Blood glucose responses and incidence of hypoglycaemia in elite tennis under practice and tournament conditions

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The purpose of the study was to specify the changes in blood glucose concentrations in the course of repeated tournament and practice matches, and to quantify the incidence of hypoglycaemia in elite tennis players. The study consisted of two parts. In the first part, 147 tournament players completed a questionnaire about the incidence of hypoglycaemic symptoms during repeated tennis matches. In the second part of the study, the players participated in two subsequent matches (one singles match followed by a doubles) under (T) tournament (n=57) and (P) practice (n=20) conditions. Of the 147 players consulted, 94 (63.9%) reported experiences with hypoglycaemic symptoms during a tennis tournament (n=80) and/or tennis practice (n=62). The warm-up period for the second match day was identified as the most sensitive point for the occurrence of hypoglycaemic symptoms (n=29), compared to the final stages of the first (n=11) or second match (n=7). Under both practice and tournament conditions, a significant (p<0.01) drop in blood glucose concentration was found during the warm-up period for the second match per day (T: from 5.8±1.4 mmol•L\(^{-1}\) to 4.3±0.8 mmol•L\(^{-1}\) and P: from 5.4±1.1 mmol•L\(^{-1}\) to 4.1±1.5 mmol•L\(^{-1}\)). In conclusion, precautions should be taken to prevent a sudden drop in blood glucose concentration and hypoglycaemic symptoms during the early stages of a player's second tennis match in one day.

Introduction

The specific demands on tournament tennis players include a rapid and precise adaptation of energy metabolism and substrate availability to repetitive, partly unforeseen and relatively intense physical activity. In many team tennis events worldwide, every player has to play two consecutive matches. Usually, a singles and a doubles match must be played, with the order of play depending on the type and level of competition. The duration of play and the duration of the rest period in between the matches are generally unpredictable. This is the same for most tournaments, when a player has to play two singles matches per day. Every outdoor event also carries the risk of rain delay, introducing another factor that can disturb metabolic homeostasis.

At rest or during fasting, there is a balance between glucose uptake in the tissues and hepatic glucose production, leading to constant blood glucose concentrations \([1]\). When energy expenditure increases at the start of exercise,
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...muscle glycogen dominates for energy delivery \(^2\). Depending on the intensity of the exercise, the muscle uptake of glucose from the blood also starts to increase at an early stage \(^3\). When blood glucose levels drop, hepatic glycogenolysis is stimulated by increased sympathetic activity accompanied by a decrease in serum insulin concentrations, which stabilises glucose concentrations at the starting level \(^4\). In case of a constant high glucose uptake of the muscle cells, a breakdown of the activity can be expected during exercises of long duration, due to hypoglycaemia \(^5\).

The literature describes the incidence of hypoglycaemic symptoms in healthy athletes at the end of sub-maximal exercise of long duration without carbohydrate supplementation \(^5,6\), or as transient rebound hypoglycaemia at the start of exercise, resulting from incorrectly-timed pre-exercise ingestion of carbohydrates with a high glycaemic index \(^1,7,8,9\). An increase in carbohydrate oxidation and hypoglycaemic risk can be expected, especially in men \(^10\) and during exercise in the heat \(^11\). There also seem to be individual differences in the sensitivity to hypoglycaemia. Endurance training seems to improve the individual’s resistance to exercise-induced hypoglycaemia \(^12\). In subjects sensitive to hypoglycaemia, a reduced sympathetic activity during exercise was found \(^13\).

During tennis match play under practice conditions a slight \(^14\) or a significant increase in blood glucose concentrations \(^15\) was found after 90 minutes. After two hours of match play, glucose levels were either unchanged \(^16\) or also increased significantly \(^17\). After three hours of match play, Mitchell et al.\(^18\) recorded a slight, non-significant decrease in glucose levels. During a 4-hour interrupted tennis match without energy supplementation (30 minutes rest after 150 minutes of match play), blood glucose concentrations decreased significantly, by about 16%. A distinct decrease in glucose was recorded after the rest period, immediately followed by an increase \(^19\). In competitive tennis tournament situations, considerable differences in sympathetic activity were found in comparison with practice sessions \(^20\). So far, no data on blood glucose changes during tournament match play have been published.

The present study first discusses the changes in blood glucose concentrations in the course of a tournament day with repeated tennis matches, as compared to match play during practice and second presents data on the incidence of hypoglycaemic symptoms in male tennis players. Our main hypothesis was that the specific work load demands in tournament tennis lead to a specific pattern of blood glucose changes including considerable decreases which are recognised by most of the players and may impact the players performance.

**Methods and procedures**

**Subjects**

The data presented in this study relate to three different sub-groups. First, 147 male tournament players (age 24.7±5.4 years) completed a questionnaire on the incidence of hypoglycaemic symptoms. All players participated in 1st to 3rd-division team tennis competitions of the German Tennis Federation. Mean playing experience was 16.0±5.5 years, mean tournament experience was 12.8±5.5 years and the stated mean tennis training volume was 7.3±2.4 hours per week during the summer season.
In the second part of the study, a sub-group of 57 male players (age 26.2±6.7 years), randomly recruited from the first part of the study, participated in a tournament singles and doubles match on a clay court, during the national and regional tennis team competitions of the German Tennis Federation. Of these players, 20 also played a singles and a doubles match during a practice session on a clay court. The players were familiar with all measurement procedures and gave informed consent in writing to participation in the study.

**Experimental design**

**Questionnaire:** The questionnaire was sent to all team captains and coaches of all 1st, 2nd and 3rd-division male tennis teams of the local association of the German Tennis Federation. The response rate was 73.1%. The questionnaire consisted of 38 questions on demographic variables, eating habits, muscle problems, and energy problems in relation to nutrition. This study covers the energy problems only.

**Field Study:** In the first part of the field study, we analysed glucose and lactate changes in capillary blood, epinephrine (EPI) levels in urine as well as the perceived energetic drive or willingness to perform (ED-scale), respectively, on the occasion of the national and regional tennis team competitions. The matches were played according to the rules of the International Tennis Federation (best of three sets, with personal coaching permitted). Nutritional intake was not regulated, but was recorded. The carbohydrate intake in grams was calculated (PRODI® 4.5, Stuttgart, Germany) from the records.

![Figure 1: Experimental design. Duration and carbohydrate intake of the time periods are indicated as means±SD. Parameters and measurement points are indicated by X.](image-url)
Measurement points (Figure 1) were defined in close relation to the normal organisation of the team competition¹. Immediately before and after the on-court warming-up period (some eight minutes for baseline and net play plus two minutes for services) and directly after match point, we analysed capillary blood glucose and the corresponding perceived energetic drive in every player. Additional samples were taken for measuring epinephrine in urine and lactate in capillary blood (Figure 1).

On a second day, at least one week later than the tournament day, a subgroup of players completed a 90-minute singles match and a subsequent 60-minute doubles match, with a 30-minute rest period between the two, during a practice session on clay court. The rules for tournament matches were applied. The players were asked to follow their usual tournament routines (tactics, food, behaviour during rest periods) during the practice game. Blood and urine samples were collected in accordance to a protocol similar to that used on the tournament days (Figure 1).

Measurements and analyses

Metabolic parameters: Capillary blood samples were analysed for glucose (Cobas-Bio-System, Hoffmann-La Roche, Basel, Switzerland) and lactate (Eppendorf-Analyser 5060, Hamburg, Germany). Urine concentrations of epinephrine (EPI) were determined using high-performance liquid chromatography (HPLC) with electrochemical detection (Chromsystems, München, Germany) after derivatization by an ion exchange technique and a radioimmunoassay method described by Lehmann et al.²¹. Urine collection times were exactly in line with the aspired periods (2 hours pre-competition, singles match and doubles match). Aliquots of spontaneous urine samples (50 ml) were supplemented with 1 ml of 25% HCL and stored at -70°C before analysis. The urine EPI concentrations are presented in µg and related to mg creatinine (creat) to eliminate differences in renal water handling. Urine creatinine was measured enzymatically, using the Cobas-Bio centrifugal analyser (Hoffmann-La Roche, Basel, Switzerland) and corresponding kits from Boehringer (Mannheim, Germany).

Perception: A linear 10-point perception scale was applied to assess energetic drive (ED-scale). This scale consists of numbers ranging from 1 to 10 with descriptive words printed alongside (ranging from ‘very low’ to ‘very high’ energetic drive). In our study, the assessment of energetic drive appeared to be advantageous, since other perception ratings described in the literature primarily address the cardio-pulmonary aspects of exertion (²²). Perception was estimated at the time when blood glucose measurements were taken, ensuring sufficient time for recovery from the preceding rallies. Reliability and validity of the ED-drive scale were not determined beforehand. The importance of these data is purely the descriptive value and the complementary information. These data are not mentioned in the final conclusion.

Statistics

The data from the questionnaire are presented in absolute and relative terms. No statistical test was calculated. The data from the field study are presented with the mean and standard deviation. A multifactor analysis of variance (MANOVA) with repeated measurements was used to determine statistical differences. Where significance was realised, simple effects were verified by
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means of the Newman-Keuls test. Heterogeneous variances were adjusted according to the Huynh-Feldt and Box procedure. The significance levels were set at p<0.05* and p<0.01**.

Results
The mean duration of play during tournaments was 99±29 minutes (1st round) versus 93±21 minutes (2nd round) for singles play and 86±23 minutes (1st round) versus 99±22 minutes (2nd round) for doubles. As a result of the rules, the rest period between singles and doubles play varied considerably between players in the first singles round (143±41 minutes) and those in the second singles round (43±27 minutes). The intake of carbohydrates during the rest period was much lower for 2nd round players compared to 1st round players (17±16g vs. 61±49g). During practice sessions, the players generally consumed fewer carbohydrates, in both singles and doubles play, than during tournaments (Figure 1). The listed diets during match play were either isotonic carbohydrate/electrolyte drinks, energy/chocolate bars, bananas or a mixture of these components. During the rest periods some players consumed Cola or lemonade combined with carbohydrates of a low glycaemic index, such as pasta or crackers. A precise comparison of the glycaemic index classification in the diet with respect to the different parts of the tournament day is not possible with the acquired data.

Blood glucose was significantly higher during tournament play than during

<table>
<thead>
<tr>
<th>Group</th>
<th>single</th>
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<th>p-values</th>
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<tr>
<td></td>
<td>pre</td>
<td>warm-up</td>
<td>post</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>time</td>
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<td></td>
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<td>t x g</td>
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<tr>
<td>T</td>
<td>5.4 ± 0.7</td>
<td>5.3 ± 0.7</td>
<td>7.5 ± 2.2</td>
<td>5.8 ± 1.4</td>
</tr>
<tr>
<td>(n=20)</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>5.1 ± 0.5</td>
<td>4.4 ± 0.6</td>
<td>5.2 ± 0.7</td>
<td>5.4 ± 1.1</td>
</tr>
<tr>
<td>(n=20)</td>
<td></td>
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<tr>
<td>T 2 sets</td>
<td>5.1 ± 0.8</td>
<td>5.1 ± 0.7</td>
<td>7.4 ± 2.0</td>
<td>5.8 ± 1.5</td>
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<td>(n=43)</td>
<td></td>
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<tr>
<td>T 3 sets</td>
<td>5.0 ± 0.7</td>
<td>4.7 ± 0.5</td>
<td>5.3 ± 0.7</td>
<td>5.7 ± 1.3</td>
</tr>
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<td>(n=14)</td>
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<tr>
<td>T 1st round</td>
<td>5.0 ± 0.7</td>
<td>4.9 ± 0.7</td>
<td>7.1 ± 2.2</td>
<td>4.9 ± 0.9</td>
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<td>(n=27)</td>
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</tr>
<tr>
<td>T 2nd round</td>
<td>5.1 ± 0.9</td>
<td>5.0 ± 0.6</td>
<td>6.8 ± 1.8</td>
<td>6.1 ± 1.5</td>
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<td>(n=30)</td>
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</table>

a significantly different at this measurement point (p<.01)
b significantly different compared to pre-value (p<.01)
Values indicate means ±SD

Table 1: Blood glucose concentration at different time points during tournament (T) and practice (P). The total sample of tournament data (n = 57) is subdivided in shorter (T 2 sets) or longer (T 3 sets) single matches and in shorter (T 2nd round) and longer (T 1st round) rest periods.
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Figure 2: Concentrations of glucose and lactate in capillary blood and of epinephrine (EPI) in the urine as well as the perceived “energetic drive” (ED-scale) after a tournament (T) and practice (P) single tennis match (n=20).

* ** T and P are significantly different at p<.05 and p<.01, respectively
Values indicate means±SD.

Figure 3: Correlation between the post-tournament concentrations of capillary glucose and urinary epinephrine.

\[ y = -1,837 + 0,038x \]
\[ r = 0,693 \, ** \]
\[ n = 20 \]
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practice sessions at two measurement points: after the warm-up and at the end of the singles match (Table 1). Likewise, lactate concentrations in capillary blood. EPI concentrations in urine and the perceived energetic drive (ED-scale) were significantly higher after a tournament (T) than after a practice (P) singles tennis match (Figure 2). There was a significant correlation between post-tournament singles concentrations of capillary glucose and of urinary EPI (Figure 3).

On tournament days, a significant increase in glucose concentrations was found in the course of the singles match (maximum value 12.3 mmol·l⁻¹), followed by two significant steps of decrease during the rest period between the singles and doubles matches and during the warm-up for the doubles (minimum value 2.3 mmol·l⁻¹). The latter decrease was also found at the starting phase of the second workload during practice (Table 1). The changes in blood glucose concentrations did not affect the mean perceived energetic

Figure 4: a. Concentration of glucose in capillary blood (n=20). b. Concentration of epinephrine (EPI) in the urine (n=20). c. The perceived “energetic drive” (ED-scale, n=20). d. The incidence of hypoglycaemia, expressed as a percentage, at different time periods during the course of a tournament day (results of a questionnaire, n=147).

* *, ** significantly different compared to pre-value at p<.05 and p<.01, respectively

Values indicate means±SD.
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drive. No significant decrease was found on ED-scale during the warm-up for the doubles (Figure 4).

Two set tournament singles matches resulted in significantly higher post-singles glucose concentrations than three set matches. In both cases, glucose concentrations decreased significantly during the warm-up for the doubles. This sudden drop in blood glucose concentration was much more pronounced in the 2nd round players who had only a short rest period between matches and was followed by a significant increase until the end of the doubles match (Table 1).

The results of the questionnaire show that about two thirds of male tournament tennis players have experienced hypoglycaemic symptoms at least once in their career during practise or tournaments (Table 2). Every tenth player described regular (once per month) or frequent (once a week) hypoglycaemic symptoms. The incidence of hypoglycaemia tended to increase during tournament situations.

Two time periods with a high incidence of hypoglycaemia were identified. Hypoglycaemia can be expected at the start of play in a first match (20.2%) and occurs even more frequently at the start of the second match (30.9%). The end of play is rarely indicated (Table 2).

**Discussion**

This study shows various changes in blood glucose concentration during tennis match play under realistic tournament conditions. Under tournament conditions, we recorded clearly higher concentrations than during training, as

<table>
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<th>Question</th>
<th>Item</th>
<th>[n]</th>
<th>[%]</th>
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<td>incidence(^1)</td>
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<td>53</td>
<td>36.1</td>
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<tr>
<td></td>
<td>very rarely (≤ 3 times per career)</td>
<td>39</td>
<td>26.5</td>
</tr>
<tr>
<td></td>
<td>now and then (1-5 times per year)</td>
<td>41</td>
<td>27.9</td>
</tr>
<tr>
<td></td>
<td>frequently (1 time per month)</td>
<td>9</td>
<td>6.1</td>
</tr>
<tr>
<td></td>
<td>regularly (1 time per week)</td>
<td>5</td>
<td>3.4</td>
</tr>
<tr>
<td>situation(^2)</td>
<td>tournament</td>
<td>80</td>
<td>85.1</td>
</tr>
<tr>
<td></td>
<td>practice</td>
<td>62</td>
<td>65.9</td>
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<tr>
<td></td>
<td>other</td>
<td>8</td>
<td>8.5</td>
</tr>
<tr>
<td>time point(^2)</td>
<td>pre 1st match</td>
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<td>2.1</td>
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<td></td>
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<td>18</td>
<td>20.2</td>
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<td></td>
<td>during 1st match</td>
<td>12</td>
<td>12.8</td>
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<tr>
<td></td>
<td>other</td>
<td>11</td>
<td>11.7</td>
</tr>
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</table>

\(^1\)single choice, \(^2\)multiple choice

| Table 2: Absolute and relative incidence of hypoglycaemia in male tennis players and the respective situations and time periods of occurrence (results of a questionnaire, n=147). |
well as significant fluctuations in concentrations in the course of a tournament day. The initial metabolic responses to tournament play and practice are of special interest in this context, since all later responses are not exactly comparable due to time course differences. Our data show that after the warm-up for the single match a significant higher blood glucose concentration was observed than during practice. Furthermore, the extremely high glucose concentrations at the end of a two-set singles match (Table 1) were particularly striking.

The increased glucose levels under tournament conditions can be explained by an increased sympathetic activity with heightened adrenalin release (Figure 2). The higher concentration of blood glucose after warm-up for the singles match reflects an endocrine and metabolic pre-start effect which guarantees a quicker adaptation of glycogenolysis to the sudden muscular glucose uptake at the start of exercise. The close correlation between the post-tournament singles match concentrations of capillary glucose and urinary epinephrine underlines this conclusion (Figure 3).

The difference in blood lactate concentration (Figure 2) may be the result of an increase in energetic drive and motivation under tournament conditions leading to an increase in overall physical activity and energetic demands of the players (e.g. legwork, power of the strokes). It further can be explained by a stimulation of muscle glycolysis and muscle and liver glycogenolysis, induced by β-adrenergic activation of the protein kinase and α-adrenergic inhibition of insulin secretion (23). As a result, a stronger mobilisation and utilisation of carbohydrates can be expected in tennis match play under tournament conditions which may lead to faster exhaustion of glycogen stores during long lasting matches. The results of the questionnaires indicate an increase in the number of hypoglycaemic incidents under tournament conditions (Table 2).

During and after the end of the first and second match of the day, the frequency of hypoglycaemia is relatively low (Table 2). This corresponds with a significant rise in blood glucose levels, especially at the end of two-set singles matches (Table 1). During longer matches (3 sets), glucose levels remained elevated until the end of the match, but dropped significantly during the doubles match (Table 1). The results indicate that glycogen stores suffice for the energy needs of singles match play under present match conditions (singles play for a maximum of three sets, some 100 minutes match play duration). At the end of the singles matches, we recorded hyperglycaemic concentrations of more than 11 mmol l⁻¹ on several occasions. This is probably the result of very high sympathetic activity with extremely high substrate mobilisation from the glycogen stores. Both the players in question normally become very nervous shortly before or during match point.

Negative disturbances of glucose homeostasis particularly occurred after the rest period, at the beginning of doubles play (Table 1). At this time, the glucose concentration in capillary blood dropped below 2.5 mmol l⁻¹ in some cases. The sudden drop in glucose levels during the warm-up was not accompanied by diminished competitiveness (Figure 4). Apparently, the changes were too minor or too short in duration to be perceived by the players (24). However, in view of the results of the questionnaire the practical significance of this temporary drop in glucose concentration during the warm-up should not be underestimated (Table 2, Figure 4). These demonstrate a clearly increased
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frequency of hypoglycaemic symptoms at the start of doubles play (2nd match of the day).

There are several explanations for this phenomenon:

1. In principle, energy consumption increases during the transition from rest to physical activity. Muscular uptake of glucose from the blood increases and serum glucose levels fall (3). With a time delay, after the start of compensation mechanisms, glucose homeostasis is restored again (4).

2. At the start of the doubles match (2nd match) substrate mobilisation as a response to the sudden increase in glucose uptake is restrained, as a result of the significantly lower release of catecholamines during doubles (Figure 4). Possibly, doubles play is of less importance to the players or is not as threatening as singles play. Furthermore, mitigation of the neuroendocrine response to repetitive physical activity has been described (25).

3. Efficient and rapid hepatic glycogenolysis is more difficult with increased depletion of both, muscle and liver glycogen stores as a result of previous activity (1st match). More evidence pointing in this direction is the fact that glucose levels drop much more sharply at the start of doubles play after lengthy matches (3 sets) than after short matches, and this cannot be reversed until the end of the doubles match (Table 1).

4. If energy intake is insufficient during the rest period, even stronger glycogen depletion and a higher risk of hypoglycaemia can be expected at the restart of activity, because no extra metabolism of externally supplied carbohydrates takes place (5). The present data show that, particularly when the rest period is short (2nd round players), the resulting lower or lack of energy intake between singles and doubles play (Figure 1) leads to a clear drop in glucose concentration (Table 1).

5. Snacks with a high glycaemic index immediately before the start of the activity induce reactive hyperinsulinaemia and - synergistically with the effect of the muscle contractions - can lead to increased muscular glucose uptake at the start of exercise, thus causing a rebound drop in serum glucose levels (1,7,8).

No final conclusions can be drawn with regard to the various possible causes, because of the inevitable lack of standardisation with a study under tournament conditions (e.g. nutrition, temperature, opponent). Nevertheless, there is strong evidence that the points 1-4 are of special importance in explaining the raise of hypoglycemic incidence during the starting phase of repeated tennis matches.

**Conclusion**

Glucose homeostasis is strongly disrupted several times during the course of team tennis tournaments. Particularly during the warm-up for a second work load on a competition day (e.g. a second tournament match or resumption of play after a rain delay or a training unit after match play), glucose concentrations drop considerably and the risk of hypoglycaemia rises. This is particularly true after a long match and a short break (30-60 minutes). Continuous carbohydrate intake is therefore important from the third set of a match and during the break after the match. By performing an off-court warm-up (jogging and exercises), sympathetic activity and the mobilisation of substrates can be increased, shifting the drop in glucose levels to the less
critical period before the start of the match.

**Footnote**

1. Organisation of team competition: A team consists of six players. Three players play singles matches at a time, followed by the next three players. The teams then play three doubles matches. Each player therefore plays a singles match (first, or second round), followed by a doubles match. Players who take part in the first set of singles matches are likely to have a longer rest period than those who play in the second round, but the duration of play (and consequently of the rest period between the matches) is largely unpredictable.

**References**