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Analysis of motor performance of professional soccer players in different environmental conditions

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Introduction. **Air temperature and humidity affect the motor activity of soccer players during matches. Analysis of soccer players' motor activity in extreme environmental conditions enables optimal players' preparation.** Aim of Study. **The study aims to assess changes in motor performance of soccer players in different environmental conditions.** Material and Methods. **The participants were soccer players taking part in the 2014 World Cup matches in Brazil. The authors used the Castrol Performance Index motion analysis system for data recording. Results. Higher air temperature reduces the performance of exercise with medium ($p \leq 0.05$) and high intensity ($p \leq 0.01$); while higher humidity has a significant positive impact on the distance covered by players with medium intensity ($p \leq 0.05$). The total number of performed sprints becomes significantly lower in higher air temperature and humidity ($p \leq 0,05$).** Conclusions. **Soccer training should emphasize high-intensity exercise as well as short-lasting and explosive exercise since the environmental conditions have a greater impact on players' speed skills than endurance skills.**

KEYWORDS: soccer, World Cup, professional soccer players, temperature, humidity, endurance, speed.

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What is already known on this topic?
The impact of environmental conditions on athletes' performance skills has been studied for some time. Researchers have established air temperature and humidity ranges in which the motor potential of soccer players can be most effectively exploited. Players' endurance and speed capacity does depend on environmental conditions.

Introduction

Top-level soccer competitions often take place in changing environmental conditions. Soccer matches can be played in different air temperature and humidity and at high elevations. An important practical implication for soccer coaching staffs that can be helpful in attaining the most optimal motor preparation levels of players can be analysis of endurance and speed capacities of soccer players who play matches in extreme environmental conditions.

The available literature includes numerous research reports on players' locomotive activity, regardless of the climatic conditions. Elite soccer players can cover from 10 to 13.5 km during a single match, depending on their playing position, while a soccer team as a whole can cover even above 120 km [1-4]. The total distance covered by a player during a match can only be a partial determinant of his physical activity during match-play. Equally significant are variables such as the number of performed sprints and other efforts of submaximal and maximal intensity. Sprint running is one of the most

important motor activities of soccer players, despite the fact that it merely constitutes from 1 to 12% of total distance covered during a match [5-7]. These distances and proportions can be quite different, if matches are played in extreme high or low air temperature.
According to Maughan et al. [8] the optimal temperature range for performing speed and endurance exercise is between 4 and 10°C. Grantham et al. [9] claim that the ambient temperature below 22°C does not pose a heat stress hazard, while temperatures above 22°C increase the risk of hyperthermia. The thermal comfort of physically active individuals is also determined by air humidity. Fluctuations in relative humidity from 20% to 60% in a moderate ambient temperature do not have an appreciable effect on thermal comfort [10].
Considering the above, it can be stated that an air temperature below 22°C and humidity below 60% are optimal conditions for exploitation of soccer players' full motor potential. However, top-level international soccer tournaments are not always played in such favorable environmental conditions. The last two World Cups were hosted by South Africa and Brazil, where air temperature often exceeds 22°C and humidity 60%. Soccer players' physiological responses to high air temperature and humidity are very individual [11, 12]. The players displaying the largest haematological adaptations were able to maintain the same activity when playing in the heat as when playing in temperate conditions [13]. In extreme environmental conditions soccer players can change the levels of their motor activity by reducing the volume of low-intensity running and thus preserving the ability to undertake high intensity activities [14].
Regardless of players' individual adaptive abilities connected with playing in adverse environmental conditions, intensive exercise – additionally intensified by high air temperature and humidity – increases the strain on the body's thermoregulation mechanisms. Heat stress and strain in exercise and sport constitute a complex system of physiological behaviors [15]. The human body possesses physiological mechanisms of losing heat in order to maintain the body's homeostasis. During a soccer match such a mechanism is sweat evaporation. In high air temperature and humidity these mechanisms can be compromised [16].
The sweat loss of elite professional players during a 90-min training session or a match is higher at 32°C – 2.2 l [17] and at 26°C – 2.0 l [18] than at 5°C – 1.7 l [19]. The sweat loss in soccer players playing in a cold environment is similar to that of elite players playing in a warm environment, but the volume of fluid ingested is lower [19].
Exercise dehydration above 2% of body mass has a detrimental effect on cognitive function, physical and intellectual capacity, and it inhibits the body's thermoregulation mechanisms [20, 21].
On the basis of data from literature the following research question can be posed: Does the high amplitude of ambient temperature and humidity affect soccer players' performance skills? The aim of this study was an assessment of changes in speed and endurance capacity of soccer players taking part in the World Cup matches in Brazil in 2014, with regard to air temperature and humidity.

Material

The participants were 607 soccer players from all 32 national teams that qualified for the 2014 World Cup in Brazil. Their mean body height was 181.16 ± 6.72 cm, body mass 76.94 ± 7.22 kg, and age 27.22 ± 3.75 years.

Methods

The Castrol Performance Index motion analysis system was used for recording players' movements during all 64 tournament matches and for processing the records into quantitative data. The following parameters were measured using the official FIFA match reports: the total mean distance covered by a team during match-play, the distance covered in the first half of a match and in the second half of a match, and the distance covered with low (≤ 11 km/h), moderate (> 11 ≤ 14 km/h) and high (> 14 km/h) intensity. Players' speed capacity was assessed on the basis of total number of performed sprints in match-play, in the first half and in the second half, and on the basis of the teams' maximal running speed.
The data on air temperature and humidity was taken from official FIFA reports. In the analysis three air temperature ranges: up to 22°C, 22-28°C, and above 28°C [9]; and two air humidity ranges: below 60% and above 60% were used [10].
The Statistica 10.0 software package was used for statistical analysis. Arithmetic means and standard deviations were calculated. To compare the mean values of examined parameters a one-way analysis of variance (ANOVA) was used. The differences between pairs of means were checked with the Fisher's least significant difference (LSD) test. The levels of statistical significance were set at $p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.001$.

Results

The effects of three air temperature ranges: below 22°C (17.42 ± 3.40), between 22 and 28°C (25.49 ± 1.65), and above 28°C (29.91 ± 1.41), and two humidity ranges: below 60% (47.44 ± 8.51) and above 60% (79.00 ± 8.96) were examined separately.

Distance covered during match-play

The World Cup matches in Brazil were played in the temperature of 24.73 ± 4.39°C and humidity of 64.56 ± 16.31%. In such conditions the players covered the mean distance of 106.24 ± 6.54 km during match-play, 53.53 ± 3.26 km in the first half, and 52.74 ± 4.63 km in the second half. The differences between these distances were statistically non-significant.

No significant differences between the distances covered by the players during match-play, in the first half and in the second half were noted with the rise in air temperature in the specified ranges (below 22°C, 22-28°C and above 28°C), and in humidity (below and above 60%) (Table 1).

Distance covered by soccer players with different intensity

During match-play, regardless of environmental conditions, the players covered the distance of 65.47 ± 7.20 km with low intensity, 17.02 ± 2.39 km with medium intensity, and 28.20 ± 4.10 km with high intensity.

Considering the impact of ambient temperature and humidity, it was observed that a higher temperature reduced the level of performance of medium intensity ($p \leq 0.05$), and highly reduced the level of performance with high intensity ($p \leq 0.01$). Higher humidity significantly increased the covered distance with medium intensity ($p \leq 0.05$) (Table 1).

Total number of performed sprints

During match-play, regardless of environmental conditions, the players performed 357.92 ± 49.49 sprints, including 177.83 ± 26.16 in the first halves and 180.09 ± 32.19 in the second halves of the matches.

The total number of performed sprints by the players was significantly reduced during match-play with the rise in air temperature ($p \leq 0.05$). 370.58 ± 54.36 sprints were performed in the range below 22°C, and 334.91 ± 44.26 in the range above 28°C (Figure 1). The number of sprints was also lower in the first halves in higher air temperature ($p \leq 0.01$), and in the second halves, but the changes in the latter were statistically non-significant (Table 2). Higher humidity also reduced the total number of sprints performed in match-play, and in the second half ($p \leq 0.05$): 371.10 sprints in humidity below 60% and 349.47 sprints in humidity above 60% (Figure 2). No significant differences were, however, noted in the first halves of matches.

Table 1. Players' endurance capacity in different air temperature and humidity ranges

Condition	Temperature			Humidity	
	< 22°C	22-28°C	28°C <	above 60%	below 60%
Parameter	$\bar{x} \pm SD$				
Distance covered during match-play [km]	105.63±8.84	106.48±5.97	106.02±5.93	106.12±5.73	106.32±7.05
Distance covered in the first half of the match [km]	54.29±3.88	53.40±3.10	53.14±3.15	53.01±2.68	53.86±3.56
Distance covered in the second half of the match [km]	51.35±7.93	53.11±3.51	52.87±3.26	53.17±3.50	52.46±5.24
Distance covered with low intensity [km]	64.20±6.58	66.29±8.08	63.81±2.68	64.31±6.33	66.22±7.65
Distance covered with medium intensity [km]	17.69±2.51	17.09±2.40	16.06±1.99	16.49±2.24	17.37±2.44
Distance covered with high intensity [km]	29.69±4.13	28.32±4.26	26.14±2.44	28.22±3.67	28.19±4.38

Table 2. Total number of sprints performed in the first and the second half of matches in different air temperature and humidity ranges

Condition	Temperature			Humidity	
	< 22°C	22-28°C	28°C <	below 60%	above 60%
Parameter	$\overline{x} \pm SD$				
Total number of sprints in the first half [number]	188.29±25.74	178.23±25.62	164.95±24.09	181.44±27.08	175.53±25.45
Total number of sprints in the second half [number]	182.29±46.54	182.16±28.41	169.95±25.51	189.66±30.66	173.95±31.83

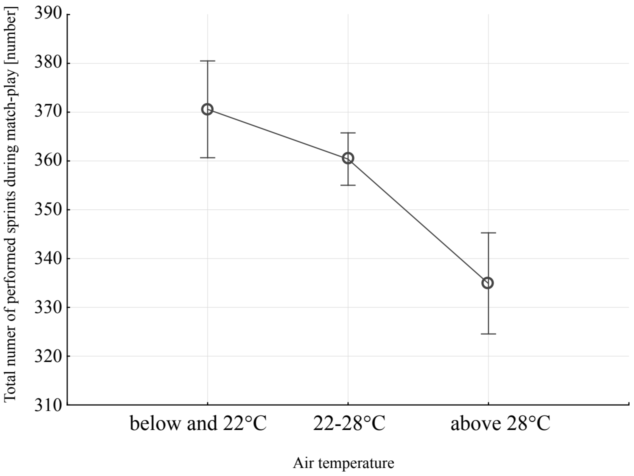

Figure 1. Total number of sprints performed by a team during match-play with regard to air temperature ranges

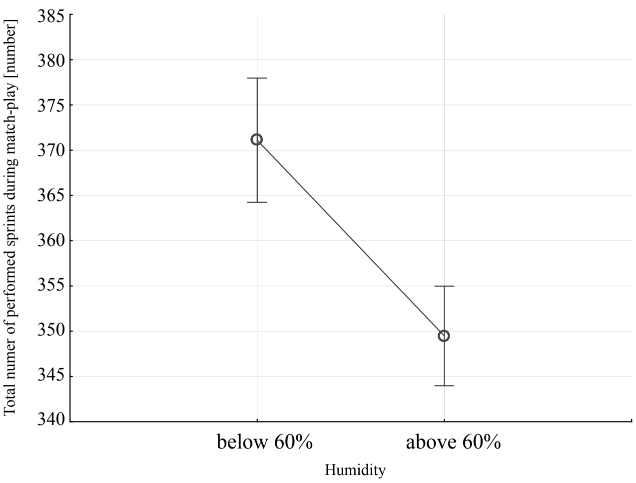

Figure 2. Total number of sprints performed by a team during match-play with regard to humidity ranges

Peak running speed

Regardless of environmental conditions the mean peak running speed attained by the 2014 World Cup teams amounted to 26.90 ± 0.81 km/h. With regard to the three air temperature ranges, two phases in the development of peak running speed were observed among the players. In the first phase the players developed increasingly higher peak running speed until the range of 22-28°C, reaching 27.03 ± 0.75 km/h. In the second phase, in the range above 28°C, the development of the peak running speed was significantly lower ($p \leq 0.05$) (Figure 3). Also the increasing humidity reduced the players' peak running speed; however, the differences were statistically non-significant.

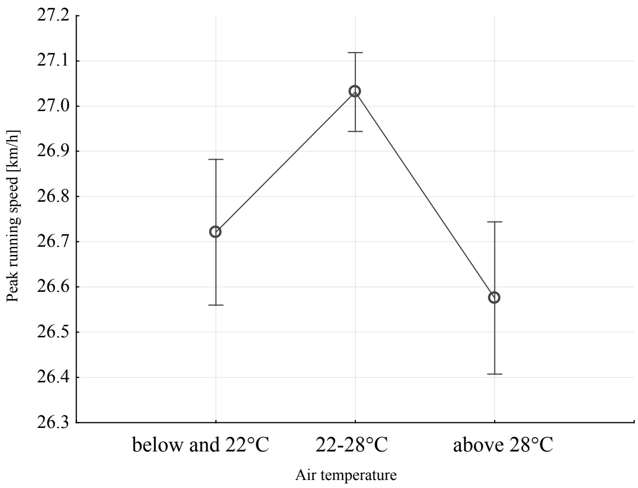

Figure 3. Players' peak running speed with regard to air temperature ranges

Discussion

During the 2014 World Cup finals in Brazil 81% of matches were played in temperature below 22°C, and 61% of matches in humidity above 60%. The maximal air temperature amounted to 33°C, and air humidity to 94%.

The locomotive activity of soccer players in difficult environmental condition remains an interesting research issue. According to Brito et al. [22] special attention should be devoted to athletes exposed to long and extensive sunny and hot conditions. A significant reduction in players' endurance and speed capacity in such conditions may directly affect the quality of match-play and the match outcome [14, 21, 23].

Research results show that the ranges of air temperature and humidity analyzed separately do not significantly affect the total distance covered by elite soccer players. This is explained by Mohr et al. [24], who stress that the total distance run by soccer players in adverse environmental conditions is also determined by match-play strategy. They prove that technical-tactical actions performed by players during match-play differ significantly in extreme temperature ranges. In high air temperature players cover a relatively longer distance with low exercise intensity in the first half, which may reduce the rate of fatigue accumulation. In consequence, soccer players may cover a similar distance in the second half, and this means an even distribution of body strength for the entire match duration. According to Andrzejewski et al. [25] in the first half of the match the teams try to assess the opponent's capacity, and by taking advantage of their technical-tactical preparation, attempt to impose their own, optimal match-play tactics on the opponent. This is directly associated with the total distance covered by the players, which is similar in both halves of the match.

The environmental conditions significantly affect the distance covered by players only with medium and high intensity, but not with low intensity. A rise of air temperature between the ranges, from below 22°C to above 28°C, significantly reduces the covered distance for 1.63 km. A rise in humidity to above 60% significantly increases the distance run by the players with high intensity for 0.88 km. Playing matches in higher air temperatures also significantly reduces the distance covered with high intensity for 3.55 km, i.e. 12%. Mohr et al. [26] noted a 26% decrease in the covered distance in high air temperature by elite soccer players. The considerable difference between Mohr et al. and the present study results can be explained by the differences in temperatures in which both studies were carries out. The tendency of changes was, however, the same.

The total number of performed sprints and peak running speed confirm the high level of speed skills of examined players. The present study revealed that teams taking part in the 2014 World Cup in Brazil performed sprints roughly every 15 seconds in 22°C, and every 17 seconds in 28°C. Such a high rate of sprints by elite soccer players was the result of their considerable motor potential, versatile speed, strength and endurance preparation, and quick recovery rate [27, 28]. The number of performed sprints was significantly reduced with the rise in humidity. Hayes et al. [29] noted a trend toward greater physiological strain while performing short-lasting exercises in high air humidity.

Peak running speed is another parameter which characterizes the speed skills of soccer players. The peak speed rises systematically, and in the temperature range of 22 to 28°C it attains the maximal value, i.e. 27.03 ± 0.75 km/h. However, in the range above 28°C the peak running speed becomes significantly reduced (for about 0.45 km/h). The attainment of the highest peak running speed in the temperature range between 22 and 28°C may be explained by the fact that in high ambient temperature players with the highest body temperature features the highest level of performance skills [26]. However, exceeding the temperature of 28°C has a negative effect on the development of peak running speed. Racinais et al. [23] claim that body hyperthermia reduces the ability to perform specific actions in a match, and that it hinders decision-making speed and accuracy.

It can be stated that a soccer team which is well-prepared and adapted to the conditions of high air temperature and humidity, and whose players are well-hydrated, will maintain a high performance level for the entire match duration. Such a team then creates a higher number of goal opportunities [16]. Since in the present study the natural conditions were shown to affect more the players' speed skill rather than endurance skills, the implication for the coaching staffs would be to focus particular attention on the process of players' adaptation by involving not only high-intensity exercise, but also short-lasting and explosive exercise in the training process.

The correlations between air temperature and humidity and the level of soccer players' motor skills during top-level soccer competitions require further research examining the concurrent impact of both environmental factors. Such studies will be highly significant with regard to the complex nature of the impact of the environmental conditions on soccer players' performance.

What this paper adds?
The motor abilities of elite professional soccer players are more affected by air temperature than air humidity. Air temperature extremes had a greater impact on players' speed than endurance. Coaching staffs should pay particular attention to players' adaptation to high air temperature, placing an emphasis not only on high-intensity training exercises but also on short-lasting and explosive exercises.

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