The effect of recovery duration on running speed and stroke quality during intermittent training drills in elite tennis players

ALEXANDER FERRAUTI,1* BABETTE M. PLUIM2 and KARL WEBER1

1Institute of Sports Games, German Sport University Cologne, Carl-Diem-Weg 6, D-50933 Cologne, Germany and 2Royal Netherlands Lawn Tennis Association, Displayweg 4, 3821 BT Amersfoort, The Netherlands

Accepted 24 September 2000

The aim of this study was to assess the effect of the recovery duration in intermittent training drills on metabolism and coordination in sport games. Ten nationally ranked male tennis players (age 25.3 ± 3.7 years, height 1.83 ± 0.8 m, body mass 77.8 ± 7.7 kg; mean ± s) participated in a passing-shot drill (baseline sprint with subsequent passing shot) that aimed to improve both starting speed and stroke quality (speed and precision). Time pressure for stroke preparation was individually adjusted by a ball-machine and corresponded to 80% of maximum running speed. In two trials (T10, T15) separated by 2 weeks, the players completed 30 strokes and sprints subdivided into 6 × 5 repetitions with a 1 min rest between series. The rest between each stroke-and-sprint lasted either 10 s (T10) or 15 s (T15). The sequence of both conditions was randomized between participants. Post-exercise blood lactate concentration was significantly elevated in T10 (9.04 ± 3.06 vs 5.01 ± 1.35 mmol · l−1, P < 0.01). Running time for stroke preparation (1.405 ± 0.044 vs 1.376 ± 0.045 s, P < 0.05) and stroke speed (106 ± 12 vs 114 ± 8 km · h−1, P < 0.05) were significantly decreased in T10, while stroke precision – that is, more target hits (P < 0.1) and fewer errors (P < 0.05) – tended to be higher. We conclude that running speed and stroke quality during intermittent tennis drills are highly dependent on the duration of recovery time. Optimization of training efficacy in sport games (e.g. combined improvement of conditional and technical skills) requires skillful fine-tuning of monitoring guidelines.

Keywords: blood lactate, monitoring guidelines, running speed, stroke quality, tennis practice.

Introduction

The duration of recovery, as well as the duration and intensity of workloads, is important for the regulation of physiological strain during intermittent exercise. Studies during sprint training (Balsom et al., 1992) and weight-training sessions (Abdessemed et al., 1999) have confirmed the importance of sufficient recovery for sustaining running speed and muscle performance. Power decrements in the course of maximal-intensity intermittent exercises have been related to a continuous degradation of phosphocreatine, thus placing greater demand on glycogenolysis and glycolysis, with increasing muscle and blood lactate concentrations associated with large reductions in muscle pH. Consequently, some early studies suggested an impairment of calcium binding to troponin during actomyosin interactions (Tesch, 1980), a decrease in the energy turnover rate and total adenosine triphosphate (ATP) resynthesis through inhibition of the glycolytic enzymes (Triverdi and Danforth, 1966), and a negative effect on central nervous activation via sensory muscle receptors and their afferents (Asmussen, 1979).

Sport games such as soccer, basketball, field hockey and tennis, which involve periods of short intensive work interspersed with recovery of variable length, are usually classified as multiple-sprint sports (Hamilton et al., 1991). As a result, intermittent sprinting exercises (mostly in a game-like situation with a technical and tactical assignment) form a typical and essential aspect of almost every training session. If these are performed regularly in a way requiring high anaerobic-lactic demands, this may lead to an acute deterioration in muscle performance (see above), a long-term disturbance of performance capacity determined by the
muscular and central nervous system (e.g. decreased agility, increased fatiguability) and development of the ‘overtraining’ or ‘over-reaching’ syndrome (Urhausen et al., 1995). Monitoring of the workload in exercise drills is even more difficult because, in addition to the effect on the metabolic system, the efficacy of training on coordination should be taken into account (e.g. shoot, throw or stroke precision). In spite of these problems, only isolated applied field studies regarding the effects on metabolism and coordination of typical training sessions in sport games can be found in the literature, with no relevant practical guidelines for coaches (Hughes, 1995; Todd et al., 1998).

Intermittent exercise drills are important in tennis practice, which is often an unavoidable consequence of group training. Since the size of the group often changes, which cannot be foreseen by the coach (one coach with either two, three or four players on court), the training load (e.g. work-to-rest ratio) is often determined more by chance than by choice. Coaches have to rely on their intuition, because there are no reliable recommendations for duration (number of strokes per workload), density (duration of rest periods) or volume (total number of strokes per exercise drill) for typical exercises. Consequently, the training load runs the risk of being too high, thus not mimicking the metabolic pathways during match-play. Since, in tennis match-play, the energy production during rallies is predominantly anaerobic-alactic, followed by aerobic oxidation of carbohydrates during the breaks (Bergeron et al., 1991; Christmass et al., 1998; Ferrauti et al., 1997), predominantly anaerobic-lactic demands during tennis practice are generally not optimal.

In this paper, we present the results of a typical drill used by elite tennis players (‘passing-shot drill’), which aims to improve tennis-specific running speed and stroke quality (precision and speed). We investigated the effect of recovery duration on metabolic demands and on stroke and running performance.

Methods

Participants

Ten trained, healthy and nationally ranked male tennis tournament players (age 25.3 ± 3.7 years, height 1.83 ± 0.08 m, body mass 77.8 ± 7.7 kg; mean ± s.d.) participated in the study. They were non-smokers and were not taking any medication during the experimental period. The players were familiar with all test procedures and gave their written informed consent to participate in the study.

Experimental design

On two occasions (T₁₀, T₁₅) separated by 2 weeks, all players completed an on-court intermittent exercise (passing-shot drill) on an indoor carpet floor. Additionally, on each test day, maximum running speed was measured pre- and post-exercise by means of a baseline sprint test (Figs 1 and 2).

Fig. 1. The experimental design ($v_{max} =$ maximum running speed).
The participants were asked to refrain from exercise on the day before the trials. On test days, a standardized and carbohydrate-rich meal was provided 2 h before exercise (3200 kJ; 68% carbohydrate, 20% fat, 12% protein). During exercise, the players were allowed to drink water *ad libitum*. The environmental conditions, ambient temperature, tennis balls (Dunlop Tournament Official, Hanau, Germany) and warm-up routines were identical on each test day.

**Passing-shot drill**

The passing-shot drill (Fig. 2, right) aims to improve starting speed and acceleration, in combination with a tennis stroke under sub-maximal time pressure and high demands on stroke quality (speed and precision). The players have to sprint along the baseline (9.5 m) and hit a forehand passing shot from the outer sideline. Standardization (rest periods between strokes, time pressure and stroke position) was guaranteed by using a ball-machine (MIHA 1000 TR, Augsburg, Germany). Time budget for stroke preparation (flight time of the ball to the hitting position minus reaction time) was individually adjusted by varying the height and speed of the balls leaving the ball-machine, and corresponded to 80% of pre-exercise maximum running speed measured during the baseline sprint test (Fig. 2, left). The players performed 30 strokes and sprints, subdivided into $6 \times 5$ repetitions with a 1 min rest between series. The recovery duration between each stroke-and-sprint lasted either 10 s ($T_{10}$) or 15 s ($T_{15}$). We focused on a work-to-rest ratio that occurred in a group of two ($T_{10}$) or three players ($T_{15}$), because those are of most practical relevance. The sequence of both conditions was randomized between participants (Fig. 1). The following measurements were performed:

1. The running time for each stroke preparation was recorded from the starting position by an electronically sensitized platform (transferring the start signal) to three different points along the baseline (distances of 2.06, 4.12 and 6.18 m; $t_1$, $t_2$ and $t_3$ respectively). Time at each measurement point was measured by a double light barrier system consisting of two infrared photoelectric cells (Imhoff Timing, Steinbach, Germany).

2. The stroke speed of each passing shot was measured by a digital Doppler radar gun (SEA Fiedel GmbH, Rudersberg, Germany). Maximum speed during the flight of each passing shot was...
displayed and recorded. Since the direction of the radar gun corresponded exactly to the direction of the stroke (forehand down the line), no angle error can be expected.

3. During the 1 min rest between each series of five sprints, rating of perceived exertion (RPE) was registered (Borg, 1973) and capillary blood samples (20 μl) were taken from the earlobe for the analysis of blood lactate concentration (Eppendorf-Analyser 5060, Hamburg, Germany).

4. Stroke precision was recorded for errors and target hits, which were subdivided into three areas (Fig. 2, right) at the opponent’s backhand corner (A = 1.37 × 1.83 m, B = 2.74 × 3.66 m, C = 4.12 × 5.49 m).

Baseline sprint test

Before and after exercise, maximum running speed was measured by a baseline sprint test consisting of five runs with 1 min rest between runs (Fig. 2, left). The running distance corresponded exactly to the passing-shot drill. The players had to start from a starting platform and complete a forehand stroke against a stroke simulator, which transfers start and stop signals to a computer-aided time measurement system and guarantees a tennis-specific movement pattern (Ferrauti, 1993). The mean value of all five trials was used for statistical analysis.

Statistical analysis

The data are presented as the mean ± standard deviation (s). Statistical analysis was carried out using two-factor (recovery duration, point-of-time measurement) analysis of variance (ANOVA) with repeated measures (Table 1, Figs 3 and 4). In the case of significance, simple effects were verified by means of a Newman-Keuls test. Heterogeneous variances were adjusted (Huynh-Feldt and Box procedure). Additional analysis was performed using the paired Student’s t-test (Fig. 5). Significance was set at P < 0.05 (*) and P < 0.01 (**).

Results

Blood lactate concentration was significantly different between T10 and T15 and increased during the course of the exercise (Fig. 3). The differences between the two trials became significant after 10 sprints. The increase occurred up until sprint 15 in T15, whereas it continued until sprint 25 in T10. Overall, the blood lactate curve flattens towards the end of the load in T10 (Fig. 3). Three players reached a lactate concentration of more than 10 mmol·l⁻¹ (maximum 13.5 mmol·l⁻¹) after finishing their task in T10. The lactate concentration of only two players remained below 8 mmol·l⁻¹ (minimum 6.4 mmol·l⁻¹). The perceived workload intensity (RPE) differed significantly (Table 1) and was generally viewed as ‘very hard’ in T10 in contrast to ‘somewhat hard to hard’ in T15.

Maximum running speed measured in the baseline sprint test tended to change in a different direction (Fig. 4). Whereas running speed deteriorated in T10, a small improvement was seen in T15. Nevertheless, no significant statistical main effects for recovery duration or the point-of-time measurement were noted (Fig. 4).

Running time for stroke preparation was slower in T10 at all measurement points (Table 1). Statistically significant differences were found for the longest measurement distance (6.18 m) only. The average loss of time in T10 compared to T15 (mean values of all sprints) was 0.014 s (approximately 5 cm) to the first measurement point, 0.009 s (5 cm) from the first to the second measurement point and 0.006 s (3.2 cm) from the second to the third measurement point, resulting in a total difference of 0.029 s (13.2 cm). The running

| Table 1. Post-exercise blood lactate concentration, rating of perceived exertion (RPE), overall exercise running time for stroke preparation (t1–3) and speed of passing shots (vstroke) in two passing-shot drills with different exercise protocols (the results of a paired t-test or ANOVA main factor ‘rest’, respectively, are indicated) |
|-----------------|-----------------|-----------------|
|                 | 10 s rest       | 15 s rest       | P    |
| Blood lactate (mmol·l⁻¹) | 9.04 ± 3.06     | 5.01 ± 1.35     | 0.001** |
| RPE (n) | 17.0 ± 1.6      | 14.3 ± 1.3      | 0.003** |
| t1 (s)  | 0.612 ± 0.050   | 0.598 ± 0.032   | 0.081  |
| t2 (s)  | 1.022 ± 0.044   | 0.999 ± 0.045   | 0.128  |
| t3 (s)  | 1.405 ± 0.044   | 1.376 ± 0.045   | 0.017* |
| vstroke (km·h⁻¹) | 105.6 ± 11.8    | 114.4 ± 7.5     | 0.018* |

* P < 0.05, ** P < 0.01.
time to the third measurement point increased significantly during the course of both drills (Fig. 3). The difference in performance between T\textsubscript{10} and T\textsubscript{15} at the third measurement point gradually increased during exercise (Fig. 3). This difference amounted to 0.040 s during the last five sprints, corresponding to a distance of approximately 18 cm.

**Discussion**

The results of this study have verified that the quality (movement pattern and coordination) of specific actions in sport games is largely dependent on the physiological strain produced during short-term intermittent exercises. Small changes in the mode of execution of typical exercise drills (e.g. recovery duration) produce considerable differences in the profile of metabolic and coordinative demands. In the case of the passing-shot drill in this study, we can speculate that the decrease in running speed results in inaccurate stroke preparation (expansion of the sideways distance to the ball during the hitting phase), leading to a decrease in stroke speed (loss in power transmission) as well as a change in stroke intention (avoiding errors vs hitting winners). Thus, coaches in sport games such as tennis, hockey and soccer are urged to pay attention to an accurate definition of the intended training goals (e.g. improvement of game-specific running speed and speed of action vs application of specific movement patterns under supramaximal physiological...
Fig. 5. Stroke precision (target hits and errors) during two passing-shot drills with different exercise protocols. Significant differences (paired t-test) are indicated (*P < 0.05).

strain) and to an adequate fine-tuning of the monitoring guidelines (intensity and duration of the workloads and duration of recovery).

In T\textsubscript{10}, the blood lactate concentration rose significantly more during the course of the exercise compared with T\textsubscript{15} (Fig. 3). In high-intensity intermittent exercise, most of the energy required is provided through anaerobic pathways (phosphocreatine degradation and glycolysis leading to lactate formation). Although lactate production in the muscle cannot be quantified exactly by the blood lactate concentration – a function of muscle efflux and peripheral removal – a greater contribution of the glycolytic pathway to the total energy requirements in T\textsubscript{10} can be assumed. The time-course of phosphocreatine resynthesis during recovery occurs exponentially, with an estimated halftime resynthesis of about 30–60 s in humans (Harris \textit{et al.}, 1976). Thus, in line with others, we consider it likely that the 5 s shorter recovery period in T\textsubscript{10} resulted in less complete restoration of phosphocreatine between the repeated sprints and passing-shots, leading to increased demands on anaerobic glycolysis to maintain the rate of energy production (Balsom \textit{et al.}, 1992; Gaitanos \textit{et al.}, 1993; Blonc \textit{et al.}, 1998).

The lactate curve was seen to flatten towards the end of the load in T\textsubscript{10} (Fig. 3). This can probably be explained by a shift of the metabolic pathways from exclusively anaerobic to partially aerobic metabolism. It has been suggested that elevated H\textsuperscript+ concentrations enhance the oxidative mechanisms of energy supply by an inhibition of the glycolytic enzymes (phosphofructokinase and phosphofructokinase) and an increase in pyruvate dehydrogenase activity (Triverdi and Danforth, 1966). Gaitanos \textit{et al.} (1993) found a significant shift to aerobic metabolism in the later stages of an intermittent exercise protocol consisting of ten maximal cycle ergometer sprints of 6 s duration with 30 s recovery in between. Since a decrease in glycolytic rate is accompanied by a decrease in total energy turnover, this has been used to explain the decline in power output seen after sprint 4 in the study of Gaitanos \textit{et al.} (1993).

In the present study, maximum running speed measured in the baseline sprint test did not differ significantly between the two types of exercise despite higher lactate concentrations (Figs 3 and 4). This suggests that, under the conditions of this test, the players were able to meet the physiological challenges presented by the short recovery period of 10 s. On the other hand, running speed for stroke preparation during the exercise drill was significantly reduced in the 10 s recovery trial (Fig. 4), particularly for the longest measurement distance. The decline in stroke preparation speed corresponds to the above theory of a metabolic shift to oxidative pathways with a decreasing rate of energy production (Triverdi and Danforth, 1966; Gaitanos \textit{et al.}, 1993). Additionally, our results may reflect other possible consequences of a fall in muscle pH, such as an impairment of muscle mechanical function (Tesch, 1980) or a negative influence on central nervous activation (Asmussen, 1979).

Recent studies have also reported conflicting results for the relationship between blood lactate concentration and power output. On the one hand, decreases in treadmill (Hamilton \textit{et al.}, 1991) and cycle ergometer sprint performance (Gaitanos \textit{et al.}, 1993), as well as power decrements during a bench press exercise (Abdessemed \textit{et al.}, 1999), have been explained by metabolic acidosis. On the other hand, no relationship
was reported between blood lactate and power output during cycle ergometer sprints with a different recovery duration (Blonc et al., 1998) or vertical jump height after two middle-distance running exercise protocols (Vuorimaa et al., 2000). Balsom et al. (1992) showed that intermittent sprint performance decreased with short rest periods despite a similar acidosis, suggesting that blood lactate is a poor predictor of sprint performance.

Weighing up the conflicting evidence, it cannot be excluded that the physiological strain during the passing-shot drill impairs players’ performance in a special way. While the measuring units in the cited sprint studies and during the baseline sprint test were well-defined (maximum power output), the specific training of sport games results in a higher complexity of demands – sub-maximal power output in the lower extremities with optimal inter-muscular coordination in the upper extremities under high cognitive demands. As a result, the number of alternative solutions and degrees of freedom increase when trying to cope with the assignments. We can assume that, under high metabolic stress, players intuitively choose the energetically more favourable solution. Since time pressure for stroke preparation was limited to 80%, a successful stroke (maintenance of stroke precision) was made possible by a reduction in stroke speed despite a lower running speed (Figs 3 and 5). This proposed theory may also explain why, in the case of clearly defined and less complex assignments in the baseline sprint test, no significant changes were found (Fig. 3).

Usually, the intended training goal of the passing-shot drill consists of an improvement in game-specific running speed and passing-shot quality. Since the quality of passing shots is fundamentally determined by stroke speed, corresponding losses should be avoided. Thus, the training efficacy for maximum running speed and optimal stroke skill can only be maintained by a sufficiently long period of recovery (e.g. a minimum 15 s rest after a 2 s maximum workload). In general, coaches should pay sufficient attention to an accurate definition of the intended training goals and to an adequate adjustment of the monitoring guidelines (intensity and duration of the workloads and duration of recovery).

### Conclusion

Running speed and stroke quality during intermittent tennis drills are highly dependent on recovery time. When recovery is too short, running speed for stroke preparation and stroke speed is decreased, while stroke precision can be maintained. The training efficacy for maximum running speed and optimal stroke skill can only be maintained by a sufficiently long period of recovery (e.g. a minimum 15 s rest after a 2 s maximum workload). In general, coaches should pay sufficient attention to an accurate definition of the intended training goals and to an adequate adjustment of the monitoring guidelines (intensity and duration of the workloads and duration of recovery).

### References


Harris, R.C., Edwards, R.H.T., Hultman, E., Nordesjö, L.O., Nylin, B. and Sahlin, K. (1976). The time course of phosphorylcreatine resynthesis during recovery of


