a moderately strong correlation between the increase in MAOD and the percentage increase in muscle activation. It can be concluded that the percentage active muscle mass only explains a small part of the increase in MAOD from horizontal to uphill running and that other factors must be responsible for the difference.

Besides a higher MAOD found during uphill running compared with level running, there is another concern related to the inclination of the treadmill, namely the VO2 slow component (SC), which is the late (i.e. secondary) increase in VO2. Pringle et al. studied the oxygen kinetics during horizontal and uphill (10% grade) running and found that the amplitude of the VO2 SC was significantly higher (40%) during uphill running compared with horizontal running. Based on this finding, it can be concluded that uphill running is less suitable for the determination of anaerobic capacity than horizontal running.

### 2.1.2 Cycling

Just as treadmill inclination was a confounding factor for the determination of anaerobic capacity during running, pedalling rate could influence the estimation of anaerobic capacity during cycling. Several studies used a fixed pedalling frequency to establish the linear PO-VO2 relationship and eventually used this relationship to determine the MAOD during all-out exercise, throughout which pedalling frequency was free to vary, without having studied the effect of pedalling frequency on MAOD.

The effect of pedalling frequency on the MAOD was investigated by Woolford et al., who established three different PO-VO2 relationships, based on submaximal exercise tests conducted on different cycle ergometers, which required pedalling frequencies in the range of 90–100 revolutions per minute (rpm), 120–130 rpm and 90–130 rpm. A higher pedalling frequency resulted in a higher oxygen demand of cycling and a higher resultant MAOD. The MAOD derived during cycling at pedalling frequencies between 90 and 100 rpm was approximately 30% lower than during cycling at frequencies between 120 and 130 rpm or at frequencies between 90 and 130 rpm.

Zoladz et al. investigated the effect of pedalling frequency on VO2 kinetics and found a gradual, non-significant increase in VO2 when pedalling frequency increased from 60 to 100 rpm and a significant increase in oxygen uptake when pedalling frequency was further augmented to 120 rpm. Besides an effect of pedalling frequency on the PO-VO2 relationship and on anaerobic capacity, there is also an effect of pedalling frequency on VO2 SC. Pringle et al. found a significant increase in the amplitude of the VO2 SC when pedalling frequency increased from 35 rpm to 115 rpm, even when the amplitude of the VO2 SC was expressed relatively to the end exercise VO2. The increase in the VO2 SC was probably due to a change in motor unit recruitment patterns.

Thus, for the use of a linear PO-VO2 relationship it is important to choose a fixed pedalling frequency in the range of 60–100 rpm and to maintain this pedalling frequency during the
exhausting exercise bout used to determine the MAOD.

2.1.3 Running versus Cycling

Billat et al.\textsuperscript{[75,76]} published two studies on the effect of exercise modality on the VO \textsubscript{2} SC, from which it became clear that VO \textsubscript{2max} did not differ between running and cycling exercise for triathletes but that the VO \textsubscript{2} SC was significantly higher during cycling compared with running (20.9 ± 2 vs 268.8 ± 24 mL \cdot min \textsuperscript{-1}). Based on these results it can be concluded that for the use of a linear PO-VO \textsubscript{2} relationship horizontal running exercise is preferred above cycling exercise, because the VO \textsubscript{2} SC is less during running compared with cycling and the VO \textsubscript{2} SC is less during horizontal running compared with uphill running.

2.2 The Duration of Submaximal Exercise Bouts

Medbø et al.\textsuperscript{[3]} suggested that submaximal exercise bouts of 10-minutes duration are required to construct the linear PO-VO \textsubscript{2} relationship from which the VO \textsubscript{2} demand of supramaximal exercise bouts can be predicted. The required duration of the submaximal exercise bouts, as proposed by Medbø et al.\textsuperscript{[3]} has been questioned by others.\textsuperscript{[57,58]} Bangsbo\textsuperscript{[57,58]} stated that the duration of the submaximal exercise bouts influences the measured VO \textsubscript{2} values. Whipp and Wasserman\textsuperscript{[77]} and Barstow and Molé\textsuperscript{[78]} found that at low cycling intensities (W) (50, 75 and 100 W) VO \textsubscript{2} reached a steady-state value within 3 minutes. VO \textsubscript{2} continued to increase after 3 minutes and did not reach a steady-state value within 6 minutes for higher exercise intensities (125, 150, and 175 W). The question that rises is: does the SC of the VO \textsubscript{2} kinetics substantially affect the computation of the MAOD?

Bangsbo\textsuperscript{[57]} constructed two linear PO-VO \textsubscript{2} relationships, one based on VO \textsubscript{2} measurements after 4–6 minutes of submaximal running and one based on VO \textsubscript{2} measurements after 8–10 minutes of submaximal running. The difference in the VO \textsubscript{2} demand, estimated from the two linear PO-VO \textsubscript{2} relationships, resulted in a difference in MAOD of 10.5 mL O \textsubscript{2} eq \cdot kg \textsuperscript{-1} (21%), with the longer submaximal bouts yielding a higher predicted VO \textsubscript{2} demand and thus computed MAOD. Thus, the duration of the submaximal exercise bouts can substantially influence the PO-VO \textsubscript{2} relationship and the calculated MAOD.\textsuperscript{[57,58]} Based on these results, Bangsbo\textsuperscript{[57,58]} concluded that it is hard to validate the use of a linear relationship between exercise intensity (i.e. running speed) and VO \textsubscript{2} for the determination of anaerobic capacity.

Buck and McNaughton\textsuperscript{[46]} studied the effect of submaximal exercise bout durations of 2–4 minutes, 4–6 minutes, 6–8 minutes, and the proposed 8–10 minutes\textsuperscript{[3]} on the estimated VO \textsubscript{2} demand, and thus the calculated MAOD. Increasing durations of the submaximal cycling bouts resulted in increasing values of the estimated VO \textsubscript{2} demand and, accordingly MAOD. The linear PO-VO \textsubscript{2} relationship based on submaximal cycling bout durations of 2–4 minutes resulted in a 25.8 ± 8.7% lower MAOD than the linear relationship based on the VO \textsubscript{2} during minutes 8–10. The results of Buck and McNaughton\textsuperscript{[46]} supported the findings of Bangsbo\textsuperscript{[57]} that the duration of the submaximal exercise bouts indeed influences the measured VO \textsubscript{2} and thus the calculated MAOD. However, Buck and McNaughton\textsuperscript{[46]} drew a different conclusion from their results. They concluded that 10-minute bout durations are necessary to establish a linear PO-VO \textsubscript{2} relationship, because otherwise the calculated MAOD is too low.

Maxwell and Nimmo\textsuperscript{[32]} also compared the average VO \textsubscript{2} during minutes 4–6 with the VO \textsubscript{2} measured during minutes 8–10 of submaximal exercise bouts. Significant (p<0.001) differences were found between the average VO \textsubscript{2} of 4–6 minutes versus 8–10 minutes (53.8 ± 3.7 vs 55.8 ± 3.9 mL \cdot kg \textsuperscript{-1} \cdot min \textsuperscript{-1}), which resulted in a different treadmill speed-VO \textsubscript{2} relationship, and thus different MAOD values. Although Maxwell and Nimmo\textsuperscript{[32]} found significant differences in the average VO \textsubscript{2} between 4–6 minutes and 8–10 minutes, no significant differences were found between 8–9 minutes and 9–10 minutes or between 7–10 minutes and 8–10 minutes. Based on these results they recommended the use of 8–10 minutes as an appropriate interval to define the linear treadmill speed-VO \textsubscript{2} relationship.
In summary, the conclusions drawn by Buck and Mc Naughton[46] and by Maxwell and Nimmo[52] are in conflict with the conclusion drawn by Bangsbo.[57] In the study of Buck and Mc Naughton[46] and in the study of Maxwell and Nimmo[52] they did not consider the possibility that the steady-state VO₂ measured during minutes 8–10 of the highest submaximal exercise bouts could be the asymptotic value that was attained after a late increase in VO₂ (the VO₂ SC).[78,79] Green and Dawson[79] found a large SC in VO₂ between minutes 3–6 for high submaximal POs and a smaller amplitude between minutes 6–10. Barstow and Molé[78] even found that the amplitude of the VO₂ SC increased with increasing PO. This SC causes the steady-state VO₂, if attained, to be larger than the VO₂ demand predicted from the PO-VO₂ relationship based on the lower submaximal exercise intensities.[78] Thus, we can conclude that the relationship between treadmill speed and/or PO and VO₂ may be non-linear for exercise intensities above lactate threshold (LT) and that the degree of non-linearity increases with increasing exercise intensity.

2.3 The Effect of the Number of Submaximal Exercise Bouts on the Linear Power Output-Oxygen Uptake Relationship

Medbo et al.[5] used an iterative procedure to determine the minimum number of submaximal exercise bouts necessary to construct a linear PO-VO₂ relationship. The iterative procedure consisted of three steps: (i) a linear PO-VO₂ relationship based on the first two submaximal exercise bouts was established; (ii) the MAOD of the supramaximal constant intensity exercise bout was determined; and (iii) the next submaximal exercise intensity and the corresponding VO₂ was added to the linear regression line. These three steps were repeated until the MAOD started to converge. At least ten submaximal exercise bouts were necessary for the MAOD to converge to a stable value.[5] Despite this early proposed number of submaximal exercise bouts, different numbers of submaximal exercise bouts have been used in the literature. PO-VO₂ relationships have been based on two,[16,32] three,[13,15,35,36,41,56,80] four,[5,19,23,26,28,29,66,67] five,[21,31,40,42,44,71] six,[7,9,11,12,24,25,30,37,38] or eight[69] submaximal exercise bouts.

Buck and Mc Naughton[47] systematically studied the effect of different numbers of submaximal exercise bouts on the linear PO-VO₂ relationship, established for bicycle exercise, and thus the calculated MAOD. Steady-state VO₂ values were determined during 10×10-minute submaximal exercise bouts at intensities between 30 and 90% VO₂max and were used to construct a linear PO-VO₂ relationship.[47] Data points were sequentially removed from the linear PO-VO₂ relationship based on 10×10-minute submaximal exercise bouts, starting with the lowest PO, the highest PO or the most central PO. This systematic removal of data points resulted in 17 different linear PO-VO₂ relationships, which were compared with the linear relationship based on 10×10-minute submaximal exercise bouts, as proposed by Medbo et al.[5] Sequentially removing the lowest or highest submaximal exercise bout from the linear relationship resulted in an increasingly larger difference in MAOD when compared with the MAOD calculated from the 10×10-minute linear PO-VO₂ relationship. Removing the most central PO from the linear relationship predictably resulted in smaller differences in MAOD compared with the other methods for removing data points.[47] It was concluded that the effect of changing the number of submaximal exercise bouts on the linear PO-VO₂ relationship and thus MAOD is dependent on the intensity of the bouts used to establish the linear relationship. Removing the highest submaximal exercise intensities had the most pronounced effect on MAOD and removing the most central exercise intensities had the least pronounced effect. That the effect of removing the lowest or the highest submaximal exercise bouts was not the same implies that the relationship between PO and VO₂ is not truly linear.

The outcome of a reduced number of submaximal exercise bouts, with and without the use of a fixed value of the y-intercept, on MAOD was studied by Russell et al.[14] The accuracy of the estimations of the VO₂ demand and the MAOD was evaluated with 95% confidence intervals.
(CIs), because they questioned the use of the Pearson correlation coefficient, as large differences in MAOD were found despite correlation coefficients \( \geq 0.99 \) in the study of Buck and McNaughton.\(^{[47]} \) Submaximal exercise bouts at intensities of 50, 60, 70, 80 and 90% of the average PO during a 2000 m rowing ergometer test, with a duration of 5 to 7 minutes, and a forced y-intercept of 5.1 mL • kg\(^{-1} \) • min\(^{-1} \) were used to establish a linear PO-VO\(_2\) relationship (5+Y). A second linear PO-VO\(_2\) relationship was established using the same submaximal exercise bouts but without a forced y-intercept of 5.1 mL • kg\(^{-1} \) • min\(^{-1} \) (5-Y). The third and last linear PO-VO\(_2\) relationship required only two submaximal bouts, at intensities between 75–82% and 85–92% of VO\(_{2\text{peak}}\), and a fixed value for the y-intercept (MED). The third regression line is named ‘procedure 3’ in the study of Medbø et al.,\(^{[3]} \) and is suggested as a less time consuming alternative procedure from which the resultant MAOD differed by only 2 mL O\(_2\) eq • kg\(^{-1} \) • min\(^{-1} \) from the MAOD estimated with the 10-point regression line. However, the use of ‘procedure 3’ and thus the use of a fixed y-intercept of 5.1 mL • kg\(^{-1} \) • min\(^{-1} \), as suggested in the study of Medbø et al.,\(^{[3]} \) has only been confirmed for treadmill exercise at an inclination of 10.5%\(^{[3]} \). The three different PO-VO\(_2\) relationships in the study of Russell et al.,\(^{[14]} \) did not result in statistically significant different values for the estimated VO\(_2\) demand and, accordingly, the MAOD. However, the size of the 95% CI was significantly smaller when using the regression line based on the 5+Y method (12.88±2.93) than when using the 5–Y method (27.63±14.47). The length of the 95% CI was of similar magnitude for the methods 5+Y and MED (16.89±10.07). Thus, Russell et al.,\(^{[14]} \) concluded that the three different regression lines resulted in similar VO\(_2\) demand and MAOD values, but that the precision of estimating the VO\(_2\) demand and thus the MAOD improved when a y-intercept of 5.1 mL • kg\(^{-1} \) • min\(^{-1} \) was added to the regression line (5+Y method).

Bickham et al.,\(^{[81]} \) evaluated the effect of different methodological improvements on the anaerobic capacity attained during treadmill running at a grade of 1%. The first PO-VO\(_2\) relationship was based on 10×4-minute submaximal bouts and a forced y-intercept, the second PO-VO\(_2\) relationship was based on 4×4-minute submaximal bouts and a forced y-intercept, and the third relationship was based on 2 submaximal bouts and a forced y-intercept, as suggested by Medbø et al.,\(^{[3]} \) Five of the ten submaximal exercise intensities used in the first linear regression line were below LT and five of them were above LT. When only four submaximal bouts were used to establish a linear regression line, the chosen submaximal intensities averaged 69%, 76%, 86% and 93% VO\(_{2\text{max}}\). Average submaximal intensities of 83% and 93% were used for the linear PO-VO\(_2\) relationship that was based on two submaximal bouts and a y-intercept. The three different regression lines did not result in significant differences in MAOD and in the accompanying 95% CIs, which means that reducing the number of submaximal bouts is acceptable when a fixed value of the y-intercept is used and submaximal VO\(_2\) data is carefully collected.

Green and Dawson\(^{[82]} \) doubted the validity of using the PO-VO\(_2\) relationship for the prediction of the VO\(_2\) demand of maximal and supramaximal cycling exercise. Therefore, they compared the linear PO-VO\(_2\) relationship based on exercise intensities below LT with the linear relationship based on exercise intensities above LT. The use of submaximal exercise intensities above LT resulted in a 14% and 6% greater slope of the regression line for cyclists and untrained men, respectively, compared with the regression line based on exercise intensities below LT. This difference was due to the disproportionally higher VO\(_2\) attained during exercise above LT. Based on these results, Green and Dawson\(^{[82]} \) concluded that the PO-VO\(_2\) relationship is non-linear for exercise intensities above LT, and that the degree of non-linearity increases with increasing fitness of the subjects.

The results of Russell et al.,\(^{[14]} \) and Bickham et al.,\(^{[81]} \) are not consistent with the findings of Buck and McNaughton\(^{[47]} \) and Green and Dawson,\(^{[82]} \) that changing the number of submaximal exercise bouts influences the estimated VO\(_2\) demand and thus the MAOD. This may be due to the use of only 4-minute duration exercise bouts for the
submaximal bouts in the study of Bickham et al.,[81] which is much shorter than the 10-minute duration of the submaximal exercise bouts in the study of Buck and McNaughton,[47] as well as in the original studies of Medbo.[3,50,51] However, Green and Dawson[82] also used 4-minute submaximal bouts to establish the linear \( PO-VO_2 \) relationship, but the difference between the study of Bickham et al.[81] and the study of Green and Dawson[82] is that Green and Dawson compared the linear \( PO-VO_2 \) relationship based on exercise intensities below LT with the linear relationship based on exercise intensities above LT and that Bickham et al.[81] only used exercise intensities above LT for the regression lines that were based on two or four submaximal bouts. The other difference is that Russell et al.[14] and Bickham et al.[81] used a fixed value for the y-intercept, which influences the characteristics of the regression line. The y-intercept was forced to be 5.1 \( mL \cdot kg^{-1} \cdot min^{-1} \) in the study of Russell et al.[14] and the mean y-intercept was 5.5 ± 0.4 \( mL \cdot kg^{-1} \cdot min^{-1} \) in the study of Bickham et al.,[81] where the mean y-intercept was 6.1 ± 2.3 \( mL \cdot kg^{-1} \cdot min^{-1} \) in the study of Buck and McNaughton.[47] In the study of Green and Dawson[82] three different y-intercept values were found for data below, at or above LT, which were 8.8, 7.2 and 2.6 \( mL \cdot kg^{-1} \cdot min^{-1} \) in well trained cyclists, and 9.5, 8.7 and 8.0 \( mL \cdot kg^{-1} \cdot min^{-1} \) in untrained men. These data suggest that there is large variation in the y-intercept when this value is not determined from resting \( VO_2 \) data or set at a fixed value of 5.1 \( mL \cdot kg^{-1} \cdot min^{-1} \) as has been reported by Medbo et al.[3] The changes in y-intercept for the data below, at or above LT were also accompanied by changes in the slope of the regression line, and even small changes resulted in large differences in the estimated \( VO_2 \) demand due to extrapolation of the regression line. The robustness of the \( PO-VO_2 \) relationship increased with the use of a fixed y-intercept, the power of predicting the \( VO_2 \) demand improved by approximately 45% in the study of Russell et al.[14] when a fixed value of the y-intercept was forced in the linear regression line. Although, it has to be mentioned that even with the use of a fixed y-intercept there was still a 95% CI of 12.88 ± 2.93 \( mL \cdot kg^{-1} \cdot min^{-1} \) with a mean value for the estimated \( VO_2 \) demand of 71.28 ± 9.49 \( mL \cdot kg^{-1} \cdot min^{-1} \).[14]

Based on the results of the described studies, we can conclude that there is an effect of changing the number of submaximal exercise bouts on the linear \( PO-VO_2 \) relationship and thus MAOD. This effect is most likely due to the non-linearity of the \( PO-VO_2 \) relationship for exercise intensities above LT. The effect of reducing the number of submaximal exercise bouts is reduced when a fixed value of the y-intercept has been used to establish the linear regression line. Thus, the robustness of the \( VO_2 \) demand prediction increases with the use of a fixed y-intercept, since values at the extremes of the regression line can profoundly affect the extrapolated \( VO_2 \) demand.

3. The Influence of Supramaximal Exercise Protocol on the Computed Maximal Accumulated Oxygen Deficit (MAOD) Values

In the original protocol of Medbo et al.,[3] a supramaximal constant intensity exercise bout was used to determine the MAOD. In more recent publications, different exercise protocols have been used to determine the MAOD. In this section we will discuss the effect of different supramaximal exercise protocols on the computed MAOD values.

Craig et al.[52] compared the MAOD of a supramaximal constant intensity (115% \( VO_{2\text{max}} \)) exercise test with the anaerobic capacity attained during 70, 120 and 300 seconds of supramaximal all-out cycling. Twelve of their eighteen subjects were high performance track endurance cyclists and the other six were sprint cyclists. Track endurance cyclists attained the highest MAOD values during the 300-second all-out protocol, and the sprint cyclists reached their highest MAOD values during the 70-second all-out protocol. This suggests that it is important to determine the MAOD during an exercise protocol that is specific for the athlete’s event.

In a study of Gastin et al.,[37] untrained and endurance trained subjects performed supramaximal constant intensity and supramaximal
all-out exercise protocols for the determination of anaerobic capacity. They found no significant differences between the mean MAOD values of the different exercise protocols. However, closer analyses of the individual data showed that individual subjects may perform better on a specific protocol. Part two of their study showed that untrained subjects achieved a higher MAOD during the supramaximal all-out protocol and that endurance-trained subjects attained a higher MAOD during the supramaximal constant intensity protocol.[37]

The effect of a continuous ramp exercise protocol on the computed value of the anaerobic capacity was investigated by Pouilly and Busso.[22] No significant difference was found between the MAOD attained during the supramaximal constant intensity protocol and during two ramp exercise protocols. However, the variability in MAOD between the two ramp exercise protocols was very high (54.5%).[22]

Tabata et al.[11] even showed that a high intensity intermittent exercise protocol could be used to determine anaerobic capacity. The MAOD of intermittent exercise was calculated by subtracting the difference between the \( \text{VO}_2 \) demand at rest and the \( \text{VO}_2 \) during the rest periods from the \( \text{VO}_2 \) deficit of each bout of exercise. The attainment of anaerobic capacity depends on the duration of the exercise intervals and the duration of the resting periods.[11]

In summary, we can say that different supramaximal exercise protocols (i.e., constant, all-out, ramp and intermittent) can be used to determine the MAOD with broadly comparable results. Nevertheless, it is probably important to choose an exercise protocol that is specific for the athlete’s event.

4. The Validity of the MAOD Method

In order to be able to use the MAOD method for determining anaerobic capacity we have to be sure that the method is valid. Is the MAOD method correct in measuring what it is designed to measure, that is, anaerobic capacity?

Bangsbo et al.[67] evaluated the validity of the MAOD method by comparing the MAOD attained by untrained males during a supramaximal constant intensity one-legged knee-extension protocol, during which only the quadriceps muscles were active, with the amount of anaerobic energy release estimated from metabolic measurements. The changes in ATP, creatine phosphate, inosine monophosphate and lactate concentration ([\( \text{La}^- \)]) were determined from muscle biopsy samples taken from the active muscles. Further, lactate efflux and \( \text{VO}_2 \) of the active muscles were estimated from measurements of blood flow and the femoral arterial-venous difference for lactate and oxygen. In order to avoid blood flow from the lower leg from influencing the measurements, an occlusion cuff was placed just below the knee. The anaerobic ATP production of the active muscle mass was calculated from these metabolic measurements and was related to the leg and pulmonary (whole-body) \( \text{VO}_2 \) deficit of the exhaustive work bout. Bangsbo et al.[67] reported that the MAOD was closely related to the amount of anaerobically attributable energy in a single muscle group during one-legged exercise. Based on these results it was concluded that the MAOD is a quantitative expression of anaerobic capacity when exercising with a single muscle group.[67]

Green et al.[83] assessed the validity of the MAOD method in well trained male cyclists by inspecting the relationship between MAOD, the amount of anaerobic ATP produced, and measures of the anaerobic potential of muscles. Muscle biopsy samples were taken from the \( M.\ \text{vastus lateralis} \) and analysed for ATP, PCr, creatine, [\( \text{La}^- \)] and ADP. Equation 1 was used to determine the amount of anaerobic ATP produced from differences in pre- and post-exercise concentrations of muscle metabolites:[83]

\[
\text{anATP}_m = 1.5\Delta[\text{La}^-] + \Delta[\text{PCr}] + (2\Delta[\text{ATP}] - \Delta[\text{ADP}])
\]

(Eq. 1)

No relationship was found between the MAOD of well trained male cyclists and the amount of anaerobically attributable ATP produced, in vitro \( \beta \) (muscle buffer value) or enzyme activities. However, there were significant relations between the amount of anaerobic ATP produced and in vitro \( \beta \) or enzyme activities, from which
Green et al. concluded that their measures of the muscle anaerobic ATP content are valid.

The results of the study of Green et al. were not in agreement with the results of Medbo and Tabata who found a close relationship between rates of anaerobic ATP turnover in the active muscles and the anaerobic energy production in the whole body, as measured by the MAOD method. Muscle metabolite concentrations (ATP, PCr and [La⁻]) were determined from muscle biopsy samples taken from the M. vastus lateralis after termination of the exhausting cycling bout, as in the study of Green et al.

Equation 2 was used to calculate the muscle anaerobic ATP production (anATPₘ) in the study of Medbo and Tabata:

\[ anATP_m = 1.5\Delta[La^-] + \Delta[PCr] + [ATP] \]

However, there were some differences between both studies that could have resulted in different outcomes. Green et al. used an extended version of the equation used by Medbo and Tabata (equation 1). Neither equation accounts for the amount of lactate released to the blood, which accounts for somewhere between 5 and 38% of the total anaerobic ATP production according to Bangsbo. Thus, the estimated amount of anaerobic ATP produced is underestimated by both Green et al. and Medbo and Tabata. Further, it is unknown if the measured muscle metabolite concentrations are representative of the concentration in the whole muscle or of the whole muscle group and the main limitation of the validation attempts of Medbo and Tabata is that the active muscle mass is unknown during whole body exercise. The amount of energy release estimated from muscle biopsy data and the MAOD were significantly correlated when the working muscle mass was estimated to be 25% of the body mass. Medbo et al. also used this percentage in the discussion of the metabolic components of the MAOD during running exercise. However, the estimation of the active muscle mass from total body mass is not based on direct measures and does not take into account differences in fat percentage between men and women and between different subjects. Additionally, the percentage of active muscle mass can also vary between subjects. The mean active muscle mass determined from magnetic resonance images in the study of Sloniger et al. was 5.6 kg for horizontal running and 6.1 kg for uphill running with a mean body mass of 59.7 ± 8.2 kg, which corresponds to 9.4 and 10.2% of the body mass of physically active female students. A lower percentage of active muscle mass, 10.2% instead of 25%, results in a much higher concentration of anaerobic ATP produced per unit of active muscle mass, 141 mmol ATP/kg instead of 63.5 mmol ATP/kg, in the same subjects. These uncertainties about the active muscle mass result in significantly different MAOD values. Besides that, there is also some doubt about the ratio between high energy phosphate produced per oxygen molecule consumed (P/O), used for the conversion of oxygen deficit in mL O₂ eq kg⁻¹ to moles. P/O ratios between 2.5 and 3.0 mmol ATP (mmol O₂)⁻¹ have been used in the literature but the results of the study of Krustup et al. suggest that the additional recruitment of type II fibres during intense exercise may result in a lower P/O ratio, which would disprove the use of a fixed value for the P/O ratio. Further research is necessary to investigate the relationship between muscle fibre type and the P/O ratio.

Another difference between studies was that Green et al. determined the MAOD during a supramaximal constant intensity exercise bout of 173 ± 24 seconds in duration, and Medbo and Tabata established the MAOD during exhausting exercise of ~30 seconds, 1 minute and 2–3 minutes. Based on the difference in number of exhausting exercise bouts, Green et al. reported that the large range of values in the study of Medbo and Tabata caused a spuriously high correlation coefficient. Bangsbo determined, from the data of Medbo and Tabata, the relationship between the MAOD and muscle anaerobic ATP production for the three different exercise durations (~30 seconds, 1 minute and 2–3 minutes), which resulted in non-significant correlation coefficients. In addition, a 2-fold range in MAOD was found for the same muscle anaerobic ATP production.
From the studies described, we must conclude that the most precise assessment of the anaerobic energy yield has been performed by Bangsbo et al. during intense dynamic knee-extension exercise. From the results of this study it could be concluded that in a small muscle mass the MAOD method is a valid method to determine anaerobic capacity.

5. The Reliability of the MAOD Method

Anaerobic capacity is an important determinant of high-intensity exercise. Thus, it would be helpful for coaches, athletes, and sports scientists if anaerobic capacity could be measured accurately. The MAOD method not only has to be valid but it also has to be reliable. Coaches need to be sure that test-retest differences are real differences in anaerobic capacity and are not due to random error.

Doherty et al. evaluated the reproducibility of the MAOD and the exercise time to exhaustion, their results are summarized in table I. Based on intraclass correlation coefficients and sample coefficients of variation they concluded that the MAOD method is a reliable measure. However, they also determined the 95% limits of agreement for the MAOD, which measures the absolute reliability. Doherty et al. found that 95% of the agreement ratios had to be between 0.80 and 1.28, which means that a subject with a MAOD of 70.0 mL O2 eq kg\(^{-1}\) the first time, could have a MAOD between 70.0 \(\times\) 0.80 = 56.0 mL O2 eq kg\(^{-1}\) and 70.0 \(\times\) 1.28 = 89.6 mL O2 eq kg\(^{-1}\) during the second supramaximal exercise bout. So, based on the 95% limits of agreement they concluded that the MAOD method was not a reliable measure.

In the study of Bickham et al., the effect of different methodological improvements on the precision of the estimated VO\(_2\) demand and on the MAOD was investigated, using 95% CIs (table I). The 95% CI of the VO\(_2\) demand, estimated from the regression line based on ten submaximal bouts and a fixed y-intercept (11-point) was 7.8 ± 2.7 mL O2 kg\(^{-1}\) and was not significantly different between the 11-point, 5-point (four submaximal bouts and a y-intercept) and 3-point (two submaximal bouts and a y-intercept) regression line. When additional error data from the metabolic system was included, the width of the 95% CI of the estimated VO\(_2\) demand became even larger, namely 13.9 ± 2.8 mL O2 kg\(^{-1}\) for the 11-point regression line, which shows that half of the possible error is related to the regression line. It also became clear that a relatively small 95% CI (7.8 mL O2 kg\(^{-1}\)) for the estimated VO\(_2\) demand could result in a large 95% CI for the MAOD (22.4 mL O2 eq kg\(^{-1}\)), the increase in the 95% CI will be larger when the length of the supramaximal exercise bout is longer. The study of Bickham et al. showed that the 95% CI of the MAOD is relatively large, which suggests that estimating anaerobic capacity with the MAOD method is not very accurate. Although the precision of a measurement influences the reliability, the 95% CI is not a complete measure of reliability. Unfortunately, Bickham et al. did not determine the reproducibility of the VO\(_2\) demand and MAOD.

Jacobs et al. determined the MAOD during two trials in order to evaluate the reliability of the MAOD method. The test-retest correlation coefficient was 0.97, from which they concluded that the MAOD method is a reliable method. This conclusion is supported by the study of Weber and Schneider, who investigated the reliability of the MAOD method at POs calculated to require 110% and 120% VO\(_2\)peak with the use of intraclass correlation coefficients. The intraclass correlation coefficients for the supramaximal exercise tests were 0.95 and 0.97, respectively. This study showed that the MAOD method resulted in highly repeatable values. However, the conclusions of Jacobs et al. and Weber and Schneider did not support the findings of Doherty et al.

In a letter to the editor, Doherty and Smith questioned the outcomes of the study of Weber and Schneider. Both Weber and Schneider and Jacobs et al. used a traditional measure of reliability, namely intraclass correlation coefficients, which has some limitations. One of the limitations is that the correlation coefficient is dependent on the range of values that are attained by the subjects. With a very heterogeneous
### Table 1. Quality criteria of studies challenging the maximal accumulated oxygen deficit (MAOD) method

<table>
<thead>
<tr>
<th>Reference (y)</th>
<th>Subjects (n)</th>
<th>Ergometer</th>
<th>Number of submaximal tests</th>
<th>Length of submaximal tests (min)</th>
<th>Protocol</th>
<th>MAOD (mL O₂ eq • kg⁻¹)</th>
<th>CIₘ O₂ demand (mL O₂ eq • kg⁻¹)</th>
<th>Muscle biopsies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bangsbo et al.(203) (1993)</td>
<td>Distance runners (14) Soccer players (150) Oarsmen (5) Cyclists (3)</td>
<td>Treadmill (5% gradient) Rowing ergometer Cycle ergometer</td>
<td>6–10</td>
<td>6</td>
<td>Constant PO protocol (120–140% of the PO at VO₂max)</td>
<td>Soccer players (running)</td>
<td>[62.2, 68.8]</td>
<td>Runners, Musculus gastrocnemius Cyclists, Musculus vastus lateralis (fibra type distribution, capillaries, buffer capacity and enzyme activities)</td>
</tr>
<tr>
<td>Bickham et al.(81) (2002)</td>
<td>Trained male distance runners (7)</td>
<td>Treadmill (1% gradient) 10 and a fixed y-intercept, 4 and a fixed y-intercept, and 2 and a fixed y-intercept</td>
<td>10</td>
<td>4</td>
<td>Constant intensity protocol (110% VO₂max)</td>
<td>11-point regression</td>
<td>7.8 ± 2.7 [95% CI 1.96 • SEₘ]</td>
<td></td>
</tr>
<tr>
<td>Craig and Morgan(66) (1998)</td>
<td>Male distance runners (9)</td>
<td>Treadmill (1% and 10.5% gradient)</td>
<td>8</td>
<td>6</td>
<td>Constant intensity protocol (2 trials: 1% and 10.5% gradient)</td>
<td>(1%, linear)</td>
<td>(1%, linear)</td>
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<table>
<thead>
<tr>
<th>Reference (y)</th>
<th>Subjects (n)</th>
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<th>CI* O₂ demand (mL O₂ eq • kg⁻¹)</th>
<th>Muscle biopsies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doherty et al.[56] (2000)</td>
<td>Physically active male students (15)</td>
<td>Treadmill (10.5% gradient)</td>
<td>3 and a fixed y-intercept</td>
<td>6</td>
<td>Constant intensity protocol (3 trials: 125% VO₂max)</td>
<td>Trial 1, 69.0 ± 13.1</td>
<td>Trial 2, 71.4 ± 12.5</td>
<td>Trial 3, 70.4 ± 15.0</td>
</tr>
<tr>
<td>Green and Dawson[58] (1995)</td>
<td>Male cyclists (10), untrained men (9)</td>
<td>Cycle ergometer</td>
<td>6 cyclists</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Green et al.[83] (1996)</td>
<td>Well trained male cyclists (10) [2 pursuists, 1 sprinter, 7 endurance cyclists]</td>
<td>Cycle ergometer</td>
<td>8–12</td>
<td>4</td>
<td>Constant PO trial (432 ± 41 W)</td>
<td>55.2 ± 10.3</td>
<td>[164.9, 286.9] (mL • kg⁻¹)</td>
<td>M. vastus lateralis</td>
</tr>
<tr>
<td>Özyener et al.[71] (2003)</td>
<td>Male subjects (10)</td>
<td>Cycle ergometer</td>
<td>5</td>
<td>10</td>
<td>Three constant</td>
<td>Moderate, constant</td>
<td>0.81 ± 0.2 L</td>
<td>Heavy, supra-lactate threshold</td>
</tr>
</tbody>
</table>

*The reported confidence intervals (CIs) of the studies of Bangsbo et al.[53] (1993), Craig and Morgan[60] (1998) and Green et al.[83] (1996) are values calculated from the published standard deviations of the energy demands (mean ± 1.96 • SD). Bickham et al.[81] (2002), Doherty et al.[56] (2000) and Green and Dawson[79] (1996) did report the length of the 95% CIs.

ATP = adenosine triphosphate; CI = confidence interval; CON = continuous; DISCON = discontinuous; dw = dry weight; O₂ eq = oxygen equivalent; PO = power output; r = correlation coefficient; SE_p = standard error of prediction; VO₂max = maximum oxygen uptake.
group of subjects (i.e. males and females, individuals of varying fitness levels) it is easy to find a strong correlation coefficient.\textsuperscript{[86]} Atkinson and Nevill\textsuperscript{[86]} suggested the use of the standard error of measurement when heteroscedasticity is absent and the use of the coefficient of variation (CV) and the limits of agreement method when heteroscedasticity is present. These measures all evaluate the absolute reliability and are not influenced by the range of measurements.

In summary, most studies\textsuperscript{[6,85]} used traditional measures of reliability, which are not sensitive enough for assessing the reliability.\textsuperscript{[86]} Adequate measures of reliability are the CV, the limits of agreement method and the standard error of measurement.\textsuperscript{[86]} Doherty et al.\textsuperscript{[56]} used the limits of agreement method (i.e. 95\% CI), which resulted in the conclusion that the MAOD method is not a reliable measure of anaerobic capacity. However, the study of Doherty et al.\textsuperscript{[56]} is one of the first studies which assessed the reliability of the MAOD method with an adequate measure of reliability and further research is therefore necessary to study the reliability of the MAOD method.

6. Conclusions

The purpose of this review was to evaluate the procedures and outcomes of studies that used the MAOD method to determine anaerobic capacity, as proposed by Medbo et al.\textsuperscript{[3]} From the reviewed literature it can be concluded that the most widely used approach to determine anaerobic capacity (the MAOD method), although clearly reasonable from a conceptual standpoint, is probably not (as currently used) a fully defensible method to determine anaerobic capacity. Further research is necessary to determine how to approach the problem of measuring anaerobic capacity. Clearly the most profitable areas of immediate concern are standardization of the number, duration and intensity of submaximal exercise bouts necessary to define the PO-VO\textsubscript{2} relationship, whether forcing the PO-VO\textsubscript{2} relationship into a linear analysis mode is the correct approach to allowing computation of an extrapolated value for VO\textsubscript{2} demand, and the relative PO (e.g. duration) and character (square wave, all-out, free range) of the supramaximal exercise bout.

We suggest the use of the following methodology for the determination of anaerobic capacity with the MAOD method. Relatively short submaximal exercise bouts are preferred for the construction of the linear PO-VO\textsubscript{2} relationship, as VO\textsubscript{2} shows a secondary increase after 3 minutes of exercise at the highest submaximal exercise intensities, which will lead to non-linearity of the PO-VO\textsubscript{2} relationship. To construct a robust PO-VO\textsubscript{2} relationship, about ten submaximal exercise tests at intensities evenly distributed between 30 and 90\% VO\textsubscript{2}\textsubscript{max} are necessary, as is the use of a fixed y-intercept, determined from resting VO\textsubscript{2} data. Furthermore, it is advisable to use horizontal running or cycling exercise at a fixed and relatively low pedalling frequency as this will also minimize the VO\textsubscript{2} SC. Linear regression analysis can be used to determine the PO-VO\textsubscript{2} relationship, as it has been shown that a curvilinear fit did not improve the relationship.\textsuperscript{[69]} A carefully considered decision has to be made about the supramaximal exercise protocol used to determine the MAOD, it is probably best to use a protocol and exercise modality specific for the athlete’s chosen event. The last recommendation is to evaluate the reliability of the MAOD method with the use of measures of absolute reliability, when heteroscedasticity is present the CV or the limits of agreement method (ratios) should be used and when heteroscedasticity is absent the standard error of measurement or the limits of agreement method (absolute values) should be reported.\textsuperscript{[86]} Thus far, the MAOD method is the most widely used and probably the best non-invasive method to determine anaerobic capacity.

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