Thermoregulatory responses during competitive singles tennis

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Br. J. Sports Med. published online 29 Nov 2007;
doi:10.1136/bjsm.2007.037002

BJSM Online First, published on November 29, 2007 as 10.1136/bjsm.2007.037002

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KEYWORDS
Core temperature; heart rate; physiology; skin temperature.

ABSTRACT

Objectives: The present investigation provides examples of thermoregulatory responses during competitive singles tennis and comparisons with continuous, steady-state running. **Methods:** Typical examples of body core (rectal) temperature, skin temperature and heart rate were selected to demonstrate the differing characteristics of tennis and running, and the corresponding thermal environments. Rectal and skin temperatures were logged each minute whilst heart rate was logged every 15 seconds throughout the competitive best of three set singles tennis matches and 60 minute continuous, steady-state running trials. Tennis matches were completed outdoors in widely varying thermal environments whilst the running trials were completed in the laboratory under stable conditions. **Results:** Rectal temperature in tennis was shown to be raised little more than resting levels, or to reach plateau after different lengths of time depending on exercise intensity and environmental conditions. Rectal temperature during tennis was found to take longer in reaching a plateau than continuous, steady-state exercise. Skin temperature during tennis varied widely depending on environmental air temperature and was lower than the running example at the same air temperature. Heart rate displays close similarity between opponents for both average and response characteristics during tennis. Wider range and higher peak values were found during the tennis example compared with running. **Conclusions:** The present investigation has provided a descriptive account of thermoregulatory response characteristics during singles tennis. Differences between outdoor tennis and continuous, steady-state running in the laboratory for each of these responses were discovered.

KEYWORDS
Core temperature; heart rate; physiology; skin temperature.

INTRODUCTION

Thermoregulatory responses to sports and exercise have been widely investigated. However, investigation of the response characteristics has been concentrated among continuous sports such as running and cycling (1-3).

A number of studies have examined thermoregulatory responses during tennis (4-14), however there were a number of limitations. Of these studies, Dawson et al (6) and Elliott et al (7) were the only to measure the important thermal strains core body temperature, skin temperature, sweat rate and heart rate. Neither of these studies, however, continuously measured rectal and skin temperatures, and heart rate throughout the match, instead making observations during each change of ends approximately 2 minutes apart. This prevents detailed plotting of these variables over the course of the match and precision in the subsequent description of the response characteristics. Furthermore, observations were made during 4 hour long matches, thus reflecting only 4 different thermal environments. Therminarias et al (13, 14) also measured rectal temperature, sweat loss and heart rate during competitive singles tennis. This study improved on the measurement of heart rate during tennis through continuous logging every 15 seconds during the matches. However, rectal temperature was measured only at the beginning and end of matches, thereby failing to describe the characteristics of this response, particularly if and when a steady-state is achieved. All other studies investigating physiological responses during tennis measured only heart rate and/or oxygen consumption, which do not provide a complete description of thermoregulatory responses and their characteristics during tennis.

Morante and Brotherhood (15) have undertaken a more comprehensive assessment of thermoregulation in tennis by making a total of 86 observations throughout each of the seasons (air temperature ranged from 14.5 to 38.4ºC). The physiological observations included all of the major thermal strains: core body (rectal) temperature, skin temperature, sweat rate and heart rate. Furthermore, the study benefited from the body temperatures being logged every minute and heart rate recorded every 15 seconds throughout the match. This enables the subsequent investigation of the response characteristics for each of these variables.

Since no known study has examined the characteristics of thermoregulatory responses during tennis, little is known about how the body responds to environmental and exercise stresses in tennis. The intermittent nature of competitive tennis would be expected to produce different responses to previously published studies for continuous, steady-state exercise. Information on tennis is important since the thermal environment, and consequently thermal transfers, are more complex in tennis compared with laboratory studies since tennis is generally played outdoors.

The present investigation aims to expand on the current knowledge base of thermoregulation during exercise and physiological responses during tennis. Case studies of body core (rectal) temperature, skin temperature and heart rate will be compared during competitive tennis with continuous, steady-state running in the laboratory.

METHODS

The examples of thermoregulatory responses (rectal temperature, skin temperature and heart rate) presented were derived from the study by Morante and Brotherhood (15), and are reflective of the entire group of 25 subjects and 86 observations.

Selection of example data

The data presented in Figures 1a, 2a and 3a were selected to demonstrate the characteristics of thermoregulatory responses in tennis. The three alternative actions for core body temperature response during exercise were selected from the data set and are presented in

Figure 1a. The association between skin temperature and environmental temperature was explored by contrasting skin temperatures observed in a cool and a hot air temperature (Figure 2a). The similarity in heart rate responses between the two players involved in a match is demonstrated in Figure 3a and is characteristics of the total 86 observations.

The responses presented in Figures 1b, 2b and 3b were selected to compare thermoregulatory responses during tennis and running. The tennis example used to compare rectal temperature response characteristics between tennis and running was selected for its representation of the 86 observed rectal temperatures (no significant difference between the example and the total data set: 38.31ºC vs. 38.40ºC, respectively). Furthermore, there was no significant difference between the average of the rectal temperature observed from the entire match and the average rectal temperature from the running example (38.04ºC for tennis vs. 37.95ºC for running). The difference in skin temperature characteristics between exercise modes was explored by selecting a skin temperature example from tennis that was measured at the same air temperature as in the laboratory for running (20.0ºC air temperature for both tennis and running). The same rationale was used for the selection of a tennis example to compare heart rate responses between the exercise modes. The average heart rate measured during running was 116.4 beats.min^{-1}, therefore a heart rate response during tennis that was not significantly different to this was selected (heart rate during tennis of 115.9 beats.min^{-1}).

Differences in thermoregulatory responses for a single player during five different matches (and thermal stresses) were explored in Figures 1c, 2c and 3c. These responses were characteristic for the group of 25 different players and 86 different sets of data.

Subjects

Tennis: Examples of thermoregulatory responses were selected from six different subjects. The individual characteristics for these six players were not significantly different from the values for the group of 25 subjects reported by Morante and Brotherhood (15). The mean ± SD age, height, body mass, maximum aerobic power (VO_2max), maximum heart rate (HRmax), sum of 9 skinfold thickness and predicted body fat for these tennis players were:
Age = 23.9 ± 3.5 years; Height = 181 ± 13 cm; Body mass = 76.8 ± 8.5 kg; VO_2max = 56.7 ± 5.4 mL.kg.min^{-1}; HRmax = 196 ± 9 beats.min^{-1}; sum 9 skinfolds = 89.7 ± 29.8 mm; predicted body fat = 11.8 ± 6.0%.

Running: Examples of thermoregulatory responses were for one runner selected from a group of 8 subjects. The age, height, body mass, maximum aerobic power (VO_2max), maximum heart rate (HRmax), sum of 9 skinfold thickness and predicted body fat for the runner was:
Running: Age = 18 years; Height = 183 cm; Body mass = 68.2 kg; VO_2max = 67.0 mL.kg.min^{-1}; HRmax = 191 beats.min^{-1}; sum 9 skinfolds = 58.5 mm; predicted body fat = 6.5%.

Each subject gave their written informed consent and the project was approved by the University of Sydney Human Research Ethics Committee.

Procedures

Observations for tennis were made during best of three tie-break set singles matches played on a hardcourt surface court between subjects of similar standard. All matches adhered to the rules set by the International Tennis Federation (16). Three new tennis balls were used for each match, with players retrieving balls between points. Conventional tennis attire was worn for all matches.

Observations during running were made in a climate chamber on a motorized treadmill. A five minute warm-up at 5 $km.h^{-1}$ was followed by the sixty minute continuous running trial at 12 $km.h^{-1}$. The treadmill grade remained at 0% throughout the entire trial.

Thermoregulatory responses

Subjects inserted a YSI rectal thermistor 10cm beyond the anal sphincter. Four YSI thermistors were attached to the skin using Opsite adhesive tape at the chest, arm, thigh and leg (17) for calculation of weighted mean skin temperature. In the tennis trials, the five thermistors were attached to a 180 g mutli-channel data logger worn on a belt around the waist for the recording of core and skin temperatures every minute throughout the match. During the running trial, rectal and skin temperatures were logged into a computer every 10 seconds. A heart rate monitor (Polar S610i) was worn by each subject, which recorded heart rate (HR) every 15 seconds during exercise. Subjects consumed fluids during the change of ends on an *ad libitium* basis throughout the trials. Measurement of subjects' maximal oxygen consumption in the laboratory and rectal temperature during tennis matches, enables the prediction of on-court exercise intensity (%VO_2max) by using the regression equation presented by Davies et al (18).

Environmental observations

Dry bulb (air) temperature was measured on-court using a whirling psychrometer shielded from direct sunlight sing a whirling psychrometer every 20 minutes throughout the match. A customized Davis Perception II weather station and WeatherLink software were used to record globe temperature and wind speed during each minute of play. A 15 cm blackened copper bulb was used to measure globe temperature (solar radiation). This was placed on the court one hour before the match to be heated by the sun in order to provide an accurate observation at the start of the match. A short arm anemometer set 1.5m from the ground was used to measure wind speed. The conditions of the climate chamber for the running trial were controlled at an air temperature of 20°C, relative humidity of 50% and an air movement of 1.9$m.s^{-1}$.

RESULTS

Body core (rectal) temperature

Figure 1a illustrates three contrasting responses of rectal temperature during competitive singles tennis. Figure 1b demonstrates the responses of rectal temperature during tennis and continuous, steady-state running in the laboratory. Figure 1c shows rectal temperature observations made on five different occasions for a single subject. Based on the subject's measured core temperature and maximum oxygen consumption, the exercise intensity during the tennis example was 57.3% VO_2max. The exercise intensity for the running example was 53.8% VO_2max, which was based on measured maximum oxygen consumption for the subject.

Figure 1

Skin temperature

Two contrasting examples of skin temperature during tennis are presented in Figure 2a. Figure 2b illustrates traces of skin temperature for tennis and running at an air temperature of 20ºC. The sharp increase for tennis and decrease for running at 30 minutes indicates the point at which subjects paused from exercise to be weighed on nearby body mass scales. This involved the tennis player moving from the outdoor court into the warmer laboratory, and the runner moving from the climate chamber into the cool laboratory. Figure 2c presents the skin temperature responses for one subject on five different occasions. This supports Figure 2a by demonstrating the relationship between skin temperature and air temperature.

Figure 2

Heart rate

Figure 3a highlights the wide variation in heart rate during competitive tennis. The two examples are of opponents during a tennis match, which illustrates the similarity between work and rest intervals (Player A: Mean = 156.8 beats.min^{-1}, range = 85 – 187 beats.min^{-1}; Player B: Mean = 145.3 beats.min^{-1}, range = 82 – 191 beats.min^{-1}). Figure 3b illustrates the response of heart rate for one subject over four different tennis matches. The contrasting response of heart rate during tennis and running is demonstrated in Figure 3b. Despite both examples producing a similar average heart rate (tennis = 115.9 ± 19.1 beats.min^{-1} vs. running = 116.4 ± 8.0 beats.min^{-1}), the range and maximum of these responses is very different (tennis = 72 - 179 beats.min^{-1} vs. running = 65 - 124 beats.min^{-1}). Figure 3c illustrates the response of heart rate for one subject over four different tennis matches.

Figure 3

DISCUSSION

Body core (rectal) temperature

There is a range of environmental conditions in which body core temperature is maintained at safe levels, independent of the environment (19). This is called the prescriptive zone, which varies depending on metabolic rate. The upper limit of the prescriptive zone decreases with increasing metabolic rate, that is, the higher the exercise intensity the cooler and less humid the conditions in which control of body temperature can be achieved (19). In conditions that exceed the upper limit of the prescriptive zone, body core temperature rises progressively during exercise (19). The lack of association between rectal temperature and air temperature is evident in Figure 1a, which demonstrates three different rectal temperature responses during tennis over relatively similar environmental air temperatures. As expected, rectal temperature remained independent of environmental air temperature, which was 25.8ºC for example A, 26.3ºC in example B and 30.3ºC for example C. Each of the examples in Figure 1a are reflective of differences in the intensity of play (metabolic rate). Example A demonstrates a continual rise in rectal temperature through the match, only achieving thermal equilibrium (indicated by the plateau in rectal temperature) after around 80 minutes of play. This must be the result of either a continual increase in the intensity throughout the match or an increasing heat load being imposed by the environment. Further analysis using bivariate regression revealed heart rate increased with match time ($P < 0.0001$), indicating there was a progressive increase in the intensity of play throughout the match. This may be attributed to improvement in play and/or increased motivation to win during the final stages of the match. Regression analysis also discovered a continual increase in mean radiant temperature (includes air temperature, globe temperature – solar radiation, and wind speed) over the course of the match. Therefore, the difficulty in the achievement of thermal balance in example A is due to the combination of increasing metabolic heat production, and convective and radiant heat gain from the environment. Example B illustrates a more typical rectal temperature response during exercise in which thermal equilibrium is achieved after an initial increase in rectal temperature. The steep rise in rectal temperature during the first 40 minutes of play reflects the onset of exercise and increase in energy expenditure. During the initial 40 minutes, the rate of metabolic heat production and heat gain from the environment exceeds the rate of heat loss via convection and evaporation of sweat. This imbalance causes heat to be stored within the body, illustrated by a progressive rise in rectal temperature. After approximately 30 minutes when a steady sweating rate has been established, evaporative heat loss is able to effectively dissipate the heat produced and gained. Thus, thermoregulation is successful and rectal temperature plateaus. Example C illustrates the rectal temperature response in a tennis match where the intensity of play is little more than resting levels. Consequently, the excess heat can be dissipated effectively from the onset of play, demonstrated by no or minimal initial rise in rectal temperature.

The average response of rectal temperature throughout a tennis match is different from a typical response during continuous, steady-state running. Figure 1b illustrates the longer time taken to achieve thermal equilibrium during tennis (approximately 40 minutes) compared with running (around 10 minutes). This may reflect a continual increase in exercise intensity during the tennis match as found in example A of Figure 1a, which is impossible during the steady-state running example. Alternatively, the heat load imposed by the environment may alter the response during tennis, whereby solar radiation and varied wind speed are additional factors not present in the laboratory. Achieving thermal equilibrium during exercise or sport is essential to prevent body core temperature reaching a critical level of approximately 42ºC, which poses a serious risk to an individual's health and safety (20).

Skin temperature

Skin temperature, unlike body core temperature, is related to environmental air temperature (21, 22). Figure 2a illustrates this by comparing the skin temperature illustrated in example B (26.93ºC) obtained on a cool, winter day (20.0ºC) with the skin temperature of example A (35.86ºC) measured on a warm, summer day where air temperature was 38.4ºC. Generally, as in example B, skin temperature is greater than air temperature. This causes heat to be transferred via convection down a thermal gradient from the skin to the surrounding environment. Therefore, the player in example B is losing metabolic heat produced during exercise via convection, which assists in the maintenance of body core temperature. In contrast, if air temperature is greater than skin temperature, as in example A, the convective heat exchange is reversed, with heat being gained from the environment. This is a concern as it adds to the metabolic heat load imposed by exercise, meaning the evaporation of sweat must occur at a greater rate in order to balance the rate of heat production and gain.

Both examples of skin temperature in Figure 2b were measured at an air temperature of 20.0ºC. Since skin temperature and air temperature are related (21, 22) and both examples were measured at 20.0°C, similar skin temperatures would have been expected. However, Figure 2b illustrates the different results between the two modes of exercise, with average skin temperature for tennis being 26.88 ± 1.36ºC compared with 28.91 ± 1.56ºC for running ($P < 0.0001$). A major factor contributing to this variation is the difference in wind speed between the tennis and running conditions (tennis = 2.6 $m.s^{-1}$; running = 1.9 $m.s^{-1}$). Air movement is an integral component of convective and evaporative heat exchange, with both being increased with higher wind speeds (22). Therefore, the rate of convective and evaporative heat loss was greater, and the wind chill factor was higher during tennis due to the faster wind speed. Combined, this explains the lower skin temperature observed during tennis compared with running at the same air temperature. In contrast, the opposite would occur if environmental temperature was greater than skin temperature with the rate of heat gain via convection being increased when wind speed is higher. A tennis player is likely to experience thermal discomfort if skin temperature is too low or too high since skin temperature has been linked with an individual's rating of thermal comfort (21-27). Thermal comfort is an important consideration for tennis player's as it is essential for enjoyment of the sport.

Heart rate

The exercise intensity of singles tennis is the same for both players regardless of their fitness level. This is demonstrated in Figure 3a, in which the mean, range and characteristics of the heart rate response over time were similar for each opponent. This suggests it would be advantageous for players to improve their fitness in order for them to work at a lower relative percentage of the workload.

The intermittent nature of tennis produces a different heart rate response compared to that of continuous, steady-state exercise. This is evident in the comparison of tennis and running heart rates over time in Figure 3b. The average heart rate for both examples was similar (115.9 beats.min^{-1} for tennis and 116.4 beats.min^{-1} for running). The trace for running shows little variation throughout the exercise compared to the large and rapid fluctuations between points and rest periods in tennis. Given the wide variation in heart rate during tennis, the overall average does not completely describe the intensity of play. Instead, the maximum heart rate may also be considered when examining the physiological strain imposed by tennis. This reveals much greater variation between the two exercise modes, with heart rate in the tennis example peaking at 179 beats.min^{-1} compared with 124 beats.min^{-1} for the running example. Thus, tennis players must be physically able to work at intensities exceeding that of continuous, steady-state exercise, and should plan training accordingly.

CONCLUSION

The present investigation has provided a description of thermoregulatory responses measured during competitive singles tennis. Comparison with thermoregulatory responses measured during continuous, steady-state running reveal differences in the response of rectal temperature, skin temperature and heart rate during tennis.

ACKNOWLEDGEMENTS

The authors gratefully thank Jerrad Borodzicz for providing the data obtained for running in the laboratory. The support of the International Tennis Federation Sport Science Research Grant Programme is also appreciated.

FIGURE LEGENDS

Figure 1a Examples of body core (rectal) temperature. A = rectal temperature measured when air temperature was 25.8ºC; B = rectal temperature measured at an air temperature of 26.3ºC; and C = rectal temperature measured at an air temperature of 30.3ºC. **Figure 1b** Examples of body core (rectal) temperature during tennis and continuous steady-state running on a treadmill in a laboratory. In both the tennis and running assessments, the subjects paused exercising at 30 minutes to be weighed on nearby body mass scales. **Figure 1c** Rectal temperature measured on one subject over a range of environmental air temperatures. Ta = air temperature.

Figure 2a Examples of weighted mean skin temperature. A = skin temperature measured at an air temperature of 38.4°C; B = skin temperature measured at an air temperature of 20.0°C. **Figure 2b** Examples of skin temperature during tennis and continuous steady-state running on a treadmill in a laboratory. **Figure 2c** Skin temperature measured on one subject over a range of environmental air temperatures. Ta = air temperature.

Figure 3a Examples of heart rate responses for opponents during a tennis match. A: Mean = 156.8 beats.min-1, range = 85 – 187 beats.min-1; B: Mean = 145.3 beats.min-1, range = 82 – 191 beats.min-1. **Figure 3b** Examples of heart rate during tennis and continuous steady-state running on a treadmill in the laboratory. **Figure 3c** Skin temperature measured on one subject over a range of environmental air temperatures.

What is already known on this topic.

- Thermoregulatory responses during tennis have been measured by a number of studies to provide a description of physiological strains
- The characteristics of thermoregulatory responses have been widely reported for sports such as running and cycling

What this study adds.

- Continuous measurement of thermoregulatory responses during competitive singles tennis provides a more detailed description of the response characteristics for these variables
- Comparison of findings for tennis (intermittent and outdoors) with those for continuous, steady-state running in the laboratory reveal various differences in response characteristics, and thus thermoregulatory strains

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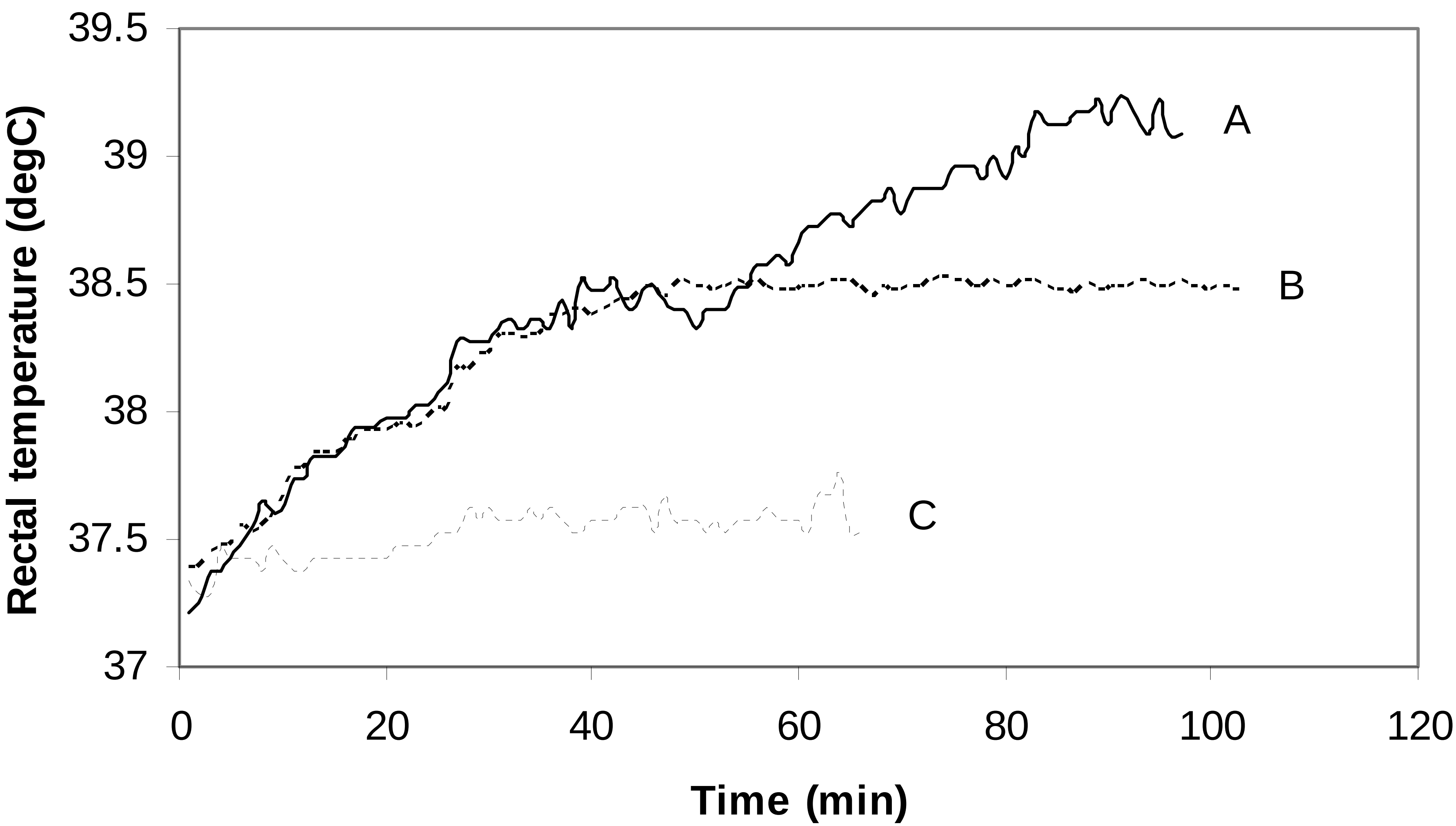
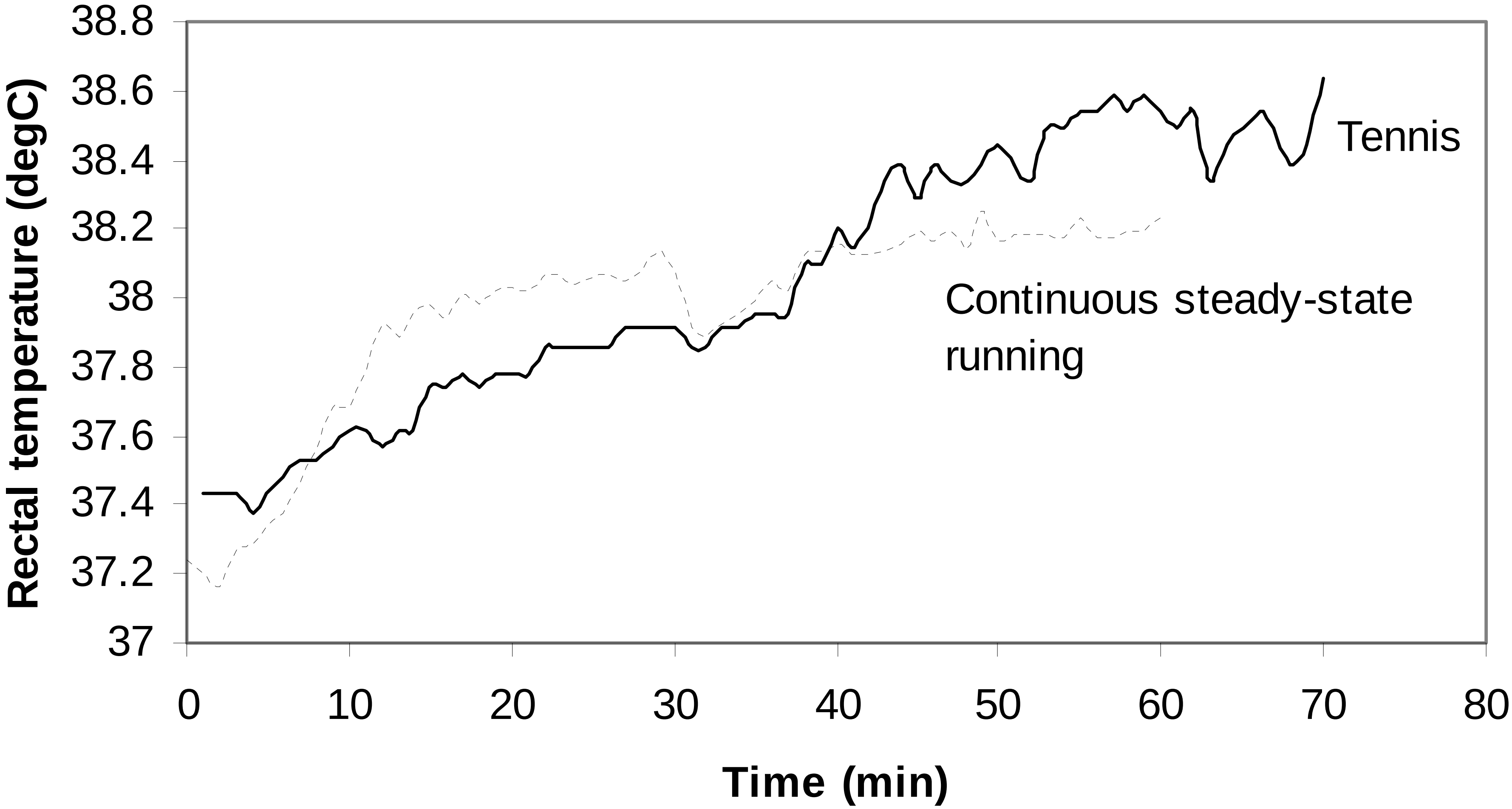


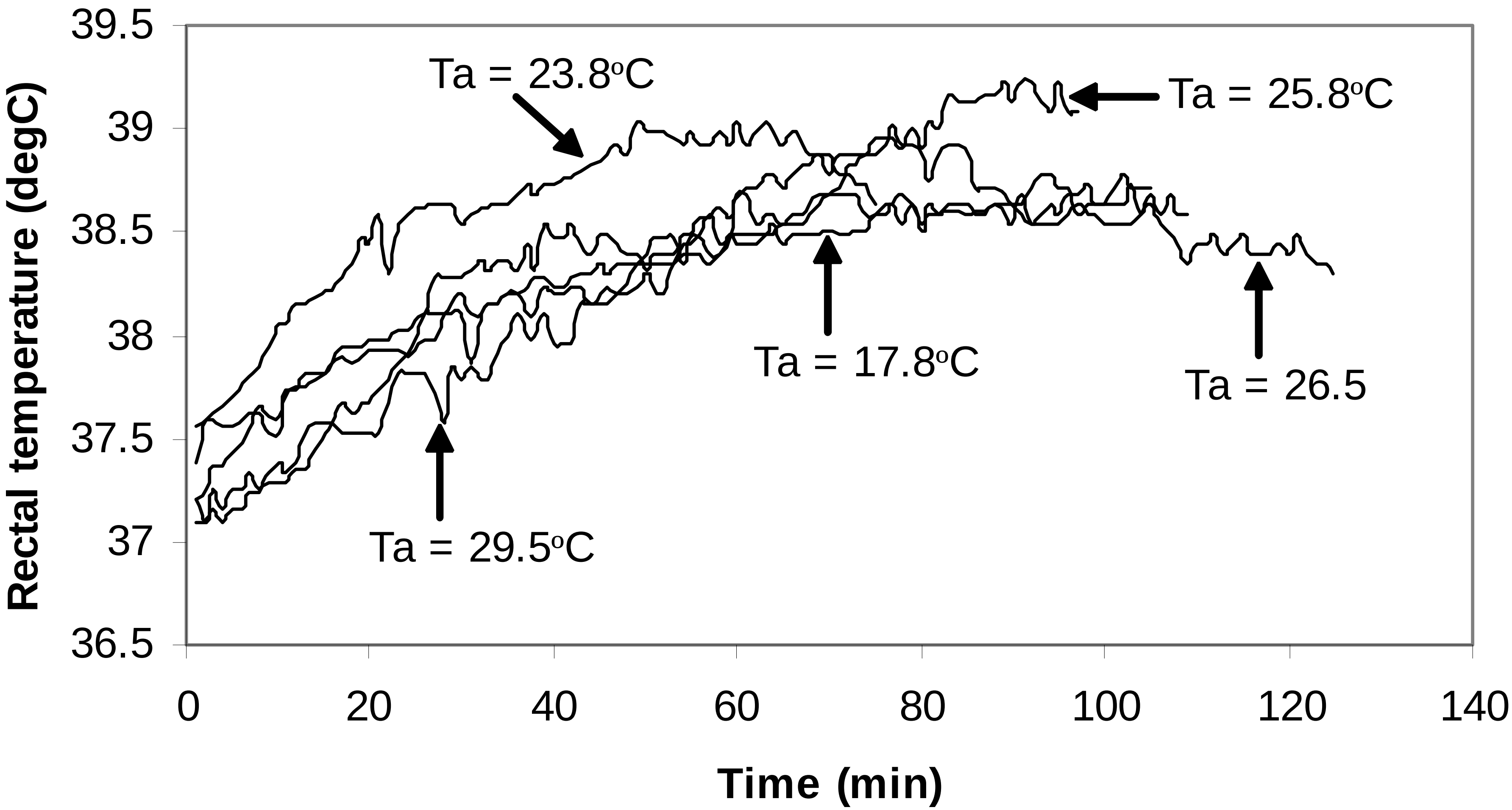
39.5
39
38.5
38
37.5
37
Rectal temperature (degC)
A
B
C
0
20
40
60
80
100
120
Time (min)

Figure 1a



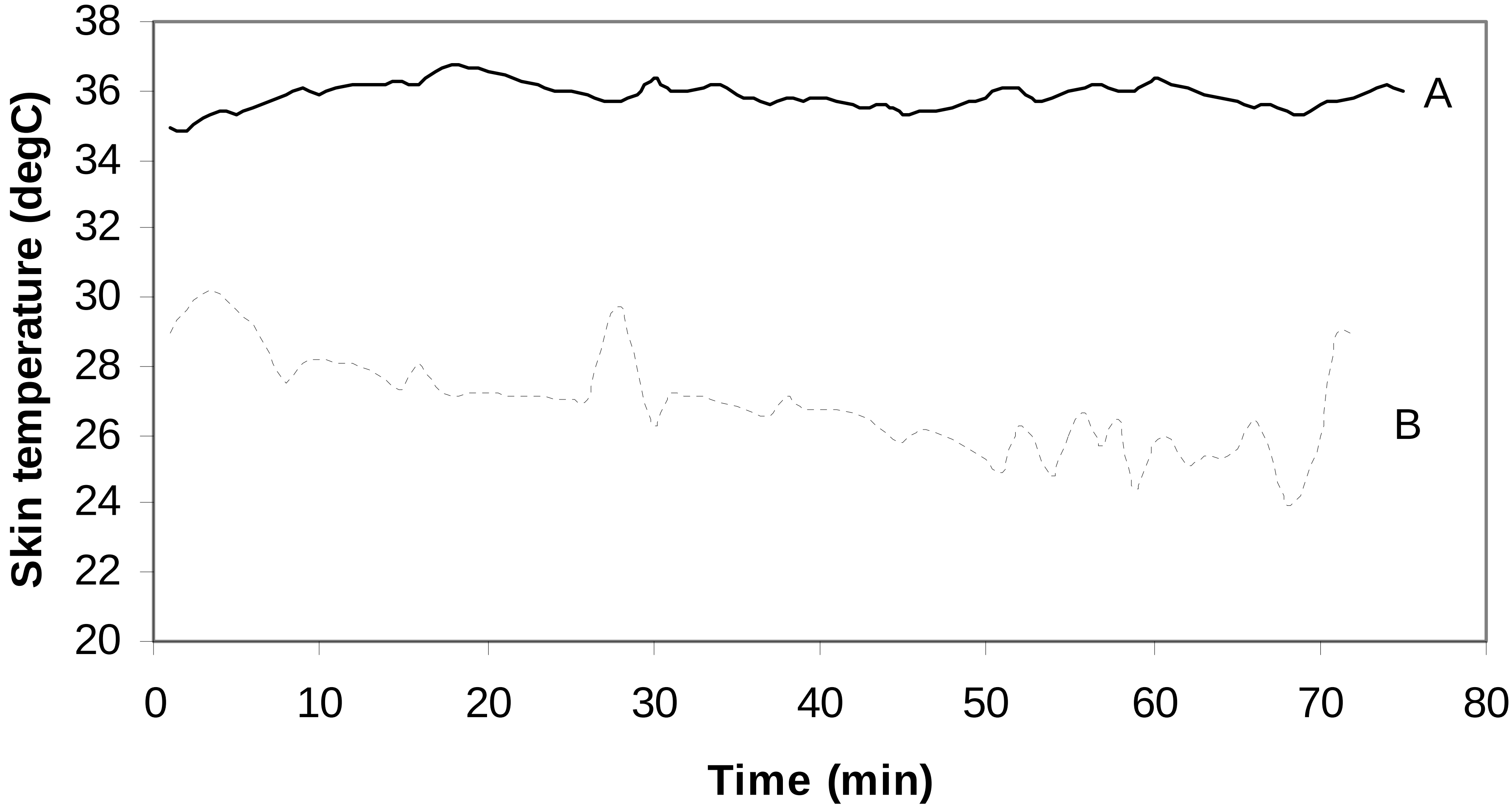
38.8
38.6
38.4
38.2
38
37.8
37.6
37.4
37.2
37
Rectal temperature (degC)
0
10
20
30
40
50
60
70
80
Time (min)
Tennis
Continuous steady-state running

Figure 1b



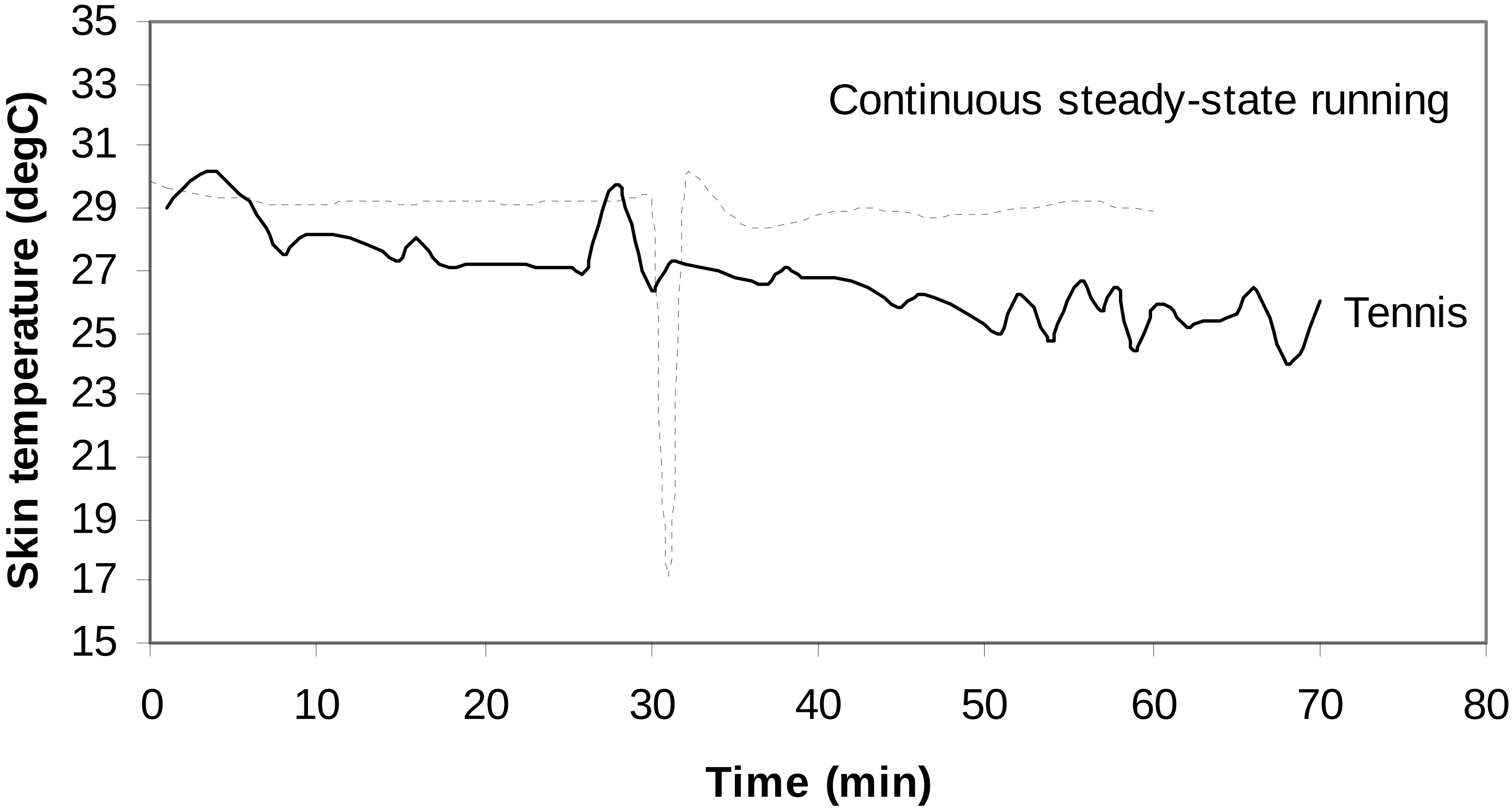
Rectal temperature (degC)
39.5
39
38.5
38
37.5
37
36.5
0
20
40
60
80
100
120
140
Time (min)
Ta = 23.8oC
Ta = 25.8oC
Ta = 17.8oC
Ta = 26.5
Ta = 29.5oC

Figure 1c



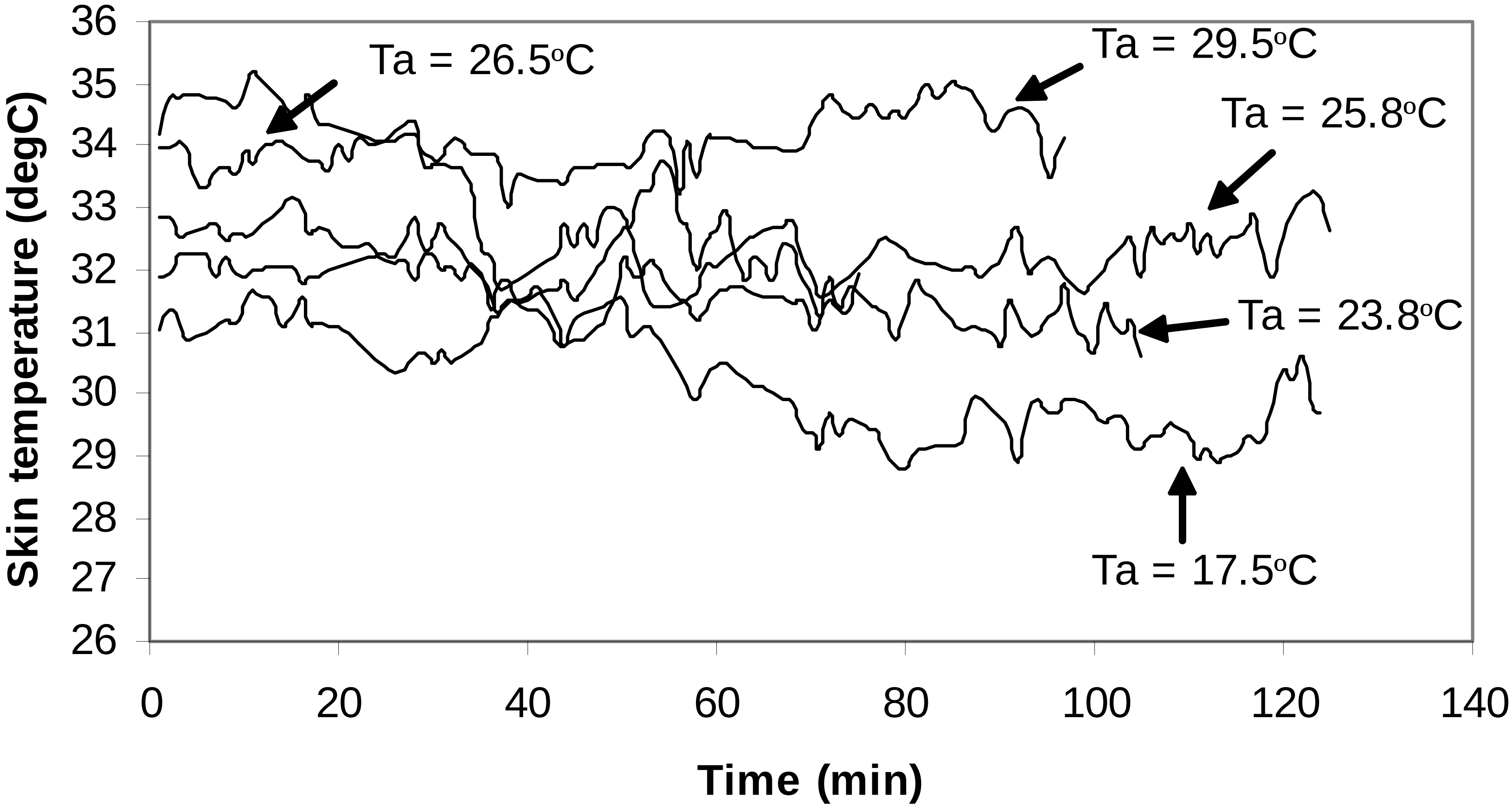
Skin temperature (degC)
38
36
34
32
30
28
26
24
22
20
0
10
20
30
40
50
60
70
80
Time (min)
A
B

Figure 2a



Skin temperature (degC)
35
33
31
29
27
25
23
21
19
17
15
Continuous steady-state running
Tennis
0
10
20
30
40
50
60
70
80
Time (min)

Figure 2b



Skin temperature (degC)
36
35
34
33
32
31
30
29
28
27
26
0
20
40
60
80
100
120
140
Time (min)
Ta = 26.5oC
Ta = 29.5oC
Ta = 25.8oC
Ta = 23.8oC
Ta = 17.5oC

Figure 2c

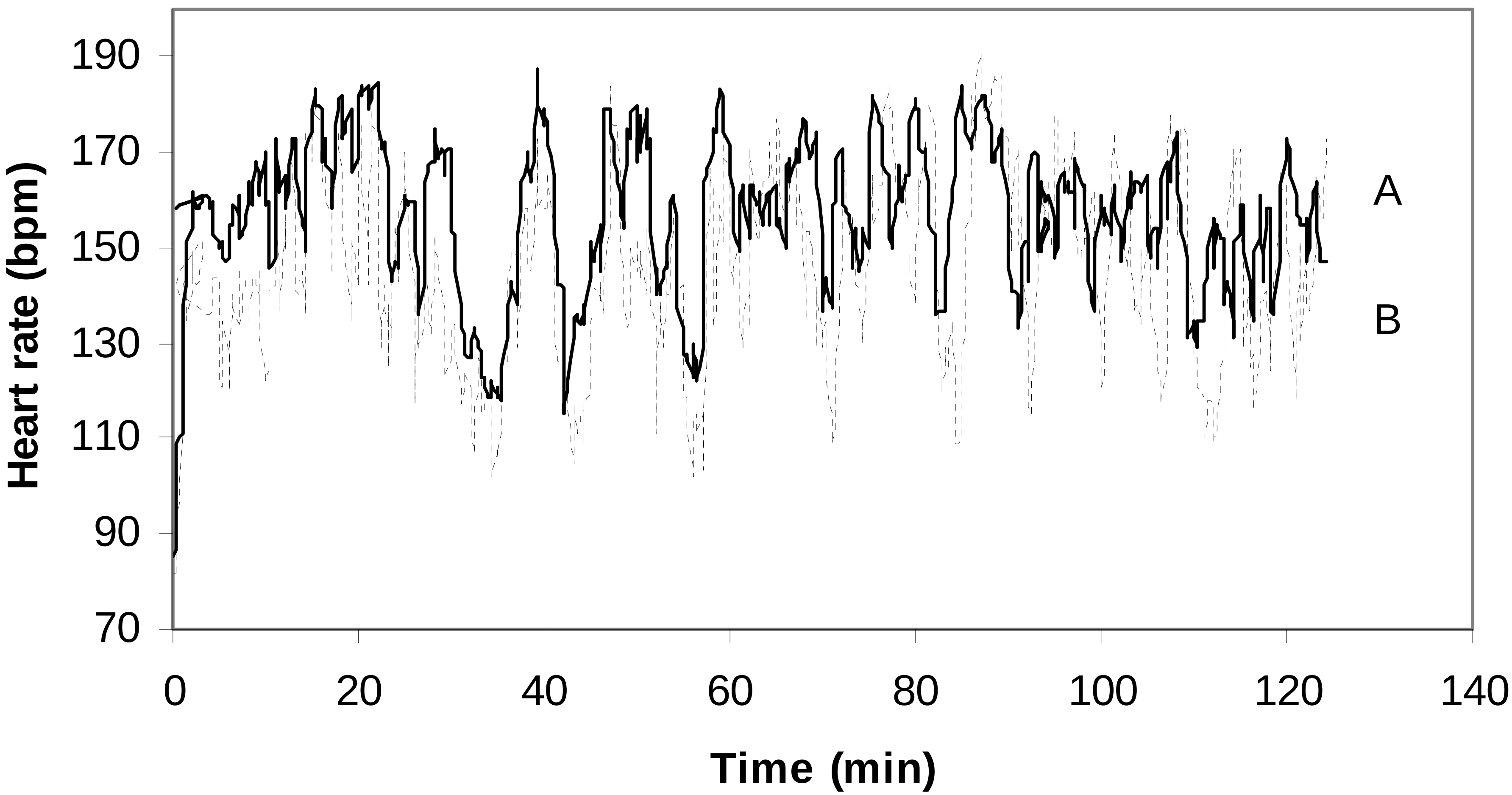

190
170
150
130
110
90
70
Heart rate (bpm)
0
20
40
60
80
100
120
140
Time (min)
A
B

Figure 3a

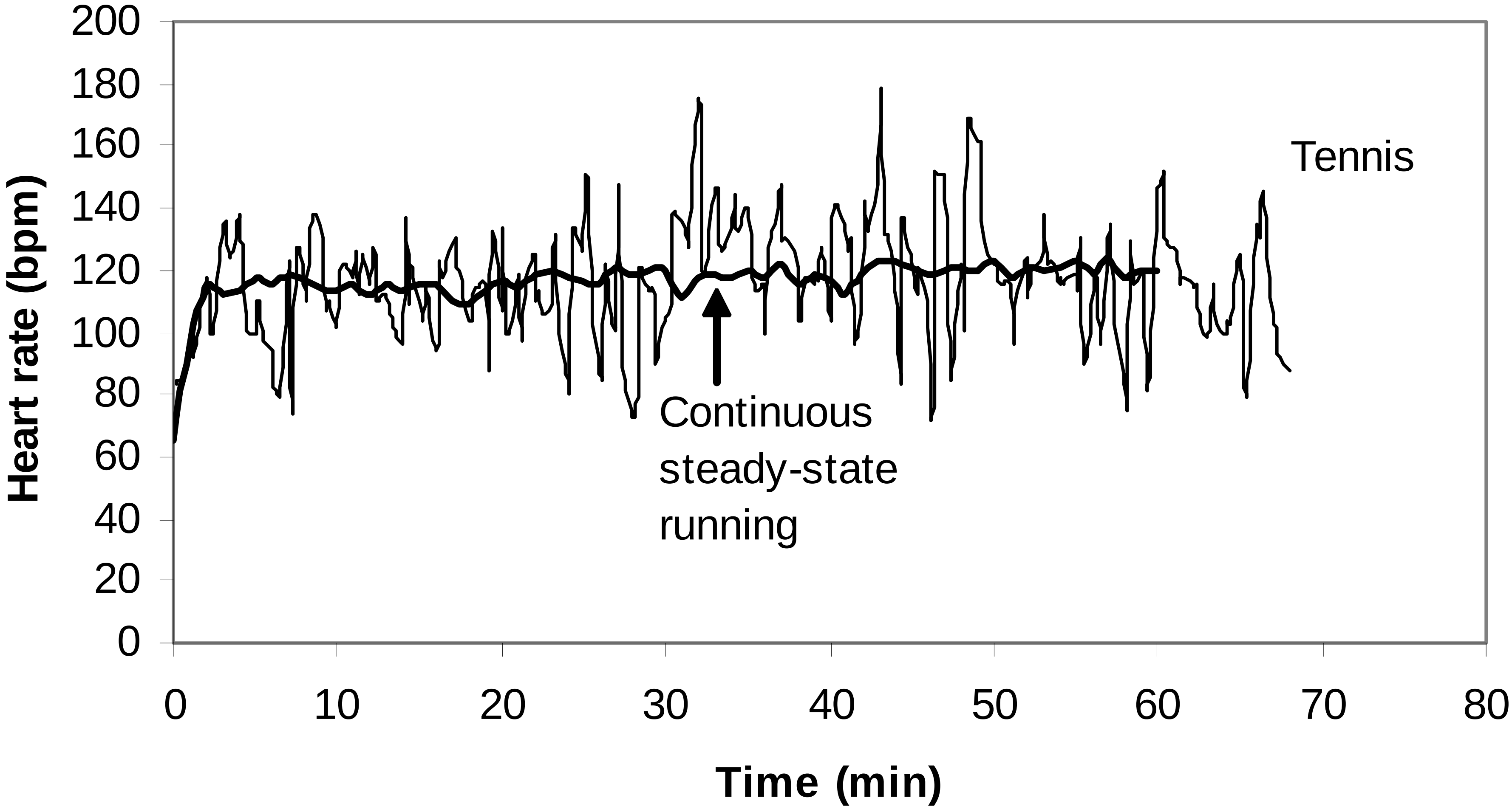
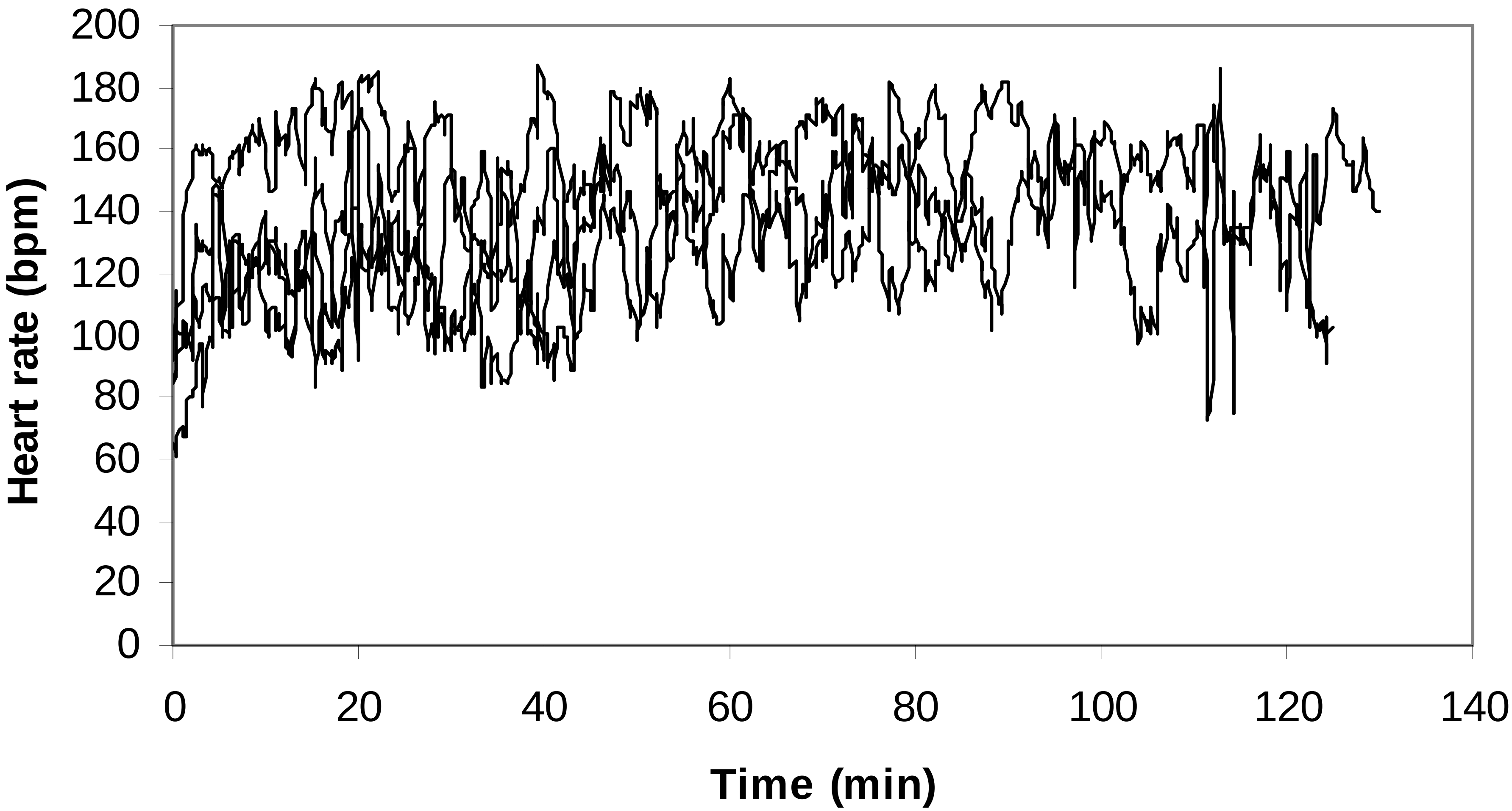

Heart rate (bpm)
200
180
160
140
120
100
80
60
40
20
0
Tennis
Continuous steady-state running
0
10
20
30
40
50
60
70
80
Time (min)

Figure 3b



200
180
160
140
120
100
80
60
40
20
0
Heart rate (bpm)
0
20
40
60
80
100
120
140
Time (min)

Figure 3c