

9<sup>th</sup> Conference of the International Sports Engineering Association (ISEA)

## Analysis of the thermal comfort in cycling athletes

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Accepted 02 March 2012

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### Abstract

This research presents a detailed analysis of thermal comfort in road cycling athletes. The data have been collected during experimental road test in prevision of the UCI Road World Championship 2013 (Florence-Tuscany, Italy), considering the different technical situations and the different environmental conditions expected as the most probable for the race's period.

The analysis presented in this work is based on the in-situ measurements of both environmental and physiological parameters (i.e.: air temperature, relative humidity, true wind velocity, apparent wind velocity, skin temperature, clothing temperature, heat transfer resistance of the clothing, internal heat production) made over different athletes in different race conditions. The recorded data have been used as input for the model "RayMan" [1], [2] for the assessment of the thermal comfort using thermal indices such as Predicted Mean Vote (PMV) and Physiological Equivalent Temperature (PET). It should be noted that the apparent wind velocity, which is a fundamental parameter in this kind of analysis but often disregarded, is evaluated in relationship with the movement and the effort made by the cyclist.

The results obtained by the comparison of the PET and PMV indices with the measured skin temperature confirm the importance of considering the variation of environmental parameters in both training and strategy assessment and provide a working method which is believed to be innovative for the applied sport research.

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*Keywords:* Cycling; thermal comfort; measurements; sport performance; strategy

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## 1. Introduction

The effect of weather and environmental conditions on sports has been extensively studied over the last few years ([3], [4], [5], [6]). Based upon the studies of Lobożewicz [7] and of Kay and Vamplew [8], Pezzoli and Cristofori [9] have studied the impact of some specific environmental parameters over different sports using a particular impact index divided into five classes. This analysis clearly shows that most of the outdoor sport activities, and in particular endurance sports, are strongly influenced by the variation of meteorological parameters. In effect the evaluation of bio-climatological conditions and of thermal comfort in endurance sports, particularly in road cycling, has a fundamental importance not only for a proper planning of the training program and the nutritional plan, but also for a better evaluation of the race strategy [10]. Despite these observations, the influence of meteorological and environmental conditions is often disregarded in the outdoor sport performance assessment.

This research presents a detailed analysis of the thermal comfort for road cycling athletes. The use of a heat transfer model (“RayMan”) for the study of the liaison between the thermal comfort and the sport performance represents the major innovation of this research. Moreover the results obtained by the comparison of the PET and PMV indices and the measured skin temperature, used as “comfort values” as indicated by Fanger [11] and Hoppe [12], confirm the importance of considering the influence of environmental parameters in both training and strategy assessment.

## 2. Materials and Methods

### 2.1 The “RayMan” model

Many methods are used to estimate human thermal comfort. Apparent temperature indices like NET [13] are often used, but they don't consider the heat transfer resistance of the clothing and the internal heat production although they contemplate combined effect of the three weather elements in human discomfort (dry air temperature, humidity and wind speed).

Recently many heat transfer models are combined with heat sensation perceived in the human body, generating universal scales of thermal sensation, which have large application in the outdoor sports like road cycling [14]. In this research we use the “RayMan” model, developed by Matzarakis et al. [1], [2], widely employed in bioclimatological studies applied to tourism activity and sport leisure [15]. It is interesting to briefly analyze, the inputs and outputs provided by this model. Regarding the inputs, these can be listed as follows:

- Date, hour and location (longitude and latitude, altitude and time zone)
- Environmental and meteorological data-base like air temperature ( $^{\circ}\text{C}$ ), the vapour pressure (hPa), the relative humidity (%), the wind speed (m/s) and the cloud covering (octas)
- Personal data concerning the subject (the weight, the height, the age and sex)
- Clothing to define the heat transfer resistance of the clothing, valuated in Clo, according whit UNI EN ISO 9920/2004 and activity to outline the internal heat production, consequential to the physical activity of the subject (W)

The outputs of the model are the two bioclimatological indices (PMV and PET) which, in agreement with Matzarakis et al. [14], provide the thermal perception and the grade of physiological stress, as reported in Table 1. It should be remembered that the PMV predicts the normalized value of the thermal comfort of a large group of people exposed to similar environmental conditions. Instead the PET has detailed thermo-physiological basis taking into account the energy balance of the human body in relationship with climatic conditions.

Table 1. Thermal sensations and PMV ÷ PET classes [14]

PMV [°C]	PET	Thermal perception	Grade of physiological stress
PMV<-3.5	PET<4	Very cold	Extreme cold stress
-3.5≤PMV<-2.5	4≤PET<8	Cold	Strong cold stress
-2.5≤PMV<-1.5	8≤PET<13	Cool	Moderate cold stress
-1.5≤PMV<-0.5	13≤PET<18	Slightly Cool	Slight cold stress
-0.5≤PMV<0.5	18≤PET<23	Comfortable	No thermal stress
0.5≤PMV<1.5	23≤PET<29	Slightly warm	Slight heat stress
1.5≤PMV<2.5	29≤PET<35	Warm	Moderate heat stress
2.5≤PMV<3.5	35≤PET<41	Hot	Strong heat stress
PMV≥3.5	PET≥41	Very hot	Extreme heat stress

## 2.2 The testing program

The testing program is based on the combined analysis of the environmental and performance data for calculating the PMV and PET values using “RayMan” model, in order to assess the thermal comfort of professional cyclists in different race conditions.

The testing program has been divided into five different parts to make a simple and repeatable analysis for different race conditions:

- Study of the race course. In this research we have studied the details of UCI Road World Championship 2013 (29<sup>th</sup> September 2013 Florence Tuscany Italy) to simulate a real race situation. A statistical analysis of the last seven World Championships, clearly showed that, from a tactical and strategical point of view, the race has always been decided in the last 30km of the track. This means that, in the case of the UCI Road World Championships 2013, the analysis should be focused on last two laps of the circuit in Florence
- Environmental analysis of the race course. It was carried out an analysis of the environmental parameters affecting the race track considering both changes in altitude and the average weather conditions expected for the competition period
- Performance analysis. The aim of this analysis is to detect the different values of power expressed by athletes in different race conditions and consequently to evaluate the internal heat production expressed in Watt (W). During this phase we registered constantly the power, the speed, the cadence of pedalling, the slope of the road and the heart rate. The power and the related internal heat production have been measured using the PowerTap system. The skin and the clothing temperature have been recorded with a two ways thermocouple recording thermometer.
- Research a target of athletes for the test who can significantly represent an average professional “climbing” cyclist category (age: 27, height: 1,75m, weight: 65kg as suggested by Lucia et al. [16]). We worked with five athletes of elite cycling category, to simulate many different race conditions (compact group, cyclist alone, drafting in small group, peak of power in sprint, etc.). One of this athletes was constantly monitored during both the environmental analysis and the performance analysis
- Analysis of the wind generated by the cyclist movement. This phase, extremely important for the performance and the thermal comfort evaluation of professional cyclists, was performed by an innovative method based on the use of an anemometer installed on the bike handle (see Fig 1). Using

this particular measurement technique it was possible to measure the head air velocity in different race condition (i.e.: drafting), taking also in account the true wind speed observed during the test days. Subsequently the data of recorded head velocity have been used as input for the “RayMan” model during the simulation of thermal comfort

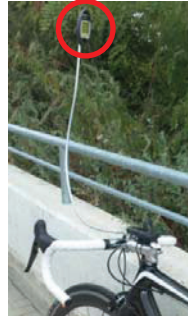


Fig 1. Placement of the anemometer on the bicycle

### 3. Results

The analysis of results showed that the performance data expressed by cyclists vary considerably depending on the different positions within the group in plain or uphill conditions. It has been noted that thanks to the higher speed reached in plain stretches, the drafting effect allows a major power (W) saving than in uphill stretches. In effect during uphill stretches or in uphill slopes steeper than 3% the cyclist needs mainly to overcome the gravity force so the drafting effect, which contributes to minimize the aerodynamic drag, becomes almost irrelevant.

The assessments of the resulting wind over cyclist were made simulating a drafting condition that might occur during the last kilometres of the Florence World Championship. During the measurements, performed over a group of three cyclists, the athlete with the anemometer remained always in the wake of the other two riders except in some precise moments that have been highlighted by a peak of the wind speed indicating an increase in headwind.

The test results demonstrate that the effect of the headwind increases significantly, by about 30%, with no sheltering of the two leaders; this leads to an increase of power required to maintain the same speed and consequently to an alteration of the thermal comfort. The drafting effect has a dual opposite effect: on one side it decreases significantly the value of required power in order to maintain the same speed and on the other hand it decreases the amount of air which invests the cyclist, reducing the cooling and altering the PET and PMV levels.

Considering the statistical analysis of meteorological variables for the area of Lucca and Florence and the performance data recorded during the testing program, it was possible to run some simulations of thermal comfort of an athlete involved in the race using the model “RayMan”. Results are reported in Table 2. It can be easily noted that the values of PMV and PET obtained even during the simulation of the same race’s phase are quite different from each other. In effect while the PET is strongly influenced by meteorological parameters responsible for the body thermoregulation processes, and particularly by the air temperature and the wind speed, instead the PMV gives an evaluation of the thermal comfort in similar environmental conditions. For this reason and in order to take in account both PET and PMV indices, it has been decided to calculate the grade of physiological stress as an average between the two indices.

We can see in Fig 2 an example of data recorded during the test of the 19<sup>th</sup> October 2011. This figure shows the comparison between the skin and the clothing temperature, the performance data such as the

power, the associated internal heat production and the altitude. The upper graph shows measured data of the skin temperature (black line) and the clothing temperature (grey line). The power (dark line) and the altitude (light line) are represented in the graphic below. It is important to note that in Fig 2 it is also highlighted the peak of the internal heat production reached during the phases 4 and 5 of our simulations.

Table 2. Simulation of the thermal comfort in different race's conditions (heat transfer resistance of the clothing : 0.5Clo)

Simulation phase activity	T <sub>air</sub> (°C)	HWS (m/s)	W	PMV (°C)	PET	Average grade of physiological stress
Phase 1: start (in group)	22	6.0	170	0.7	18.5	No thermal stress-Slight heat stress
Phase 2: escape during first stretch	24	7.2	380	3.7	19.2	Slight heat stress-Moderate heat stress
Phase 3: first laps in group during city circuit	24	4.0	280	2.5	21.8	Slight heat stress
Phase 4: decisive escape during last laps	24	5.0	400	3.7	19.1	Slight heat stress-Moderate heat stress
Phase 5: peak of power before arrival	23	6.5	500	4.4	13.8	Moderate heat stress-Strong heat stress

Legend - T<sub>air</sub> (air temperature), HWS (head wind speed), W (power/internal heat production), PMV (Predicted Mean Vote), PET (Physiological Equivalent Temperature)

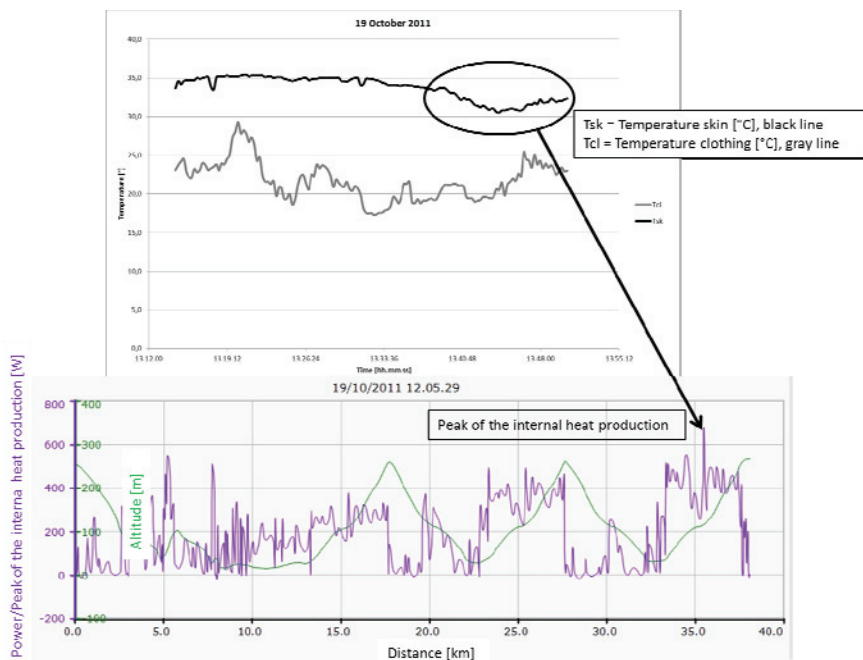


Fig. 2. Test of 19th October 2011: T<sub>air</sub>=20±25°C, U<sub>R</sub>=60%, true wind speed=1.0m/s, head wind speed=7m/s (in the peak period), cloud coverage=2/8, heat transfer resistance of the clothing=0.5Clo (the values of the test are equivalent to the input of the "RayMan" model with which it was simulated the Phase 5 as shown in the Table 2)

#### 4. Conclusion

The results obtained by the comparison of the PET and PMV indices confirm the importance of considering the variation of environmental parameters in both training and strategy assessment. Moreover results clearly demonstrate that assessing the grade of physiological stress using both PET and PMV allows to better estimate the real thermal comfort of cycling athletes avoiding false results. This is confirmed by measurements of the skin temperature taken during different stress conditions.

It can be seen from Fig 2 that, during the simulation of Phases 4 and 5 (decisive escape in the final laps with peak effort), the skin temperature decreases at the expenses of an increased effort associated, however, to an increased head wind speed as the athlete is escaping. It is interesting to note that the decreasing of the skin temperature has been associated by the tester athlete with an improved thermal comfort. In effect in some cases, although the skin temperature decreases with an improvement of the thermal comfort feeling, the internal heat production increases considerably. This leads to an increase in sweat production which is not often felt by the athlete due to the cooling generated by the wind. This apparent positive feeling may lead to a non-adequate hydration which would be, on the other hand, fundamental in order to recover energy both during and after race.

The methodology proposed in this paper provide also a working method which is believed to be easily repeatable and extremely innovative for the applied sport research.

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