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Med Sci Tennis 2008;13(2):8-9

Physiological and behavioural responses to thermal stresses in tennis

Background: Tennis is played year-round throughout the world in a wide variety of weather conditions. Often players in the Australian Open, held in the middle of summer, are faced with air temperatures exceeding 40°C. The current Extreme Heat Policy used at the Australian Open postpones play at an absolute air temperature ≥ 35°C and a Wet Bulb Globe Temperature ≥ 28°C. This is based on the American College of Sports Medicine's Exertional Heat Illness Policy for distance running. Therefore, this policy may be inappropriate for tennis where activity is interspersed with rest periods which reduce the overall exercise intensity. Furthermore, there has been no known scientific evaluation of this policy. However, a review of its applicability to tennis using the current information base is difficult since there is no objective information about the effects of environmental conditions on players' physiological responses, comfort and behaviour. Tennis players of all levels would benefit from objective and comprehensive information relating to how the thermal environment affects their health and safety, and comfort. Such information enables them to make decisions about whether they choose to play tennis on a given day, the duration and intensity at which they play, the required fluid replacement, strategies to manage thermal comfort (e.g. wetting the skin, moving to the shade or fanning), and tactical modifications. These decisions enable players to minimise the risk of developing heat illness, and maximise comfort in adverse weather conditions.

Research objectives: The aim of this thesis was to obtain comprehensive data on environmental and metabolic heat stress, and body temperature regulation during competitive singles tennis matches over each of the seasons in Sydney, Australia. These data were then be used to determine whether a steady-state core body temperature and thermal comfort are being achieved in tennis, in addition to the mechanisms responsible for their attainment (i.e. autonomic / physiological thermoregulation or behavioural / psychological thermoregulation?). These data were also used for the rational analysis of heat stress, which will enable prediction of all thermal exchanges and thus, tolerable environmental conditions for tennis. Finally, these data enabled an evaluation of the current Extreme Heat Policy and the suggestion of an alternative method for assessing heat stress in tennis (the Belding and Hatch Heat Stress Index).

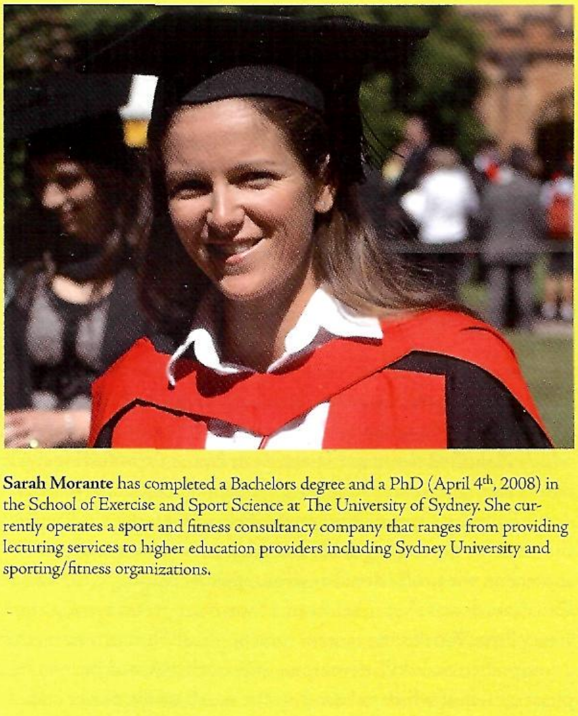
Hypotheses: There is expected to be a range of environmental conditions (the prescriptive zone) in which thermoregulation is successful and body core temperature is maintained relative to the workload but independent of the environmental stress. Whilst environmental conditions within the prescriptive zone enable the maintenance of body core temperature, skin temperature is hypothesized to rise with increasing ambient temperature up to approximately 36°C in order to maintain convective heat dissipation. Since the thermal gradient for convective heat loss is reduced as air temperature approaches skin temperature, with heat being gained when skin temperature exceeds air temperature, the evaporation of sweat becomes the major if not sole method of heat dissipation. Therefore, sweat rate would be expected to increase with ambient temperature in order to maintain thermal equilibrium. Whilst core body temperature is maintained within tolerable levels during the prescriptive zone, players may subjectively rate conditions within the prescriptive zone as intolerable due to thermal discomfort that results from high core and skin temperatures and/or skin wettedness. In more stressful environmental conditions, or when players are experiencing physiological or subjective strain, players are expected to modify their behaviour to reduce the workload and heat production. This would be indicated by a reduction in effective playing time, point duration and stroke frequency. Within the prescriptive zone, it is anticipated that thermoregulatory responses will agree with previously published studies including: metabolic heat production of approximately 680 W, heart rate of around 145 beats.min^{-1}; body core (rectal) temperature of around 38.2°C; and sweat rate of approximately 0.93 $L.h^{-1}$. When conditions exceed the prescriptive zone, core body temperature is expected to be higher in response to the greater heat load that results in thermal equilibrium being achieved at a higher core body temperature. However, it is unknown whether the thermal environment and exercise intensity will represent a stress level above the upper threshold of the prescriptive zone during the experimental tennis matches within this study.

Methods: In the laboratory, the maximum aerobic power (VO_2max) and body composition for each subject was assessed. Experimental tennis matches were completed by men and women of varying standards in a range of thermal environments. Each of the six thermal stresses (air temperature, humidity, solar radiation, air movement, clothing and metabolic heat production) were measured or predicted for each tennis match and player. A whirling psychrometer was used to measure dry bulb (air) temperature and wet bulb temperature (for humidity) at 20 minute intervals throughout each tennis match and player. Mean radiant temperature (for solar radiation) was assessed by a globe thermometer, which recorded globe temperature each minute throughout matches. Air movement was also logged each minute throughout matches by a mechanical anemometer. An additional observation, natural wet bulb temperature, was measured at 20 minute intervals for the calculation of Wet Bulb Globe Temperature (WBGT). The thermal properties of clothing were predicted for normal tennis attire. Metabolic heat production was predicted from a known regression equation developed for the association between relative workload (% VO_2max) and rectal temperature. The regression equation determined for oxygen uptake (VO_2) and heart rate in the laboratory for each subject was also used to predict metabolic heat production. The thermal strains measured during tennis included rectal temperature, skin temperature, sweat rate, heart rate and subjective responses. Rectal temperature and four skin temperatures (arm, chest, thigh and leg) for each player were recorded every minute throughout matches by custom-built temperature loggers. Each player's heart rate was recorded at 15 seconds intervals throughout play using a heart rate monitor. Body water loss for sweat rate was determined by weighing subjects fully clothed and equipped before play, after 30 minutes of play and at the completion of the match. Body mass changes would also include evaporative water loss from the respiratory tract and metabolic fuel used during activity. However, these changes are considered negligible and do not detract from the validity and reliability of this method of sweat loss assessment. Drink bottles were weighed at the same times to account for fluid intake. During the change of ends after every six games, players indicated subjective responses of perceived exertion, thermal comfort, sweatiness and a rating of conditions (thermal sensation). Notational analysis was conducted throughout matches to assess activity patterns and workload.

Results: Air temperature ranged from 14.5 to 38.4°C, relative humidity ranged from 21.8 to 73.7% and WBGT ranged between 13.5 and 29.2°C. Mean point duration was 5.8 ± 1.3 s and effective playing time (the proportion of the match spent in play) averaged 23.7 ± 5.2 %. This equates to a work to rest ratio of approximately 1 : 3.5. Positive associations were found for the change in rectal temperature with both point duration ($P < 0.001$) and effective playing time ($P < 0.05$). Heart rate was also positively correlated with point duration ($P < 0.0001$) and effective playing time ($P < 0.05$). Rectal temperature averaged 38.5 ± 0.4°C (62% VO_2max) and mean heart rate was 136.8 ± 13.6 beats.min^{-1} (66 % VO_2max). Both rectal temperature and heart rate were unaffected by the two components of the current Extreme Heat Policy (air temperature and Wet Bulb Globe Temperature), even in conditions exceeding the thresholds for each index (35°C and 28°C, respectively). Skin temperature demonstrated a positive association with air temperature ($P < 0.0001$). Sweat rate averaged 13.32 ± 5.56 mL.kg.h^{-1} or 0.92 ± 0.42 L.h^{-1}, and demonstrated positive relationships with air temperature ($P < 0.0001$), skin temperature ($P < 0.0001$) and rectal temperature ($P < 0.03$). Thermal comfort declined with increasing rectal temperature ($P < 0.03$) and skin temperature ($P < 0.0001$). Both point duration ($P < 0.002$) and effective playing time ($P < 0.0002$) were reduced as conditions were rated increasingly difficult. Oxygen uptake (VO_2) during tennis was 2.5 ± 0.5 L.min^{-1} when predicted from rectal temperature and 2.6 ± 0.5 L.min^{-1} when predicted from heart rate, which corresponds to metabolic heat production of 459.5 ± 76.3 W.m^{-2} and 483.9 ± 95.4 W.m^{-2}, respectively. The required evaporation for thermal equilibrium (E_{req}) for the observations averaged 415.0 ± 104.5 W.m^{-2} and was associated with the observed sweat rate ($P < 0.0001$). However, the relationship between the predicted Ereq and the observed sweat rate was weaker than expected ($R^2 = 0.33$). Air temperature and relative humidity were modelled to predict conditions where E_{req} exceeded the maximum evaporative capacity of the environment (E_{max}), resulting in body heat storage.

Conclusions: Core body temperature remained controlled in environmental conditions at and a little beyond the two heat stress indices comprising the current Extreme Heat Policy. This suggests the current policy does not exceed the upper limit of the prescriptive zone and thereby endanger players. Both autonomic / physiological thermoregulation (increase in skin temperature and sweat rate) and behavioural / psychological thermoregulation (reduction in point duration and effective playing time) were involved in the control of core body temperature. The rational analysis of heat stress provides a more comprehensive approach to setting environmental limits. However, the prediction of thermal exchanges using standard equations was less accurate than expected, meaning these equations will need to be modified for improved prediction in tennis.

About the author



Sarah Morante has completed a Bachelors degree and a PhD (April 4th, 2008) in the School of Exercise and Sport Science at The University of Sydney. She currently operates a sport and fitness consultancy company that ranges from providing lecturing services to higher education providers including Sydney University and sporting/fitness organizations.