Effect of the Environment on the Sport Performance: Computer Supported Training - A Case Study for Cycling Sports

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Abstract. The effect of weather and environmental conditions on sports has been extensively studied over the last few years. Most of the outdoor sport activities, and in particular endurance sports, are strongly influenced by the variation of meteorological parameters.

Notwithstanding the conditions of the outdoor environment are often not considered when evaluating sport performances, as if they were not important, the sport performances are strongly related to the environmental conditions.

The aim of this paper is to assess how much atmospheric variables may influence both the athletic performance and the comfort level for different sport disciplines. The analysis of a case study, focused on the cycling sport, shows how the computer supported training can help the Coaches and the Athletes to consider simultaneously the sport performance and the environmental data.

Keywords: Sport performance · Environmental data · Computer supported training · Cycling

1 Introduction

Environmental and meteorological conditions have an important effect on outdoor sport performances. For instance wind direction and wind speed are important, during marathons, rowing and sailing races [1]. Air temperature is also very important during long running events.

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Considering marathons, the American College of Sports Medicine has established guidelines for preventing health effects due to extreme weather conditions [2]. The guidelines are based on the “wet bulb-globe-temperature” index (WBGT index) which is based on the combined effects of air temperature, relative humidity, radiant heat and air movement. For example race cancellation or voluntary withdrawal are recommended when WBGT > 28 °C. Recently El Helou et al. [3] found that air temperature and performance are significantly correlated.

In effect the assessment of bio-climatological conditions and of thermal comfort in endurance sports, particularly in road cycling, is essential not only for a proper planning of the training program and the nutritional plan, but also for a better evaluation of the racing strategy [4, 5].

Water temperature, for example, plays an important role in swimming, particularly during triathlon races. Indeed, below 13 °C, the maximum swim distance is usually shortened (e.g. Rulebook of the British Triathlon Federation). Moreover, at temperatures below 11 °C it is recommended that open water swimming does not take place.

Among the meteorological variables that strongly influence the sport activity the most important are temperature, wind, precipitation, fog, atmospheric pressure and relative humidity. The usefulness of weather forecasts in performance sports management has been demonstrated by Pezzoli et al. [5] and Pezzoli and Cristofori [6]. The results obtained by such Authors show how the role of the meteorological parameters becomes crucial for sporting activities carried out in an outdoor environment.

Beside meteorological variables, other environmental variables play an important role, such as, for example, pollution levels. It is well known and demonstrated [7, 8] that the air concentration of particulate matter (PM10 and PM2.5) has deleterious effects on the respiratory functions, even if they persist only for short times. The same statement holds for other pollutants.

Notwithstanding the conditions of the outdoor environment are often not considered when evaluating sport performances, as if they were not important, the sport performances are strongly related to the environmental conditions [9].

The aim of this paper is to assess how much atmospheric variables may influence both the athletic performance and the comfort level for different sport disciplines. The availability of these specific information leads to a more detailed knowledge of the race area and opens up the possibility of making considerations on past trends, as well as on the predictability of future atmospheric situations and meteorological phenomena.

This research is articulated in three parts. The first one is based on a new methodology that, by means of structured interviews to athletes and coaches of the major national teams of the Italian Olympic Committee, has shown how environmental variables may influence sport performances. Then it has been studied how different lead-time weather forecasts can contribute to the improvement of the performance itself.

In the second part is analyzed how, a specific software, which consider simultaneously environmental data and sport activity parameters, may help coaches and athletes to better evaluate their performance.

The third part of the research has been devoted to the analysis of a case study applied to the cycling sport. In this context, some tests carried out with the help of a professional athlete, have demonstrated the actual influence of the environmental parameters on the sport performance. The results confirm the need to develop a specific software capable of integrating simultaneously the analysis of sport activity parameters and the environmental data.

2 Methods and Materials

This paragraph analyzes the methods adopted and the materials used to develop the research, during the three different phases described above (environmental analysis, software for analyzing environmental data and sport performances, case study).

2.1 Environment and Sport Performance

Based on Lobozewicz [10], Kay and Vamplew [11] and Pezzoli and Cristofori [6] studies, it was conducted a qualitative-quantitative assessment of the influence of environmental variables on sport performance using the Haddon matrix [12].

William Haddon Jr. developed his conceptual model, the Haddon matrix, in 1980. Since that time, the matrix has been used as a tool to assist in developing ideas for preventing injuries of many types.

The application of the Haddon matrix in the field of the sports activities allows to determine the factors that mostly affect the performance, such as (Fig. 1):

- Personal factors (psychophysical preparation);
- Vector or Agent Factors (materials and opponent);
- Physical Environmental factors (meteorological and environmental analysis). Hereafter the "Physical Environmental factors" will be called "environmental parameters" and they will be referred to meteorological parameters (i.e.: air temperature, air humidity, wind, rain, etc.…) that affect the sport performance;
- Socio-environmental factors (of internal and external social environment).

Focusing on Fig. 1, and in particular on the column "Physical – Environmental Factors", it is evident how different methodologies have to be used for the analysis of the environmental parameters during the different temporal phases of a specific sport event. During the pre-event phase a climatological and statistical analysis proves to be the most suitable. On the other hand, during the event, a deterministic forecast methodology, associated with very short-term numerical weather prediction models, is

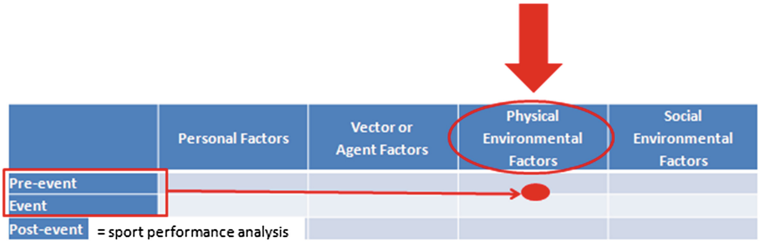

Fig. 1. Haddon matrix.

suggested. Finally, in the post-event phase meteorological measurements can be used, if available, for refining the performance analysis.

If the environmental parameters are not taken into account, one column would be missing within the Haddon matrix and hence an error would be produced using the performance assessment model.

The importance of Environmental Analysis for sport performance is often underestimated by coaches and sport managers. This is mostly due to the lack of knowledge about the added value brought by innovative techniques for both measuring and predicting environmental parameters.

The different time-scales for conducting a proper environmental analysis and a weather forecasting, during a general sport event, can be divided as follows:

- Long term (up to 30 days before the event);
- Medium term (from 30 days before the event to 8 days before the event);
- Short term (from 8 days to 6 h before the event);
- Very short term (from 6 h before the event until the 'action').

This subdivision, and the related weather forecasts, have to be used with regard to the possibilities offered by each Sports' Rule for what concerns the use of meteorological information.

With this kind of meteorological analysis, and according to the Haddon matrix, a proper assessment of the environmental parameter is assured.

A series of in-depth focus groups conducted with different stakeholders (athletes, coaches, managers, performance analysts) coming from the main National Sports Federations of the Italian Olympic Committee (CONI) has allowed to estimate the importance of meteorological variables and the impact of different lead-time weather forecasts on the general performance, for several sports [13, 14].

In particular the following disciplines have been analyzed:

- Cycling: road;
- Rowing;
- Canoe and Kayak;
- Athletics: Marathon and Race Walks;
- Modern Pentathlon;
- Equestrian Sports;
- Tennis;
- Archery;
- Shooting Sports;
- Triathlon;
- Sailing.

2.2 Computer Supported Training

The prototype software is able to load the training data (e.g.: time, position and heart rate) monitored by specific tools that are widely used even among non-professional practitioners (Garmin, Polar, Suunto, etc.). The software tool is also able to load the meteorological data, or other environmental data, measured by one or more monitoring stations of interest. Other important data to analyze are those monitored on the athlete, such as for example his/her skin temperature or humidity [5]. These last data are important when testing the features of particular clothing. All the above mentioned data are generally measured in different positions and in different times. In order to carry out the analysis all the external data must be time interpolated to get them on the same times at which the performance is available (synchronization process).

In a similar way, when the meteorological data are measured by more than one station, a spatial interpolation is needed to estimate the values at the same positions where the performance has been registered. There are situations where it is not correct to perform the spatial interpolation, in such cases it is possible to indicate a radius of influence of each station, or to define areas of competence of each monitoring stations.

Of course the spatial interpolation may be more reasonable in some situations than in other ones. For example, if N stations are measuring wind speed and direction during a sailing race over a relative small water surface, the spatial interpolation is more than reasonable. On the other hand, if the same number of stations is measuring the same variables during a cycling race over a mountain region, the simple spatial interpolation might not be reasonable. In such cases a diagnostic meteorological model (e.g. CALMET) would do a better work, but it cannot be easily incorporated in a software as the one described here.

For other variables, such as temperature, specific algorithms are available to carry out spatial interpolation even in complex terrain [15]. Indeed, air temperature at the ground depends on some variables, such as altitude above sea level, air temperature vertical gradient and land cover type. The interpolation of sparse measurements of temperature over the domain should account for these parameters.

Other meteorological variables are calculated by the software if not available among the measurements. For example, solar radiation can be estimated starting from the geographic location of the athlete, which depends on the time, and on cloud cover, which can be obtained, for example, from METAR (Meteorological Aerodrome Report) data.

The software is developed with .NET framework 3.5 in Visual Basic language. The cartographic layers has to be found by an Open Access map to be used freely by the Coaches and the Athletes. The Open Street map [16] is an efficient GIS data that can be integrated into the sports performance software.

2.3 Case Study: Cycling

Considering the contents of the two previous paragraphs, it has been decided to apply the environmental analysis to a sport which is particularly influenced by the environmental conditions. For these reasons the sport of cycling has been chosen since, as it will be shown later in this paper, it is strongly influenced both by environmental conditions and by weather conditions.

In order to carry out the tests, whose results have been analyzed with the computerized methodology described in Sect. 2.2, the protocol developed by Pezzoli et al. [5] has been applied. Particular attention has been given to the following topics:

Fig. 2. Track of San Francesco al Campo, Turin – Piedmont – Italy.

- Study of the test course. It has been decided to carry out the tests on an oval track, in order to keep constant some important variables (altitude, slope, etc.) and to avoid the introduction of possible bias factors. In this way the repeatability of the test conditions has been guaranteed, making comparable the results obtained in the different test sessions. The tests have been carried out on the circuit of San Francesco al Campo, Turin, Piedmont, Italy (Fig. 2).
- Environmental analysis of the race course. The tests took place on 2 September 2013, from 10:25 LT to 11:55 LT, and all the environmental parameters have been measured during this time interval. The following meteorological variables have been measured in continuous with a sampling rate of 1′:

  (a) Wind direction and speed;
  (b) Air temperature;
  (c) Relative humidity;
  (d) Atmospheric pressure.

An high-precision anemometer (JDC – SKYWATCH Geos 11) was used; this tool has already proved extremely performing in the application of meteorology to sport [5]. The meteorological variables have been used to calculate the apparent temperature index. Considering the studies of Leung et al. [17] and Robaa [18] it has been decided to use the NET index, which is more complete of the Heat Index (HI) and of the Windchill (WC) because it is also a function of wind speed, in addition to air temperature and relative humidity.

Finally the temperature of the track surface has been measured in continuous with a sampling time of 15″ by means of a thermocouple recording thermometer model JDC - Center 306.

- Research of a target athlete and of clothing for the test. It has been decided to work with a single professional athlete, belonging to a high-level elite, capable to guarantee the perfect reproducibility of the tests. Two different typologies of clothing have been compared in order to verify that the described protocol, and the software, are capable to give reliable results with respect to the expected results:
  (a) "Infrared Carbon" short-sleeved shirt and shorts, manufactured by B-Emme;
  (b) Ceramic short-sleeved shirt and shorts, manufactured by B-Emme.
- Performance analysis. The aim of this analysis is to detect the different values of power expressed by athletes in different test conditions and consequently to evaluate the internal heat production expressed in Watt (W). During this phase the following parameters have been constantly registered: power, speed, cadence of pedaling, slope of the road and heart rate. The power and the related internal heat production have been measured using the PowerTap system. To measure the skin temperature, it was decided to use the iButtons, small sensors constituted by a chip enclosed in stainless steel which is 16 mm thick (Fig. 3). Due to its very small size, the instrument can be easily applied to the skin of the tester without interfering with the movement or the technical gesture. The iButton can be mounted virtually anywhere because it is rugged enough to withstand harsh environments (indoors or outdoors). It has many application fields, lately it has also been used in different sports for the measurement of environmental parameters [19]. Six iButtons have been used, placed in pairs on the right and on the left of the following muscles: pectorals, lumbar, and dorsal.

Fig. 3. iButton.

- Test protocol. A total of five tests has been carried out. The first one, appositely performed to bring the tester to a regime situation, has been discarded because the athlete did not reach the sweating condition. Then two pairs of tests have been performed changing the two previously-described types of clothing. The two intermediate tests (i.e. tests 2 and 3) have been analyzed. Tests 4 and 5 were still significant, however it has been preferred not to use them because the athlete already did three tests reaching the threshold conditions. The tests have been done according to the following protocol:
  (a) 3′ of "dead time" to entry and exit from the plant;
  (b) 4′ at average-frequency intensity (250–290 W);
  (c) 3′ at threshold intensity (320–380 W).

3 Results

The results of the research are analyzed in the following parts, considering the three different phases (environmental analysis, software for analyzing environmental data and sport performances, case study).

3.1 Environment and Sport Performance

The analysis of the data extracted from the focus groups, showed that each of the analyzed sports is strongly influenced by the following meteorological variables:

- Temperature;
- Humidity;
- Wind.

Some sports, and among them tennis, cycling and, in general, all shooting disciplines, are also influenced by rain and fog (Fig. 4).

It was also observed the high impact that long-term weather forecasting can have on all sports considered (Fig. 4). This analysis leads to believe that all major sporting events (Olympics, World Championships) are to be considered as "situ-specific". Then athletes, coaches and technicians can use a careful climatological analysis to finalize the sports training well in advance from the date of the event.

		Impact of meteorological parameters on the sport performance						Impact of the meteorological forecast at different time-scales on the sport performance			
Sport	Disciplines	Atmospheric Pressure	Air Temperature	Wind	Rain	Fog	Air Humidity	Long term (up to 30 days before the event)	Medium term (from 30 days before the event to 8 days before the event)	Short term (from 8 days to 6 hours before the event)	Very short term (from 6 hours before the event until the 'action')
Cycling	road	3	4	5	4	3	4	5	4	3	2
Rowing	all	2	4	5	3	1	4	5	5	4	4
noe & kayak	all	2	4	5	3	1	4	5	4	3	2
Athletics	Marathon - Race Walks	2	5	3	3	3	5	5	5	3	1
Modern Pentathlon	Equitation, Running, Shooting	2	5	5	3	5	5	5	4	3	3
Equestrian Sports	all	1	5	3	3	4	5	5	5	4	3
Tennis	all	1	4	4	5	5	4	5	4	3	1
Archery	all	1	3	5	3	4	3	5	4	4	5
Shooting Sports	all	1	2	5	4	5	2	5	4	4	3
Triathlon	all	3	4	5	4	2	4	5	4	4	2
Sailing	all	1	4	5	3	4	4	5	5	5	5

Impact Index: 1 = Very Low
2 = Low
3 = Medium
4 = High
5 = Very high

Fig. 4. Impact of meteorological parameters and meteorological forecast on the sport performance.

		Weather forecast at different time scale and impact on the improving of the sports performance			
Sport	Disciplines	Long term (up to 30 days before the event)	Medium term (from 30 days before the event to 8 days before the event)	Short term (from 8 days to 6 hours before the event)	Very short term (from 6 hours before the event until the 'action')
Cycling	road	training program (physical and mental); decision about the training's site; nutrition planning; material development	training program (physical and mental); nutrition planning (hydration); strategy of the race	nutrition planning (hydration); mental training; pre-race conditioning; selection of the bicycle and clothing; strategy of the race; decision of the placement on the bike	nutrition planning (hydration); strategy of the race
Rowing	all	training program (physical and mental); decision about the training's site; nutrition planning; material development	training program (physical and mental); nutrition planning (hydration); trim of the boat	nutrition planning (hydration); mental training; pre-race conditioning; selection of material; strategy of the race; post-race conditioning	trim of the boat

Fig. 5. Impact of weather forecast at different time scale on the improving of the sport performance (example for cycling and rowing).

Finally, it was evaluated as the weather forecast with different lead-times can be used to improve sports performance (Fig. 5).

This further analysis confirms that the sports training of an athlete should be considered as a complex system where only the correct interaction between information from different sources can lead to the achievement of excellence's performance.

3.2 Computer Supported Training

The software reproduces the training track on a map (the Open Street Map database is used), and for each point a lot of information is given as, for example, wind speed and direction in a specific training location, temperature, or important indices such as the wind chill or the Net Effective Temperature [17]. Of course, each point is also related to the training data, as for example, the time elapsed from the start of the exercise, the total distance, the average and instantaneous speeds, the heart rate, etc. The user is also allowed to export the track in KML or KMZ format in order to view it on Google Earth.

The performances are also summarized in tabular format, and the user is allowed to export the tables in many formats in order to use them in presentations or for further analysis.

The first version of the software is still being developed as a desktop application for PCs. Future versions could be available also for Android and iOS tablets.

The basic idea of the development of the software are reviewed in Fig. 6.

As shown by Fig. 6 an important part of the software is related to the time and space interpolation. By means of the methodology described by Bellasio et al. [15] it is possible to interpolate the surface temperature at any point of the domain considering also the terrain elevation of the meteorological stations and the type of surface by means of the leaf area index.

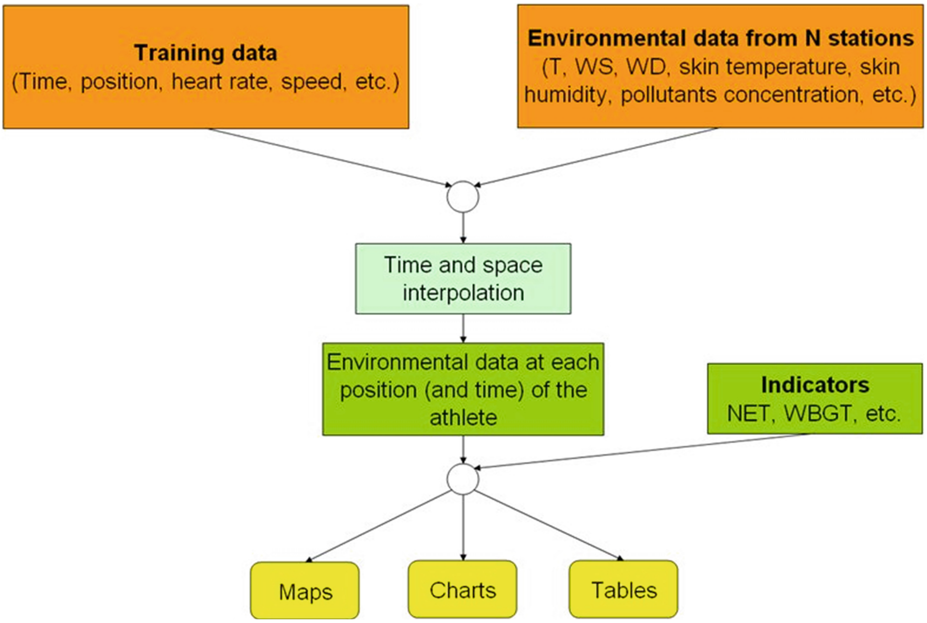

Fig. 6. Flow chart of the software.

All the measured and derived data (both referring to the sport performance and to the environment) will be represented in a synchronous way, by allowing coaches and athletes to analyze their performance to the light of the meteorological and environmental conditions at the time of the performance itself.

As it will be shown in the next paragraph, this kind of software is of great importance for the final user, since it allows to correctly consider all the parameters which influence the sport performance.

On the other hand, as illustrated in Sect. 3.1, it is no more possible to disregard the effects of environmental and meteorological parameters, as they greatly affect all the outdoor sports activities.

3.3 Case Study: Cycling

The computerized analysis of the meteorological and environmental data measured during the test (late morning of 2 September 2013) is summarized in Table 1.

Figure 7 shows the sport performance parameters monitored during the five tests. As shown in Table 2, during tests 2 and 3 the tester had physiological characteristics and speeds completely comparable, confirming the high reliability of the tester and, as a consequence, of the tests themselves.

Finally, two different sport clothing have been tested. According to the clothing manufacturer one should expect better results in test 3 than in test 2. In fact, the ceramic

Table 1. Environmental and meteorological data measured during the test.

Environmental Data	02-Sept-13
Test Hours	[10.25LT ; 11.55LT]
Apparent Temperature – Average [°C]	24.7
Apparent Temperature – Range 60% [°C]	[+23.0 ; +26.5]
Surface Track Temperature – Average [°C]	34.6
Surface Track Temperature – Range 60% [°C]	[+32.0 ; +37.1]
Sky	Clear

Table 2. Performance data. The square brackets indicate the 60 % of frequency of occurrence.

	Power [W]	Bike Speed [km/h]	Heart rate frequencies [bpm]
Test 2	282 [265;299]	39,6 [37.2;42]	158 [149;167]
Test 3	290 [273;307]	40 [37.5;42.5]	157 [148;166]

material has shown better transpiration features with respect to the “Infrared Carbon” material.

As shown by Figs. 8 and 9 and by Tables 3 and 4, prepared with the help of the integrated analysis software, at the moment of maximum effort the use of the ceramic material not only shows a drop in temperature in the breastplate, but also shows a sharp drop in humidity thanks to the “pumping” effect.

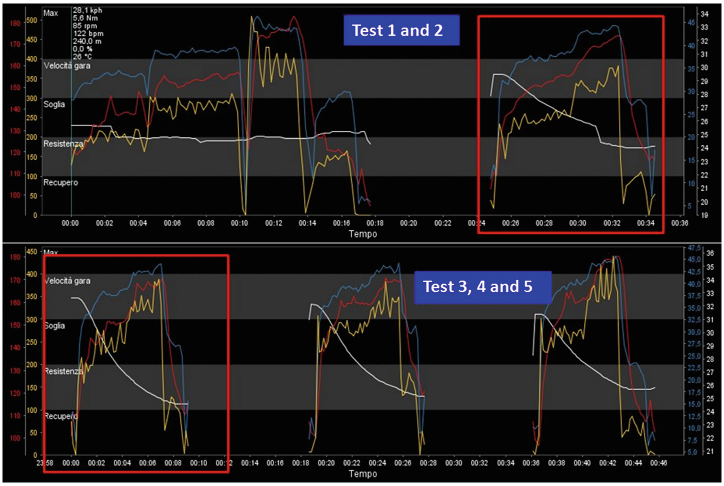

Fig. 7. Performance parameters: bike speed (blue line), heart rate (red line) and power (yellow line). The two tests considered for the analysis (tests 2 and 3) are reported within the red boxes (Color figure online).

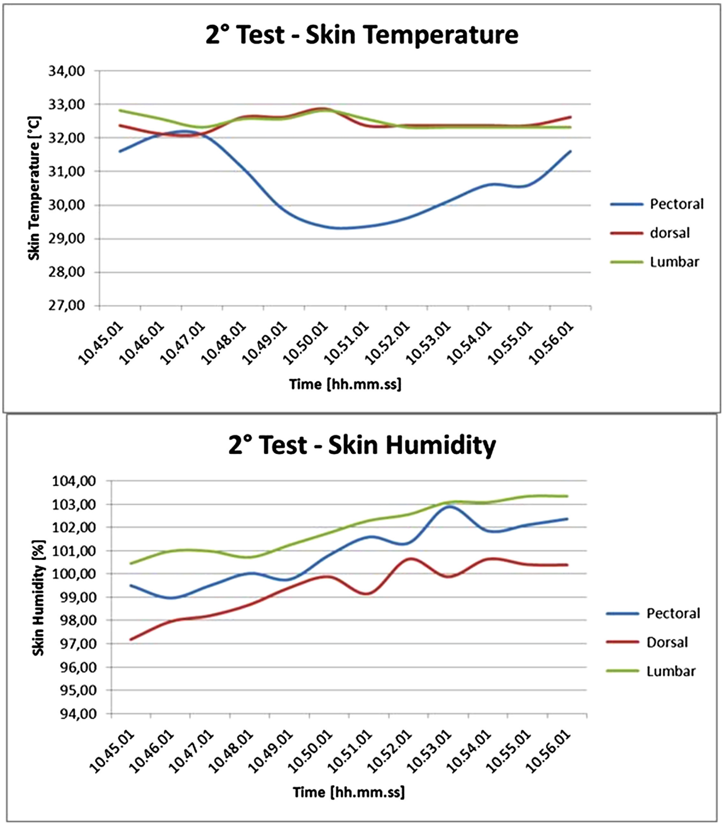

Fig. 8. Measurements of skin temperature (above) and skin humidity (below) carried out during test 2 ("Infrared Carbon" short-sleeved shirt and shorts, manufactured by B-Emme) (Color figure online).

Table 3. Data measured during the 2nd test.

Thermal Comfort Data	2nd Test
Hours	[10.45LT ; 10.56LT]
Skin Temperature – Average [°C]	31.8
Skin Temperature – Range [°C]	[31.4 ; 32.1]
Skin Humidity – Average [%]	100.6
Skin Humidity – Range [%]	[99.5 ; 101.7]

These tests show that, independently from the significance of the data obtained, a data processing tool that enables the user to analyze in synchrony all measured data (concerning both sport performance and environmental data) is absolutely essential.

All the analysis carried out with this kind of software can integrate in a holistic view the parameters that affect performance in sport.

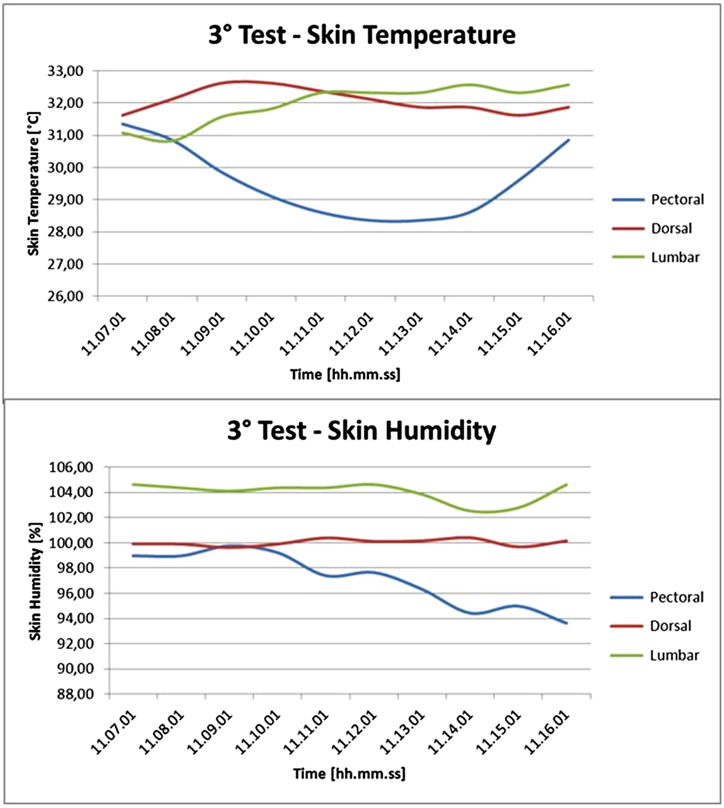

Fig. 9. Measurements of skin temperature (above) and skin humidity (below) carried out during test 2 (Ceramic short-sleeved shirt and shorts, manufactured by B-Emme) (Color figure online).

Table 4. Data measured during the 3rd test.

Thermal Comfort Data	3rd Test
Hours	[11.07LT ; 11.16LT]
Skin Temperature – Average [°C]	31.1
Skin Temperature – Range [°C]	[30.8 ; 31.4]
Skin Humidity – Average [%]	99.9
Skin Humidity – Range [%]	[99.0 ; 100.8]

Fig. 10. Wheel of the sport performance analysis.

4 Conclusion

This analysis clearly shows that both meteorological and environmental parameters have a significant impact on the sports performance for outdoor events. Therefore the assessment methodology presented in this work can be considered as innovative for applied sport research.

It follows that the Performance Analyst should develop relevant competences needed for conducting an integrated data analysis, taking into account the environmental parameters as well.

Moreover the Performance Analyst has to take care of the results' communication of this integrated performance data analysis to the coaches through understandable and meaningful messages.

From the focus groups and from the case study, it was concluded that, in the sports Performance Analysis the following well-known areas need to be addressed (Fig. 10):

- Motion Analysis
- Match and Timing Analysis
- Notational Analysis

In addition to these areas, two new areas must be faced, namely:

- Rule Analysis
- Environmental Analysis

These considerations are in agreement with innovative researches carried out on the Team Sport [20–22], on the cycling [5], on the water sport [1] as well as in the winter sports [23, 24].

Therefore National Sports Federation should pay particular attention to train these specific competencies in order to create sports operators that can fulfill the role of Performance Analysts with the necessary awareness. In addition the technicians will need a specific and continuous education allowing the achievement of the fundamental knowledge in the field of environmental analysis.

Finally it has been demonstrated that the use of an innovative computer supported training system, taking into account all the sport performance parameters and the environmental conditions, can be useful for both coaches and athletes.

This tool, not yet developed in the Sport Technology, is able to deliver to both coaches and athletes added value information since it is simultaneously taking into account both the environmental and the sport performance values.

This technology that allows the comparison of the sport performance in relationship with the environmental conditions in which it was carried out, represents an innovative topic, within the ‘environmental sensible’ sports, which would need further investigations.

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