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Influence of fatigue on upper limb muscle activity and performance in tennis

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ABSTRACT

The study examined the fatigue effect on tennis performance and upper limb muscle activity. Ten players were tested before and after a strenuous tennis exercise. Velocity and accuracy of serve and forehand drives, as well as corresponding surface electromyographic (EMG) activity of eight upper limb muscles were measured. EMG and force were also evaluated during isometric maximal voluntary contractions (IMVC). Significant decreases were observed after exercise in serve accuracy (−11.7%) and velocity (−4.5%), forehand accuracy (−25.6%) and consistency (−15.6%), as well as pectoralis major (PM) and flexor carpi radialis (FCR) IMVC strength (−13.0% and −8.2%, respectively). EMG amplitude decreased for PM and FCR in serve, forehand and IMVC, and for extensor carpi radialis in forehand. No modification was observed in EMG activation timing during strokes or in EMG frequency content during IMVC. Several hypotheses can be put forward to explain these results. First, muscle fatigue may induce a reduction in activation level of PM and forearm muscles, which could decrease performance. Second, conscious or sub-conscious strategies could lead to a redistribution of muscle activity to non-fatigued muscles in order to protect the organism and/or limit performance losses. Otherwise, the modifications of EMG activity could also illustrate the strategies adopted to manage the speed-accuracy trade-off in such a complex task.

1. Introduction

Neuromuscular fatigue represents “any exercise induced reduction in the ability to exert muscle force or power, regardless of whether or not the task can be sustained” (Bigland-Ritchie and Woods, 1984). Accordingly, the ability to limit the loss of power, velocity and accuracy appears be a key of performance during tennis match play. Fatigue effects in tennis can be manifested as mistimed strokes (velocity and precision), altered on-court movements (velocity, footwork and positioning to the ball), and incorrect tactical choices (Davey et al., 2002; Girard and Millet, 2008). The potential effects of fatigue on stroke production and the behavior of the player represent a key research topic in tennis. Indeed, several studies have focused on performance degradations (see review (Hornery et al., 2007a)) and EMG changes (Fabre et al., 2012; Girard et al., 2008, 2009) related to fatigue in tennis. For example, an exhausting tennis simulation test led to a 69% deterioration in hitting accuracy of the groundstroke and a 30% decline in accuracy of the service (Davey et al., 2002), while a strenuous 2 h training session resulted in a decrease of ball velocity for groundstrokes and serve, as well as an increased percentage of errors and decreased accuracy during second serve (Vergauwen et al., 1998). In addition, EMG activity and force measured during isometric maximal voluntary contraction (IMVC) decreased progressively in knee extensors (Girard et al., 2008) and plantar flexors (Girard et al., 2009) during a 3-h tennis match.

Although there is a recent and substantial literature about fatigue in tennis, to the best of our knowledge no study has been developed on EMG changes in upper limb muscles. That may be surprising since the participation of the upper extremity in tennis performance is universally admitted. Thus, the novelty of this study is the upper limb muscle EMG analysis during the tennis strokes in fatigue state. Indeed, this kind of protocol is original since the precedent EMG studies about fatigue in tennis involve only lower limb EMG during IMVC tests (Fabre et al., 2012; Girard et al., 2008; Girard et al., 2009). Previous studies carried out in other activities have shown that fatigue can alter upper limb muscle activation patterns in single- and multi-joint tasks, such as fast elbow flexion (Corcos et al., 2002), swimming (Ikuta et al., 2012; Stirn et al., 2011) and rowing (Gerzevic et al., 2011). The increased EMG amplitude is interpreted as a fatigue index resulting from supplementary motor units recruitment (Edwards and Lippold, 1956), an increase in firing rate and/or synchronization of motor units recruitment, and/or a slowdown of muscle fiber conduction

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velocity (Gandevia, 2001; Lindstrom et al., 1970). On the contrary, during sustained IMVC until exhaustion or performed after a fatiguing exercise, the decrease in EMG amplitude refers to a activation deficit or a loose of muscular excitability (Girard and Millet, 2008). In addition, it has been demonstrated that the central nervous system employs different neuromuscular adjustments, i.e. compensatory strategies, to overcome fatigue effects in order to conserve the same movement performance (Bonnard et al., 1994). More precisely, during a hopping task, Bonnard et al. (1994) emphasized the existence of two strategies: one strategy based on a preactivation of fatigued muscles in order to compensate for the stiffness decrease, and the other inducing a redistribution of muscle activity among muscles of different joints. Recent studies reported intermuscular compensatory strategy in rowing (Turpin et al., 2011) and pedaling (Dorel et al., 2009), whereas some studies showed an increased activity level with no modification in the muscle activity profile in vertical jumps (Rodacki et al., 2002), or a change in muscle coordination during intermittent cycling sprints (Billaut et al., 2005). As one study (Hornery et al., 2007b) showed no reductions in serve velocity and accuracy in professional players despite a technical degradation of service elements (i.e height of the tossing arm at ball release, and position and height of the ball toss) as match progressed, this may suggest that fatigue induced by tennis exercise can lead to significant modifications in upper limb muscle recruitment level and/or temporal pattern. The tennis matches correspond to long exertion but mean values are not sufficient to understand fully the demands of tennis. Indeed, high intensity crucial periods (e.g end of the set or tie-break) generally determine the issue of the game (Fernandez et al., 2006). Thus, the aim of the present study was to explore the influence of such high intensity tennis bouts on strokes velocity and accuracy which are the principal keys of performance, and upper limb muscle EMG activity. We hypothesized that fatiguing exertion would result in fatigue expressed by a performance degradation, a decreased IMVC strength of some muscles and an adaptation of the muscle recruitment pattern. In addition, this fatigue level generated by strenuous tennis exercise induces perturbations of muscle recruitment pattern, which may lead to a decrease in ball velocity and accuracy depending on the kind of stroke (i.e serve or forehand drive).

2. Methods

2.1. Participants

Ten skilled and well-trained tennis players (mean ± SD: age = 23.8 ± 4.0 years, height = 178 ± 9.4 cm, mass = 71.8 ± 11.2 kg, International tennis number ranging from 2 to 4) volunteered and signed an informed consent form to participate in the study, which was approved by the local ethics committee Sud Est II. All participants had practiced tennis for at least 10 years. All tests were completed at the same time of day to account for circadian variation (Drust et al., 2005). Participants avoided exhaustive exercise in the 48-h prior to the testing session and maintained usual dietary habits. They were required to eat properly 2–3 h before the test to avoid hypoglycaemia.

2.2. Procedures

The study was conducted on an indoor tennis court (24 m long by 11 m wide). A 15 min standardized warm-up was performed by each player before the testing session. It consisted of 4 min running, 3 min serve on both sides and 8 min forehand drive rallies against an opponent, and a ball machine. Isometric maximal voluntary contractions (IMVC) and skill tests were operated before and after a fatiguing intermittent exercise composed of four sets of intense tennis strokes. These three sessions (i.e IMVC, skill test, fatiguing exercise) lasted respectively 5 min, 7 min and 40 min. Maximal isometric force, EMG level, rating of perceived exertion (RPE), blood lactate concentration ([La]), heart rate (HR) and performance indices were measured during the protocol as depicted in Fig. 1.

2.2.1. Isometric maximal voluntary contraction

Participants were asked to perform three IMVC tests (Table 1) (Chopp et al., 2010; Konrad, 2005) against a strain gauge dynamometer (Ergometer, Globus, Codogne, Italy) separated by 90 s rest. Players performed two trials and were instructed to reach peak force as rapidly as possible. Each IMVC test was performed for 5 s with a rapid increase of contraction over 1 s, a sustained maximum for 3 s, and a gradual release over the final second (Boettcher et al., 2008). All isometric tests were conducted while sitting on a chair and participants were strictly controlled and instructed to maintain the required position. The positions and length of attachment were standardised. Maximal force was recorded for each IMVC and the average of both trials was used for the data analysis. Players were strongly encouraged to perform maximally.

2.2.2. Tennis skill test

Participants were instructed to "serve first serves flat and down the T" at match pace. The players served two sets of six balls on each side of the court with 60 s rest between sets. Forehand assessment required participants to hit three sets of ten successive crosscourt forehand drives in the deuce diagonal against a ball machine (Airmatic 104, Pop-Lob, France) and with 90 s rest between sets. The players were requested to return balls maximally at their own style (avoiding sliced forehand) and at match pace. Tennis balls were thrown with a frequency of 0.3 Hz by the ball machine located on the opposite side, 1 m behind the baseline of the tennis court. The balls landed 1.5 m from the singles sideline and at a depth the midpoint between the baseline and service line. The ball machine was used to ensure protocol standardization and repeatability (ball speed and placement). The principal markers of performance, i.e. ball velocity, stroke accuracy and consistency, were measured (Vergauwen et al., 1998). Peak ball velocity was measured in real time using a radar gun (SR3600, Sports-radar, Homosassa, FL, USA), which was positioned approximately 2 m behind the player and at a height equal to the center of the racket head at the point of ball contact. Direct feedback of velocities was provided to encourage maximal effort. The accuracy and consistency scores for both serve and crosscourt forehand drives were determined by counting the number of times the ball landed within the designated target perimeter (Fig. 2). Accuracy assessment has been performed during the test and controlled retrospectively from video recordings (JVC, Ottawa, Ontario). Target position and dimensions were designed considering preliminary trials, similar methodologies and available resources, and through discussion with players and coaches.

Shots landing within the court perimeter and target areas were ranked according to a 1, 2, 3, 4 scoring system (Fig. 2). Balls failing to pass over the net or landing outside the perimeter of the target received a 0 score. An accuracy index (sum of coefficient values/total number of strokes) and consistency (number of balls landing within the target areas/total number of strokes) were calculated for each tennis skill test and both kinds of strokes.

2.2.3. Fatiguing intermittent exercise

Players performed an intermittent exercise consisting of 12 repetitions of [one serve followed by eight crosscourt forehand drives]. Each repetition lasts about 20 s and alternated with 20 s