Thermal stress during table tennis bouts under high ambient temperature with and without fluid replacement

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Abstract

The present study compared thermoregulatory and cardiovascular stresses during prolonged, simulated intermittent table tennis bouts (8×10-min bouts with 3-min rest intervals) at high ambient temperatures (30℃, 70% RH) with (F_I) and without (F_0). Four college table tennis players played against a table tennis robot that delivered 60 balls per min in the 2 environmental conditions. The performance task was to return the ball to a specific table target area on the table. During rest periods during F_I the subjects drank a commercial sport drink ad libitum. Pre- and post-trial measurements of body weight demonstrated a similar loss of sweat during F_0 and F_I after correcting the latter for fluid replacement. Rectal temperature (T_{re}) and heart rate (HR) were significantly higher ($P<0.01$) during F_0 than F_I. During both dehydration and fluid replacement in hot environment mean skin temperature (T_{sk}) followed similar patterns and no differences were observed between F_0 and F_I. This might be associated with similar rate of sweating during table tennis bouts in both trials. The intake of the carbohydrate-electrolyte fluid during F_I did not significantly affect plasma lactate. Thus the fluid intake during prolonged intermittent table tennis bouts was effective in reducing heat stress on thermoregulatory and cardiovascular functions.

Introduction

High ambient temperature and humidity reduce the capacity to perform prolonged exercise because of dehydration and thermoregulatory stress contributing to fatigue. Water loss by thermoregulatory sweating causes a reduction in plasma volume, leading to a higher heart rate and core temperature(1). If no fluid is ingested during prolonged exercise, the water and electrolyte losses in sweat will increase plasma sodium concentration and osmolality(2). Because increased plasma osmolality due to dehydration reduces skin blood flow(3), fluid intake is important to maintain plasma osmolality in activities where dehydration and thermoregulation are of primary concern(4). Therefore, one important intervention to protect against disturbances of homeostasis from exercise and heat stress is the consumption of adequate fluid volume with appropriate constituents during exercise.

If the exercise intensity which is performed under high temperature and humidity is prolonged, but of only moderate intensity, then the exercise duration thermoregulatory stress may not be appreciably affected, but the physiological homeostasis and motor performance might be more subtly altered by the environmental conditions and more difficult to observe. Recently, attention has been focused on table tennis as an ideal leisure-time physical activity as a means of combating inactivity and the risk of related chronic diseases because of its convenience and moderate exercise intensity. However, often the conditions in facilities where table tennis is played are not adequate to seasonally prevent heat stress. The activity may be in a small room with inadequate ventilation in order to prevent air movement from affecting the ball and thus heat and humidity generated by the participants may contribute to the already unpleasant conditions.

Apparently, no information is available about thermoregulatory stress during table tennis in a hot and humid environment and how the performance skill may be altered. Therefore, the primary purpose of this study was to measure the thermoregulatory and cardiovascular stress during a controlled, simulated table tennis match under conditions of high and moderate temperature and humidity; secondly, we wished to determine the effects of drinking a commercially available carbohydrate-electrolyte beverage before and during the exercise on these responses.

Methods and Procedures

Subjects

Four male college table tennis players volunteered for the study and informed consent was obtained. The mean (±SEM) values for age, height, body weight, %body fat, body mass index (BMI), and resting heart rate (HR_r) were 19.5 (0.3) yr, 169 (2.1) cm, 64.1 (3.4) kg, 15.7 (5.4) %, 22.6 (1.6) kg/m^2, and 63.3 (4.3) bpm, respectively. These data are summarized in Table 1. The %fat was measured using a body impedance technique (Weight Manager 2.05, RJL Systems, Clinton, MI).

A maximal exercise test was administered prior to experiments employing the Bruce protocol on a motor driven treadmill (Quinton Medtrack ST 65, Quinton Instrument Co., Seattle, WA). During this test the subjects wore a mask connected to an automated gas analyzer (Oxycon Gamma, Jager, Mijnhardt, Netherlands). In addition, maximal isometric strength on the

Table 1. Physical and physiological characteristics of subjects.

Age (yr)	Height (cm)	Mass (kg)	Body fat (%)	BMI (kg/m^2)	HR_{rest} (bpm)	HR_{max} (bpm)	VO_{2max} (ml/kg/min)	Strength (kg)
19.5	169.0	64.1	15.7	22.6	63.3	186.3	56.7	71.3
(0.3)	(2.1)	(3.4)	(5.4)	(1.6)	(4.3)	(5.1)	(2.4)	(10.0)

Values are mean (SEM)

leg extensors was measured using a digital dynamometer (TKK 1269k, Takei, Tokyo). The mean values for maximal heart rate (HR_{max}), oxygen uptake (VO_{2max}), respiratory exchange ratio (REP_{max}) and isometric muscle strength of the knee extensors are also presented in Table 1.

Experimental protocol

The test trials consisted of two sets of table tennis bouts for each subject. Two trials at high ambient temperature and humidity were given in August, one with (F_I) and one without fluid intake (F_0). The F_0 and F_I trials were separated by at least 10 days. To eliminate any order or training effect, the order of these trials was selectively randomized. Ambient temperature and humidity were measured in the gymnasium near the playing table. Dry bulb temperatures and % relative humidity (from wet bulb temperature) were recorded every 10 min during each experimental trial. During F_0 and F_I the means were 29.7 (0.1) ℃ and 69.4 (0.5) % and 29.8 (0.3) ℃ and 70.0 (1.2) %, respectively.

For each test trial the subjects were matched against a standardized table tennis robot (Newgy 5000, Nihon Takkyu Inc., Tokyo). The robot was programmed to consistently present 60 balls per minute with a slight topspin to the subject. During each trial the subjects played eight times for 10 min continuously with a three min rest period between each bout, totaling 101 min. The performance task of the subjects was to return the ball to an area on the far side of the table which was 1/8 the total table.

For the F_I trial, the subjects consumed 500ml of Pokarisweat^R (6% glucose, 18 mEq/L Na^+) 30 min prior to testing and drank *ad libitum* during every rest period. The temperature of the drink was about 10℃. All two tests were conducted at the same time of the day.

Each subject reported to the laboratory eight hr post-prandial on all test days. Upon arrival the subjects were given a standardized snack and then rested quietly on a couch before beginning the test bouts.

Temperature measurements

Before each test, nude body mass was measured after voiding urine and a thermocouple (Yellow Springs Instruments Co., Yellow Springs, OH) was inserted to a depth of 10 cm beyond the anal sphincter to monitor core temperature. Mean skin temperature ($\bar{T}_{sk}$) was derived from pectoral (Tp, a point 1 cm inferior to the right axilla, along a line running from the anterior fold to the nipple); biceps (Tbi, the middle of the anterior aspect of the right arm at a point midway between the acromion process and the olecranon process); thigh (Tt, the midline of the right anterior thigh midway between the inguinal crease and the proximal border of the patella); and calf (Tc, the midline of the medial aspect of the lower right leg at the level of maximal calf girth). The calculation for the mean skin temperature (T_{sk}) was determined by Ramanathan's [5] formula.

$$\bar{T}sk = 0.3\ Tp + 0.3\ Tbi + 0.2\ Tt + 0.2\ Tc.$$

Electrodes for ECG were placed in the CM 5 position. Rectal temperature (T_{re}), skin temperature (T_{sk}) and heart rate (HR) were continuously measured using a portable temperature and heart rate memory (Vine Ltd., Tokyo) and subsequently processed by computer to obtain minute-by-minute T_{re}, T_{sk} and HR values.

Blood sampling and analysis

With subjects seated, venous blood from an arm vein (10 ml) was collected in lithium heparinized syringes at rest, immediately after the 4th exercise bout (mid-trial) and immediately after the last bout (post-trial). Lactate concentration of whole blood was obtained immediately after sampling (1500 Sport L-lactate analyzer, Yellow Springs Instrument Co., Yellow Springs, OH).

Sweat rate

Sweat rate (L/hr) was calculated as change in nude body weight (±10 g) corrected for fluid intake. Nude body weight was recorded before the first rally bout and immediately after the last bout after subjects had carefully wiped the sweat from the skin.

Statistical analysis

A two-way analysis of variance (ANOVA) for repeated measures on both factors (trial condition × time) was used to determine whether significant differences ($P<0.05$) existed between responses to the trials in the two different conditions. Paired t-tests were also used to test pre-post differences among the three trials. Post-hoc Tukey tests were used to identify where the differences lay. All values are reported as mean (±SE).

Results

Sweat rate and weight loss

No difference was found in total body weight loss in both F_0 and F_I (Figure 1). Pre- and post-trial measurements of body weight demonstrated a similar loss of 1.54 (0.08) kg during F_0 and 1.45 (0.24) kg during F_I, after correcting the latter for the fluid replacement of 1.94 (0.18) L. These values indicate a sweat loss of 0.87 and 0.83 L/hr for F_0 and F_I, respectively.

Cardiovascular, thermoregulatory and metabolic responses

Heart rate: There was no significant difference in HR_{rest} among the subjects prior to the two test trials, the values being 75.0 (3.7) and 74.8 (2.9) before F_0, F_I, respectively. Figure 2 shows the mean values for HR plotted for the two trials at end of each bout, each point being an average of the last 30 seconds of each bout. The HR at the end of each bout was always lower, by an average of 13 bpm, for F_I than for F_0 and significantly

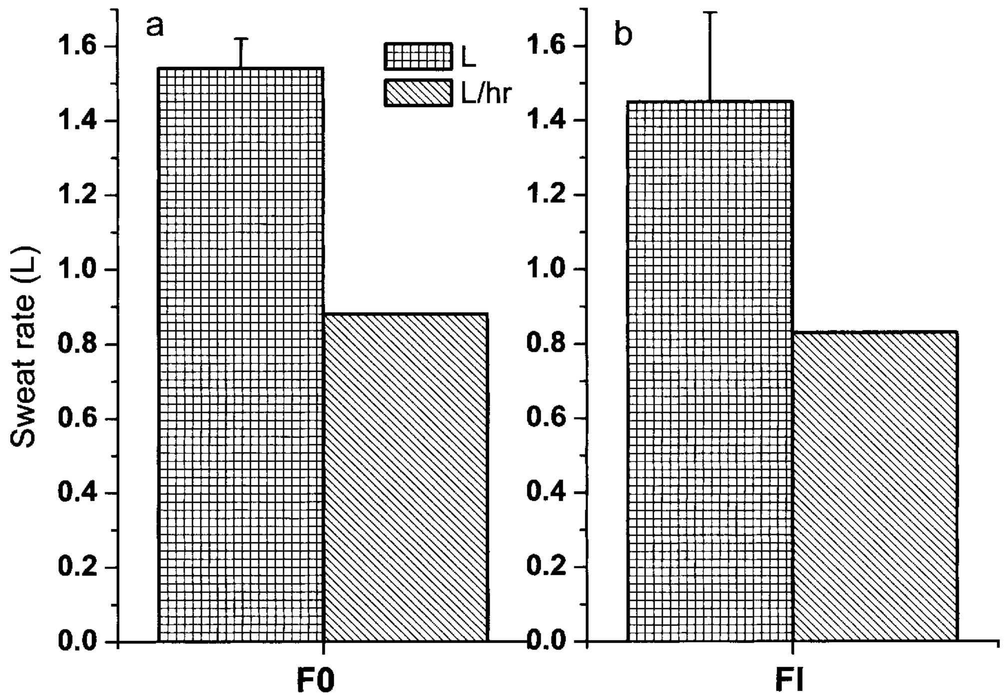

Figure 1. Sweat rate during table tennis bouts in two trials. Values are means (±SEM).

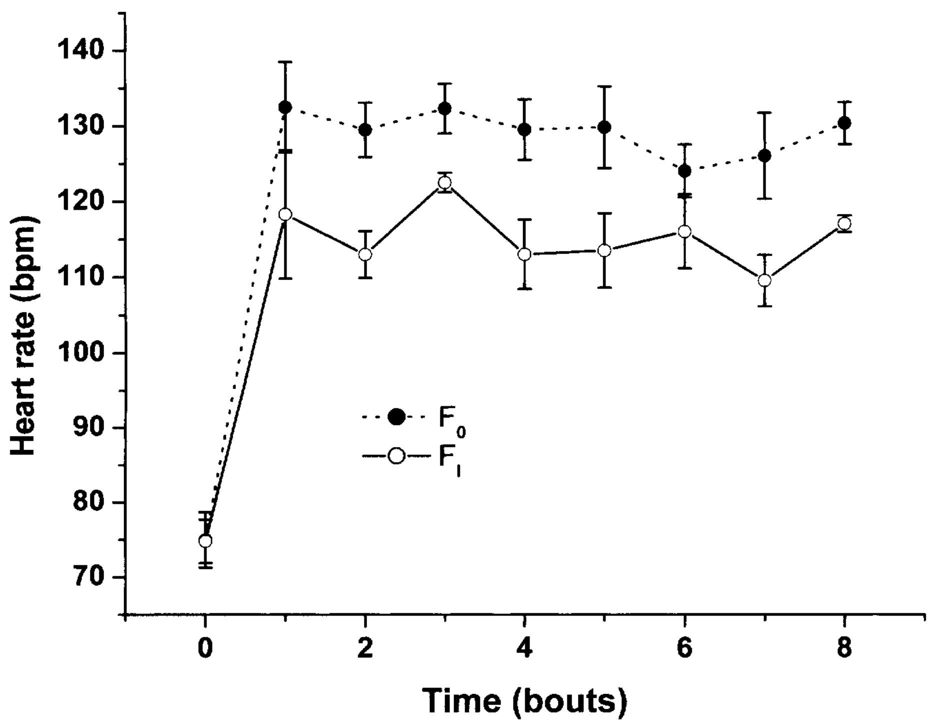

Figure 2. Mean heart rates during table tennis bouts in two trials.

lower for all but the 6th bout (P<0.05).

Body temperature: Figure 3 gives the mean variations in rectal (T_{re}) and the mean skin temperatures ($\bar{T}_{sk}$) as a function of time. Resting T_{re} before the two trials was similar, with values of 37.9 (0.2) and 37.6 (0.1) ℃ during F_0 and F_I, respectively. As shown by mean values during each bout in the top of Figure 3 (a), T_{re} gradually rose during the first 4 bouts after the onset of the bouts and then remained stable for the rest of the bouts at approximately 37.9-38.0℃ during F_I. During F_0 the T_{re} continued to rise throughout the trial. During the the trials the ANOVA and post hoc comparisons indicated significantly (P<0.05) lower T_{re} during F_I than during F_0 after the 5th bout of the trials.

The bottom of Figure 3 (b) shows mean variations in $\bar{T}_{sk}$ as a function of time. Hydration exhibited no significant effect on

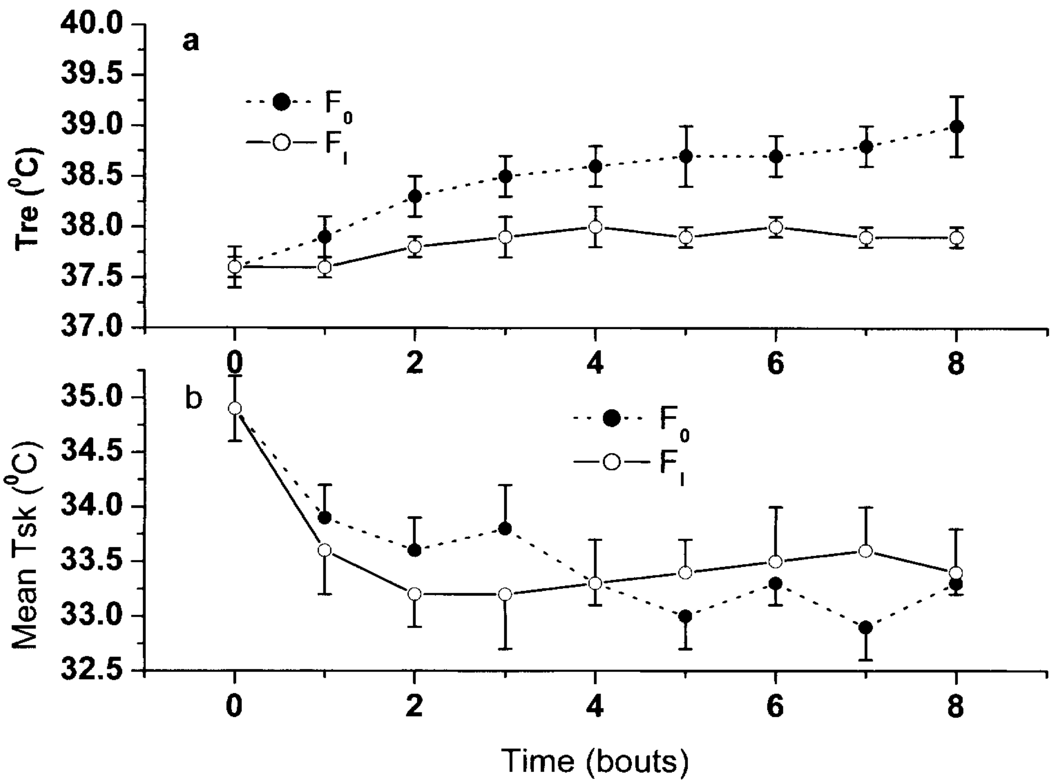

Figure 3.　Mean rectal (top) and mean skin (bottom) temperatures during table tennis bouts in two trials.

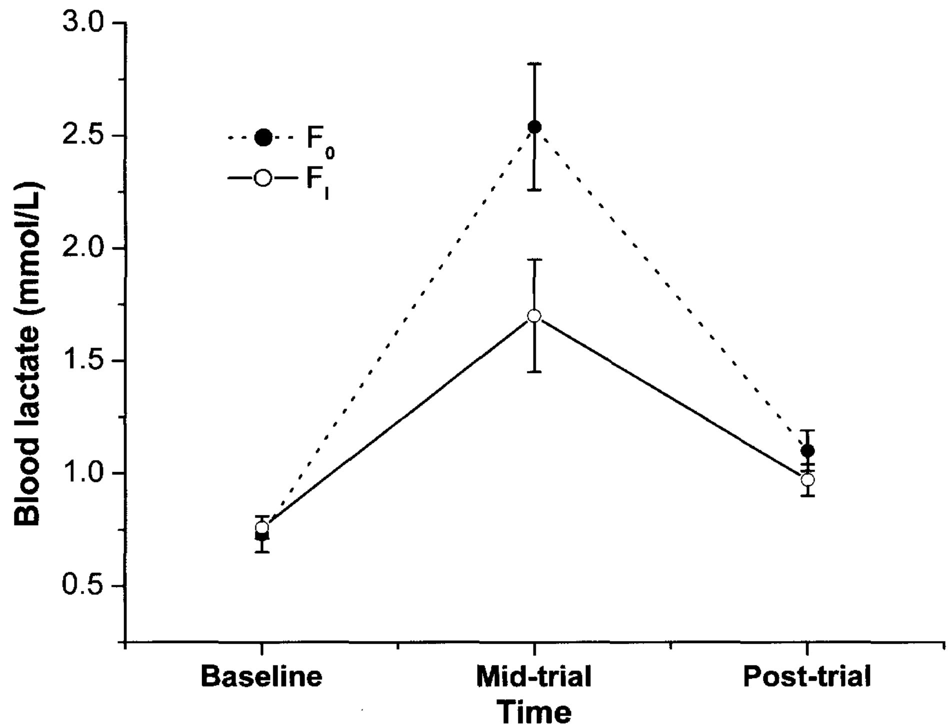

Figure 4. Blood lactate concentrations (mean ± SEM) at pre-, mid- and post-trials during tennis bouts.

$\bar{T}_{sk}$. After the onset of the bouts, $\bar{T}_{sk}$ in both trials abruptly decreased and remained relatively stable during rest of the bouts.

Blood lactate: Lactate levels increased significantly ($P<0.001$) above rest at the mid-point during the two trials, by 1.81 mmol/L during F_0 and 0.94 mmol/L during F_I and then declined significantly to baseline by the end of the trials (Fig. 4).

Physical performances

Anaerobic test and table tennis performance scores have been reported elsewhere(17).

Discussion

Many studies have been carried out to determine the efficacy of fluid replacement during and after exercise in elevated temperatures(6, 7). Most of these studies have been carried out under controlled laboratory ambient conditions, but a few studies [8, 9]. Apparently no studies have reported physiological responses to playing a simulated table tennis match in the heat. In the present study these performance and the physiological responses were compared to those in a thermoneutral environment between conditions with and without fluid intake.

The main finding was that cardiovascular and thermoregulatory stresses during a prolonged, intermittent, moderate-intensity trial in a hot environment were quite marked, but were greatly attenuated with intake of a carbohydrate-electrolyte beverage. The responses and performance scores were generally similar to those measured in a moderate environment.

Body temperature, as reflected by T_{re}, was a limiting factor in the performance of this prolonged exercise even though the intensity of the activity was moderate. T_{re} tended to stabilize during the last half of the bouts in environmental condition, as well as in the humid heat when fluid was ingested by subjects (Figure 3, a). During both dehydration (F_0) and fluid replacement (F_I) $\bar{T}_{sk}$ followed similar patterns (Figure 3, b) and no differences were observed between two trials. Thus hydration exhibited no significant effect on T_{sk}. These responses might be associated with identical amount of sweat rate in F_0 and F_I during the bouts. That is, evaporative cooling during exercise was adequate for both trials. Fluid intake might prevent circulatory stress during exercise in high ambient temperature because of the increased volume of blood contained in the dilated cutaneous veins. However, sweat losses in our subjects during exercise in hot environments were unaffected by fluid intake, which is in accordance with other investigations in which prolonged moderate intensity exercise were conducted in hot conditions [7, 10].

Less physiological stress was evident in the subjects when ingesting fluid prior to and during this table tennis exercise in high ambient temperatures. A commercial sport drink, containing 6% carbohydrates and electrolytes, was given to the subjects. The optimal formulation of beverages designed to enhance performance and minimize homeostatic perturbations is controversial. Millard-Stafford(11) concluded in his review that a moderately concentrated carbohydrate-electrolyte beverage (4 to 8% carbohydrate) was appropriate for optimizing fluid and energy delivery during prolonged exercise and caused no adverse effects. Coggan et al.(12) stated that CHO supplements could improve performance in intense exercise lasting one hour. We did not measure serum Na^+ concentrations in the present study. Daries et al.(7) observed that serum Na^+ concentration did not fall when enough fluid containing 16 mEq/L of Na^+ was ingested, thereby supporting the benefit of consuming electrolyte-containing drinks during prolonged exercise. Dangerous falls in plasma Na^+ concentration have been observed when subjects drank pure water rather than a commercial CHO-electrolyte solution in a hot environment(13). However, some studies(14, 15) have reported that compared to water, the addition of electrolytes to a CHO drink had no effect on thermoregulation and exercise performance.

Previous research has shown that blood lactate levels are elevated during exercise in the heat when compared to exercise in thermoneutral environments(16). Although the difference did not reach significance in the present study, blood lactate concentration in F_0 tended to be higher as compared to that in F_I (Figure 4). Fluid intake did not have an appreciable influence on lactate concentration, but reduced it only during the mid-point of the trial. It is interesting to note the low concentrations during the table tennis trials and that the rise and fall as the trials progressed under all conditions. This probably indicates that table tennis depends primarily on aerobic energy production, especially because the aerobic power of these subjects was relatively high as shown in Table 1 (mean VO_{2max}: 59 ml/kg/min), at least partially due to their running training.

In summary, in college male table tennis players high ambient temperatures and humidity increase thermoregulatory and cardiovascular stresses during prolonged table tennis bout. However, fluid ingestion during this exercise in the heat served to minimize the significant physiological overloads. It seems clear that the performance decrements (to be published elsewhere) and premature fatigue were associated with high body temperatures and circulatory stress caused by a loss of plasma volume. For recreational players, who mainly play for health and fitness, a frequent and adequate intake of a commercially available CHO-electrolyte beverage is highly recommended.

This study was presented at the 3rd World Congress of Science and Racket Sports, Paris, 2003[17].

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高温環境での下卓球練習における暑熱ストレスに対する水分補給の影響

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要　約

目的

近年，卓球は健康づくりや生涯スポーツの両面から実践者が増加している。高温多湿な本邦の夏季における長時間の卓球運動時の身体に対する暑熱ストレスはかなり大きいものと思われる。他方，各種スポーツにおけるスポーツ飲料の活用は目覚しい。そこで本研究では高温多湿の環境下における長時間卓球練習時の生体に加わる暑熱ストレス軽減に対する水分補給効果について検討を試みた。

方法

被検者：4名の健康な男子大学卓球部員が被検者としてこの研究に参加した。被検者の平均最大酸素摂取量（ml/kg/min），脚伸展筋力（kg）および体脂肪率（%）はそれぞれ56.7（±2.4SEM），71.3（±10.0），15.7（±5.4）であった。このことから被検者は高いレベルの体力を備えた者であるといえる。

運動プロトコール：被検者はロボットマシンから1分間に60球打ち出されるボールを卓球台上のきめられたソーンに打ち返すことをタスクとして課せられ，それを10分間継続して3分間の休息をはさんで8回繰り返した。被検者はこの打球運動を次の2つの異なる環境下で行った；

平均環境温度と相対湿度が30℃，70%の高温環境（8月実施）

① テスト時の水分摂取が認められない……F_0

② テスト開始直前に500mlの摂取とラリー運動中の休息時にアドリビタムに水分補給（ポカリスエット®）をする……F_1

測定：卓球ラリー運動による発汗量を求めるためにテスト開始直前と終了直後に裸体による体重測定を行った．運動テスト時の心拍数（HR）は胸部電極誘導から，深部体温は直腸（プローブを10cm挿入）温（T_{re}）

から，そして平均皮膚温（$\bar{T}_{sk}$）は胸部，上腕前部，大腿前部，下腿背部の4箇所の皮膚温度測定から求められた。これ以外に，運動開始前，運動時中期（開始後50分），そして運動終了直後の血液サンプル採血によって乳酸値濃度を求めた。

結果

発汗量：水分補給の有無に関係なくF_0とF_Iの運動に伴う体水分喪失量に差が見られなかった。F_0，F_Iの発汗量はそれぞれ1.54（0.08），1.45（0.24）Lであった。

運動時心拍数：F_Iトライアルでのラリー運動時HRはほぼ全ての時点でF_0より有意に低く，運動中の水分補給の影響が示された。

体温：運動開始とともに直腸温はラリー運動テストのほぼ半ばにあたる45分まで徐々に上昇し，その後F_Iではレベルオフの形状を示し37.9～38.0℃となった。これに対して，H_0ではT_{re}の変化のレベルオフが見られず運動中上昇し続けた。高温環境下でのF_0とF_Iの二つの運動時平均皮膚温（T_{sk}）は運動開始とともに低下し，その後はほぼ横ばいのケ上を示した。

血中乳酸濃度：高温環境下での二つの運動では運動開始後血中乳酸値濃度は運動テスト中間時点において有意（$P<0.001$）に上昇し，運動終了時時点までには両群の乳酸値濃度はほぼベースライン濃度にまでに低下した。

考察

通常環境温度と比較して，高温環境下での長時間卓球ラリー運動時における体温調節および循環系に対する負荷は有意に増幅された。しかし，運動開始前および運動時における水分補給は暑熱ストレスを大いに軽減させることに寄与した。水分補給テストでは体深部温度（T_{re}）はラリー運動時後半において定常な状態を示したのに対して，脱水テストでのT_{re}は緩やかではあるが運動終了時まで上昇を続けた（図3 a)。これに対して平均T_{sk}は運動開始とともに低下し始め，ラリー運動時を通して低い値にとどまった。しかし，直腸温と異なり，F_0とF_Iで平均T_{sk}に有意な差が見られず，水分補給による発汗冷却の効果を観察することができなかった。このことはラリー運動にもとづくトータル発汗量（体水分喪失量）が水分補給の有無に影響されなかったことに関連するものであろう。F_Iの運動時心拍数はF_0のそれより有意に低い値を続けたことは（図2)，水分補給が高温下で拡張した皮膚血管の血液量増加をもたらして運動時の循環系に

対するストレスを防ぐことに影響したことを示すものであろう。F_0, F_I ともに，血中乳酸濃度はラリー運動によって有意に（P<0.001）上昇するが，運動終了時までには運動開始前値のレベルに戻る（図 4)。このことから卓球は基本的には有酸素的エネルギー産生による活動であることを示したといえよう。