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WAS THE CONCONI TEST VALIDATED BY SPORTING SUCCESS, EXPERT OPINION OR GOOD SCIENCE?

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ABSTRACT

The application of the scientific method in sport demands that regular and standardised testing must be implemented by the coach or scientist to determine whether the intervention, for instance training, has had the desired effect on sporting performance. However, the test administered by the coach or scientist must have been rigorously evaluated for acceptable validity and reliability. Moreover, the judgment as to the validity of a test must not be influenced by the popularisation of a test. Despite scientific evidence to the contrary, a popular incremental field test for endurance athletes (Conconi Test) has been uncritically accepted as valid by some coaches and sport scientists. The Conconi Test is assumed a non-invasive measure of the anaerobic threshold through the identification of a coincident deflection in heart rate. This paper briefly considers the methodology and biological explanation for the Cononic Test. The paper also elaborates on the historical context within which the popular Conconi Test was developed and how factors other than scientific evidence have led to the popularisation of this test amongst sport scientists and coaches. Users of this test should consider the possibility that at least some part of the accepted validity of the Conconi Test was due to appeals to authority (eminent scientists, prominent athletes, magnitude of the feat, medal counts, records), popularity and coincidental correlation (performance and test result).

Key words: Testing; Validity; Conconi; Anaerobic threshold; Heart rate

INTRODUCTION

The popularisation of invasive and non-invasive means of measuring the anaerobic threshold were strongly influenced by an entrenched theoretical paradigm (Figure 1). This theoretical framework provided the foundation to which all practical applications of anaerobic threshold testing appeal for ultimate justification. A competing theoretical framework, using a complex systems-based approach, has been suggested as a viable alternative to the anaerobic threshold model (St. Clair Gibson & Noakes, 2004). It is the contention of this paper that the historical backdrop against which non-invasive measures of the anaerobic threshold such as heart rate deflection (HR_D) (Conconi *et al.,* 1982; Conconi *et al.,* 1996) were developed, must be considered. Arguably, the historical context within which this method was developed and implemented, served to popularise, and to some degree, validate the method. Consequently, this paper will attempt to briefly trace the scientific evidence and historical factors, which have led to the popularisation of a field-based method to estimate the anaerobic threshold, specifically the use of HR_D.

THE CONCONI TEST: DETERMINING THE ANAEROBIC THRESHOLD BY NON-INVASIVE MEANS

The influence and acceptance of anaerobic threshold testing by not only athletes and coaches, but also sport scientists, was likely extended and entrenched even further by the work of Italian sport scientist and medical doctor Professor Francesco Conconi who developed the popular Conconi Test (Conconi *et al.,* 1982; Janssen, 1987; Edwards, 1994; Conconi *et al.,* 1996; Sleamaker & Browning, 1996). This test is based on the premise that a HR_D obtained during an incremental exercise test could be used to non-invasively estimate the anaerobic threshold (Figure 1 and Figure 2). In fact, the Conconi Test has been described as *"the bloodless method of establishing the deflection point"* (Janssen 1987: 20). Similar statements have been made by other sport scientists (Edwards, 1994; Sleamaker & Browning, 1996). The suggestion that heart rate can be used to identify blood lactate thresholds has also led sport scientists to produce lactate–pulse rate curves (Janssen, 1987).

Prior to wrist-mounted heart rate monitors sport scientists and coaches collected heart rate data either through cumbersome data loggers, laboratory-based electrocardiograms or manually (Montoye *et al.,* 1996). The Conconi Test required portable technology that would measure and record heart rate continuously during the incremental test. Such equipment was available for researchers, but was neither designed nor marketed with the athlete or coach in mind (Rodahl *et al.,* 1974; Conconi, 1991). The introduction of accurate wrist-mounted heart rate monitors in 1983, due to advances in microchip technology (Laukkanen & Virtanen, 1998), was arguably an important contributing factor in the growth of the popularity of the Conconi Test. Furthermore, this new generation of portable, wireless heart rate monitors was designed and marketed with the sporting and research communities in mind (Edwards 1994; Laukkanen & Virtanen, 1998). Notably, the Conconi Test has been included in popular commercial heart rate analysis software (Polar Heart Rate Analysis SW, 1992; Polar ProTrainer, 2010) and software which accompanies computer-interfaced wind load trainers for cyclists (Elite, 2010).

The validity of the Conconi Test was not evaluated by well-designed experimental work, but rather on the basis of initial positive studies from principally one laboratory (Conconi *et al.,* 1982; Droghetti *et al.,* 1985; Cellini *et al.,* 1986; Conconi *et al.,* 1988). Subsequently, the underlying methodology and biologic plausibility of the Conconi Test have been questioned (Leger & Tokmakidis, 1988; Van Handel *et al.,* 1988; Jeukendrup *et al.,* 1997). Furthermore, the accomplishments of Italian cyclists during the 1980's, notably the establishment of new sea level and altitude records for the individual hour ride and the Olympic gold medal for the 100 km team time trial, are promoted as examples of the success and validity of the Conconi Test (Janssen, 1987; Edwards, 1994; Sleamaker & Browning, 1996).

Proponents of the Conconi Test have asserted that the training programmes of successful elite athletes have been devised around the results of the Conconi Test (Edwards, 1994; Sleamaker & Browning, 1996). Hence, a causal link between the use of the Conconi Test and athletic success is strongly implied. For instance, Edwards (1994: 115) states that:

> "Using this test, Conconi devised a training program using periodic workouts at heart rates close to the threshold for Francesco Moser .... Conconi used anaerobic

> threshold training as the cornerstone of Moser's special training program and the result astonished the cycling community as Moser broke the World Hour Record twice ….".

Validity of the Conconi Test on the basis of scientific evidence

The Conconi Test is controversial (Bodner & Rhodes, 2000) with enthusiastic proponents (Janssen, 1987; Edwards, 1994; Sleamaker & Browning, 1996) and outspoken critics (Van Handel *et al.,* 1988; Burke, 1995; Jeukendrup *et al.,* 1997). Proponents of the test argue that i) the test is non-invasive, easy to administer, not costly, highly specific and can be incorporated as a field test into the athletes training programme, ii) HR_D coincides with the anaerobic threshold (r=0.84 to r=0.99), iii) HR_D is reliable (r=0.99), iv) HR_D correlates with endurance performance (r=0.80 to r=0.99) and v) HR_D defines an exercise intensity that can be maintained for prolonged periods (Conconi *et al.,* 1982; Droghetti *et al.,* 1985; Cellini *et al.,* 1986; Janssen 1987; Argentieri *et al.,* 1988; Conconi *et al.,* 1988; Edwards, 1994; Sleamaker & Browning, 1996; Grazzi *et al.,* 1999/2008; Gripp *et al.,* 2009).

Since the first paper by Conconi *et al.* (1982), evidence has been accumulating disputing the methodology and the proposed underlying physiological mechanism of the Conconi Test. First, the blood lactate data that was presented by Conconi *et al.* (1982) was not collected at the same time as the heart rate data and used a different and more prolonged protocol with recovery between bouts. Furthermore, the blood lactate protocol consisted of three speeds chosen below and three speeds above the velocity at which HR_D occurred. Surprisingly, heart rate data obtained during the blood lactate trials were not reported and blood lactate data was collected in a small sample of the subjects (Conconi *et al.,* 1982; Leger & Tokmakidis, 1988; Tokmakidis & Leger, 1989). Consequently, this protocol would have substantially increased the likelihood of a significant, positive association between HR_D and the blood lactate threshold and would explain the unusually high correlation coefficients for biological data reported by Conconi and associates (Leger & Tokmakidis, 1988; Tokmakidis & Leger, 1989). It is also surprising that results from Conconi's laboratory always indentify HR_D in athletes (Conconi *et al.,* 1982; Droghetti *et al.,* 1985; Cellini *et al.,* 1986; Conconi *et al.,* 1988; Grazzi *et al.,* 2008). However, high correlation coefficients between HR_D and anaerobic threshold and performance indices do not imply a cause-effect relationship (Lucia *et al.,* 1999).

Secondly, in response to criticism of the original constant stage length protocol (Conconi *et al.,* 1982), the protocol was modified to constant stage durations (30 seconds) (Conconi *et al.,* 1996). Despite the modification, Pokan *et al.* (1999) concluded that the HR_D was still strongly dependent on the incremental test protocol. Furthermore, steady state heart rates will likely not be attained at higher speeds, increasing the possibility of detecting HR_D (Achten & Jeukendrup, 2003).

Thirdly, to date Conconi and associates have not presented an investigation that specifically tests the metabolic hypothesis forwarded to explain the HR_D (Lucia *et al.,* 1999). Studies have shown evidence for non-metabolic explanations of the HR_D (Hofmann *et al.,* 1994b; Lucia *et al.,* 1999/2002; Hofmann *et al.,* 2005; Lepretre *et al.,* 2005). Interestingly, Ozcelik and Kelestimur (2004) tested a core assumption of the Conconi Test by having eight subjects breathe room air and a 12% O_2 gas mixture during two incremental tests. The investigators reported that the HR_D did not occur in all subjects during the hypoxia trial, the HR_D did not coincide with the anaerobic threshold in any subjects and when the HR_D occurred it was at higher workloads than the anaerobic threshold.

Additional criticisms of the test are that:

- the heart rate response to incremental exercise varies in shape between individuals to include linear and sigmoidal patterns (Hofmann *et al.,* 2005),
- a HR_D is not always identifiable (Jones & Doust, 1997; Carey *et al.,* 2002) or is totally absent (Kuipers *et al.,* 1988),
- the HR_D is not reliable (Jones & Doust, 1995),
- there is no physiological rationale for linking the sudden increase in ventilation and blood lactate concentrations with a plateau in the heart rate (Bourgois *et al.,* 2004),
- the HR_D is an artifact of the protocol (Leger & Tokmakidis, 1988; Tokmakidis & Leger, 1989/1992; Jeukendrup *et al.,* 1997; Achten & Jeukendrup, 2003),
- there is a dissociation between the HR_D and the anaerobic threshold (Tokmakidis & Leger, 1992; Jones & Doust, 1997; Vachon *et al.,* 1999; Bourgois *et al.,* 2004),
- in those subjects where HR_D does occur it can manifest at work rates well above a true lactate turnpoint, increasing the likelihood of over-training (Jones & Doust, 1997; Vachon *et al.,* 1999; Bourgois *et al.,* 2004),
- there are significant differences within and between observers when selecting the HR_D (Carey *et al.,* 2002),
- there are significant differences between visual and computer generated HR_D (Carey *et al.,* 2002),
- careful laboratory work suggests that to obtain reproducible HR_D may require precisely controlled, progressive work output and computerised analysis of heart rate response which negates the supposed ease with which results can be obtained during field trials (Hofmann *et al.,* 1994a),
- the HR_D should not be confused with representing an anaerobic threshold, but rather as a quantification of exercise intensity (Brooks *et al.*, 1996),
- endurance performance is predicted accurately with other methodologies and indices, which use the same data but do not rely on HR_D assumptions (Tokmakidis & Leger, 1992; Petit *et al.,* 1997).

Validity of the Conconi Test based on two athletic achievements

World one-hour cycling record

Proponents of the Conconi Test often cite the performance of Italian professional cyclist Francesco Moser, who successfully improved the prestigious world one-hour cycling record during the period 1984 to 1988 (Wikimedia Foundation, 2010), set 12 years earlier by the legendary Belgian cyclist Eddy Merckx, as evidence for the validity of the Conconi Test (Janssen, 1987; Edwards, 1994; Sleamaker & Browning, 1996). In his first attempt on 19 January 1984 at the Mexico City Sports Center, Mexico, Moser broke the magical barrier of 50 $km.h^{-1}$ and raised the bar to 50.808 $km.h^{-1}$. Four days later, at the same venue, Moser raised the mark even further to 51.151 $km.h^{-1}$ (Peronnet *et al.,* 1991). By 1988, Moser had made three more successful attempts at the record, establishing records for both altitude and sea level events (Peronnet *et al.,* 1991).

Importantly, Conconi had made extensive use of his heart rate-based test in the training and preparation of Moser for his world record attempts (Conconi, 1991). Interestingly, Conconi reports that during his training of Moser for the hour attempts, Moser's speed at HR_D and actual race pace dissociated. Consequently, prior to Moser's successful attempt at the Stuttgart velodrome in 1988, the measure for his readiness was not the result of the Conconi Test, but rather a 30 minute time trial (Conconi, 1991). In fact, a week prior to the failed attempt at Moscow in 1987, the Conconi Test that was performed revealed nothing untoward and the anaerobic threshold was high according to Conconi (1991). However, while completing his last high intensity training session (3 x 10 km @ 50 $km.h^{-1}$) four days before the Moscow attempt, Conconi (1991: 28) noted that *"even though he managed to ride at 50 kph, it cost him more than it should have"*. Cleary, Moser was showing signs of overtraining from his road training and racing, yet the Conconi Test was not able to detect it. Prior to the first successful Mexico attempt in 1984, Moser completed a 3 x 10 km @ 50 $km.h^{-1}$ with ease and Conconi judged Moser to be *"in excellent physical condition"* (Conconi, 1991: 9). Contrary then to the assertion of proponents of the Conconi Test (Janssen, 1987; Edwards, 1994; Sleamaker & Browning, 1996), it was likely that the feedback from steady state trials provided more valuable information than the Conconi Test. Indeed, there is good evidence for the validity and reliability of steady state protocols (Brooks *et al.,* 1996; McGehee *et al.,* 2005; Vobejda *et al.,* 2006).

Some sport scientists readily acknowledge Conconi's involvement in the training of Moser (Janssen, 1987; Edwards, 1994). However, they do not fully appreciate that Moser was the first of the modern-era cyclists who significantly reduced aerodynamic drag for his six one-hour record attempts through attention to altitude, riding position, clothing and bicycle design (Conconi, 1991; Peronnet *et al.,* 1991). It was also the first recorded case in the history of the hour ride that used blood boosting (transfusional polycythaemia) (Armstrong & Reilly, 1996; Sawka *et al.,* 1996; Leigh-Smith, 2004; Waddington & Smith, 2009).

Only more recently (2000 to 2005) did modern era cyclists using standard bicycles under the new International Cycling Union (UCI) rules and at sea level, better the 1972 altitude record and the 1967 sea level record (UCI, 2009). The more recent sea level rides of Chris Boardman and Ondřej Sosenka and Merckx's 1972 altitude ride amounted to an approximate 3% improvement over Bracke's 1967 sea level attempt. In contrast, Moser's 1984 altitude ride was 6% better than Bracke's 1967 ride. Clearly, some extraordinary measures must have been employed during Moser's 1984 attempts to improve the world hour cycling by an astounding 3 058 m - altitude, specialised clothing and bicycle equipment and artificial manipulation of physiological parameters.

Moser's use of mechanical means to reduce air resistance and physiological means to increase his skeletal muscle power output are considered ergogenic aids (Williams, 1989), both of which were legal at that time although it could be argued were against the ethical intent and spirit of the rules. Not surprisingly, Merckx who had beaten Moser in every time trial they had ever met in and used standard road equipment and clothing for his 1972 hour ride, is quoted as saying of Moser's successful 1984 hour attempt that *"for the first time in* *the history of the hour record, a weaker man has beaten a stronger man"* (Mulholland, 1991: 81).

Mechanical ergogenic factors

Although some would argue that Moser's achievement was the result of superior testing and training techniques (Edwards, 1994), Peronnet *et al.* (1991) demonstrated quite elegantly that between 1967 and 1988 the improvements in the world one-hour cycling record, with the assistance of altitude and/or aerodynamic improvements of the rider-bicycle system, were not inherently better than the mark of 48.093 $km.h^{-1}$ set in 1967 at sea level using a standard road racing bicycle. In other words, the increase in speed of 3.058 $km.h^{-1}$ between 1967 and 1988 was due to aerodynamic improvements and not because of superior athletes. The effect of aerodynamic refinements is also demonstrated by Moser's most recent and final attempt on 15 January 1994 in Mexico City, aged 42 years, under the guidance of Conconi (Wikimedia Foundation, 2010). Moser rode using the now UCI-outlawed Obree praying mantis riding position and exceeded his distance of 51.151 km set 10 years earlier by 689 meters, earning him the UCI veterans record for the hour ride.

More recent work from an independent group has extended the Peronnet *et al.* (1996) analysis to include successful hour attempts up to 1996 and used more accurate and directly obtained data to develop a mathematical model (Bassett *et al.,* 1999). This study has confirmed the dominant effect of aerodynamics (60%) on the increase in the hour record, compared with 40% due to physiological factors (Bassett *et al.,* 1999). Moreover, Moser's attempts were not inherently better than Merckx's 1972 ride. Although Moser trained specifically for the hour event more so than his predecessors did (Conconi, 1991), his hour performances were due principally to altitude and aerodynamics. The more recent rides of Boardman, Rominger and Indurain have been due to increases in power output not aerodynamic improvements because since Graham Obree's 1993 ride, positions and equipment have not materially changed. By adjusting all hour records since 1967 to sea level and using Chris Boardman's 1996 aero-equipment and position, Merckx would have achieved the fifth best distance ever, with Moser the seventh (Bassett *et al.,* 1999).

Physiological ergogenic factors

Another factor that played a significant role in Moser's achievements, was his self-confessed use of blood doping under the direction of Conconi and others (Leigh-Smith, 2004; Waddington & Smith, 2009). Twelve years prior to Moser's confession, it was alleged that accompanying Moser was *"an entourage of two cardiologists and eight men, 18 to 20 years of age, who were chosen several months before because of their blood type compatibility with Moser"* (Brien & Simon, 1987: 2761). Blood doping, declared illegal in 1985 by the IOC (Armstrong & Reilly, 1996), has been shown to significantly improve endurance performance (Sawka *et al.,* 1996; Leigh-Smith, 2004). Furthermore, all attempts at the hour record have taken place at altitudes <2 500 m above sea level (Peronnet *et al.,* 1991), such that blood doping would have had an ergogenic effect. Interestingly, none of this is mentioned in Conconi's book wherein he details the preparation of Moser for the hour attempts (Conconi, 1991). Over the period 1997 to 2004 Conconi and Ferrari, co-authors of the original paper (Conconi *et al.,* 1982) and both medical doctors who were involved in preparing Moser for his hour rides (Conconi, 1991), were implicated in doping offences related to erythropoietin

(EPO) and subsequently charged (Hoberman, 2001/2002; Waddington & Smith, 2009). However, because of the statute of limitations, Conconi and Ferrari were acquitted of all charges (Waddington & Smith, 2009). Notably, the presiding judge concluded that Conconi and associates were fully aware of the use of EPO by athletes and actively engaged in providing support to optimize EPO usage (Waddington & Smith, 2009).

Donati, leading anti-doping advocate spearheaded the investigation into doping in Italian sport and scathingly alleged that:

> "…. it was under the pretext of administering the Conconi test, which I've scientifically proven to be useless, that he was able to practise blood doping [i.e. the original red cell augmentation technique] on my athletes. But the world of sport is a stupid and imbecile one and that's why Conconi and others have been able to rampage about with impunity" (Cycling News, 1997).

Hoberman (2001: 252) offers another insight into the involvement of Conconi in the doping of athletes:

> "It is also possible that he is one of the well-situated amoralists of the elite sport world who move easily back and forth across the line that separates 'legitimate' from 'illegitimate' sports medicine. Indeed, Conconi's career at the cutting edge of high-performance sports medicine may well have encouraged in him a keen, relativist and cynical view of the often subtle differences between the natural and the artificial, between nutrients and stimulants. His insights into the arbitrary nature of these classifications may have led him to conclude that such distinctions make no sense at all".

One hundred kilometer cycling team time trial

The second impressive achievement by Italian cyclists, referred to by proponents of the Conconi Test to justify its use, was the foursome Bartalini, Giovannetti, Poli and Vandelli that set world and Olympic records on their way to winning the 1984 Olympic 100 km road team time trial gold medal (Sleamaker & Browning, 1996). The Italian team was also the first since 1960 to break the 50 $km.h^{-1}$ mark (50.6 $km.h^{-1}$) over 100 km. These athletes reportedly also used the Conconi Test to prepare for their Olympic performance (Sleamaker & Browning, 1996). To make their feat even more impressive was the fact that former Union of the Soviet Socialist Republic (USSR) teams had won the previous three Olympic 100 km team time trials (1972 to 1980) (*Athletics Weekly*, 2008).

However, this feat must be placed within its proper historical context. Firstly, from 1972 to 1992 the former USSR and Eastern Bloc countries dominated the event, winning 9 of the 18 medals (4 gold, 4 silver, 1 bronze), in comparison to 1 bronze medal in the period 1960 to 1968 (*Athletics Weekly*, 2008). Secondly, apart from the 1984 gold, Italy had won the event only once before 1960. Thirdly, the former USSR and East European countries boycotted the 1984 Los Angeles Games in retaliation for the American boycott of the 1980 Moscow Games. Fourthly, upon their return, the former Eastern Bloc countries once again won gold

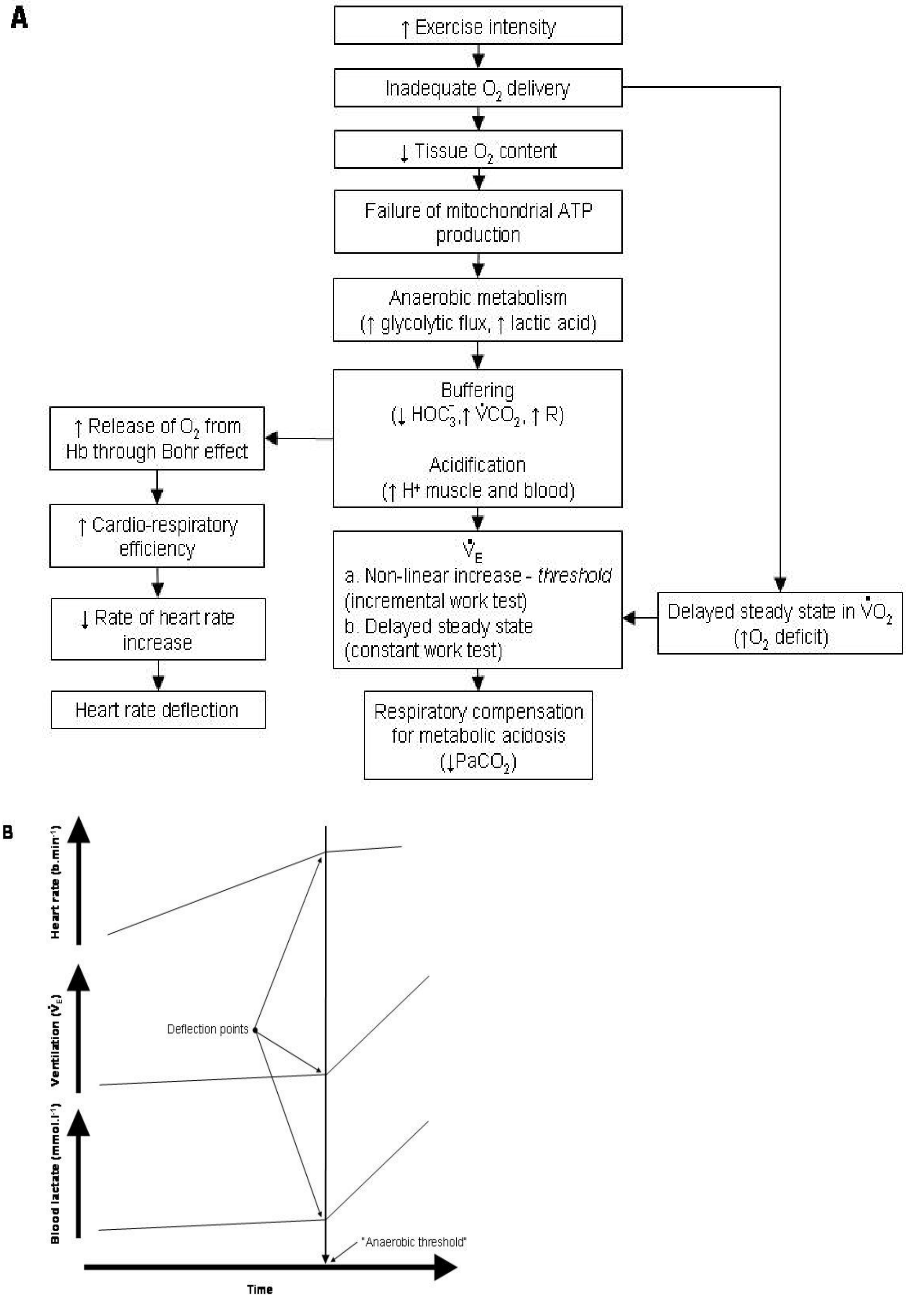

FIGURE 1: **DIAGRAMMATIC REPRESENTATION OF THE THEORETICAL PARADIGM UNDERLYING THE ANAEROBIC THRESHOLD**

and silver in 1988 and a unified German team triumphed in 1992 with Italy in the second place. Fifthly, on their return, the German Democratic Republic (formerly East Germany) team achieved the best time ever for the event in 1988 (50.9 km.h^{-1}) (*Athletics Weekly*, 2008). Seen against this backdrop, Italy's triumph in 1984 was against current trends and probably due more to the effects of the Cold War than the purported efficacy of the Conconi Test. Moreover, the 1984 Los Angeles Games was a watershed in terms of blood doping, such that up to that point many athletes, including Italian runners and cyclists, were employing this performance enhancing technique (Armstrong & Reilly, 1996). However, the author is not aware of any statement implicating the 1984 Italian 100 km time trial team in blood doping.

The Hill-Meyerhof-Wasserman hypothesis suggests that increasing work rate results in a threshold at which the oxygen demand of the active skeletal muscle is greater than the oxygen supply to the mitochondria, resulting in a greater reliance on anaerobic metabolism, which culminates in changes in blood lactate concentration and gas exchange variables (Wasserman *et al.,* 1973; Noakes, 1988; Conconi *et al.,* 1996). The Conconi hypothesis builds on the Hill-Meyerhof-Wasserman hypothesis, suggesting that the heart rate deflection is linked to the increasing glycolytic flux (A). The Hill-Meyerhof-Wasserman-Conconi hypothesis predicts that blood lactate, ventilator and heart rate thresholds or deflections coincide (B).

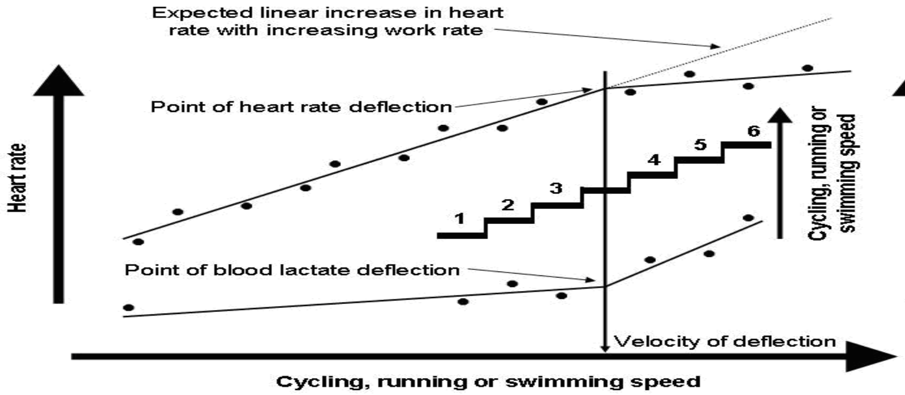

FIGURE 2: **DIAGRAMMATIC REPRESENTATION OF THE CONCONI TEST**

The Conconi Test is dependent on a deflection in the heart rate–work rate relationship away from the expected linear increase in heart rate. The testing protocol requires a progressive, regular increase in work rate with heart rate monitored at each stage and plotted against the velocity. A linear regression line is determined for the lower data points and a deflection point from the regression line is usually visually adjudged. Alternatively, a linear regression line is also determined for the upper data points and the deflection point calculated from the intersection of the lower and upper regression lines. A right-shift in the heart rate deflection point and thus the velocity of deflection would indicate improved performance. The heart rate and blood lactate concentration deflection points are said to coincide at the anaerobic threshold. The speed at which the heart rate deflection occurs is defined as the velocity of deflection (Burke, 1995).

CONCLUSION

The adoption of a fitness or performance test must be preceded by reports of acceptable validity and reliability that are consistent between independent laboratories. This has not been the case with the Conconi Test, which has shown divergent levels of validity and reliability between independent laboratories. Alluding to selected positive examples of elite athletes trained by eminent scientists as evidence for the validity of a test is an appeal to authority and popularity. Rather, those elite athletes that have performed well using the Conconi Test probably did so because regular performance testing would have implied the use of the scientific method in sport, at least to some degree. It is likely that successful implementation of the Conconi Test in selected prominent athletes was the result of i) the methodological bias inherent in the Conconi Test which makes finding an HR_D more probable and ii) individual heart rate responses to the Conconi Test that resulted in a consistent HR_D. Moreover, the HR_D occurred at speeds such that correct training intensities could be inferred and thus not over-train. Insightfully, Tokmakidis and Leger (1989: 446) concluded that:

> "…. considering the results of our study and the success that Conconi obtained with his method on world class athletes, one may wonder if it is the method itself or individual talent and endowment that was responsible for the gold medals and world records".

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