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A Comparison of Wrist Angular Kinematics and Forearm EMG Data for an Elite, Intermediate and Novice Standard Tennis Player Performing a One-handed Backhand Groundstroke

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Abstract. Wrist angular kinematics (flexion/extension) and electromyography (EMG) data of a one-handed tennis backhand groundstroke were compared for an elite, intermediate and novice standard tennis player. For this purpose, synchronisation of the data with respect to ball impact time was achieved by a system of wireless and wired triggers and receivers. All three players maintained wrist extension for the 0.6 second period centred on ball impact. The elite and intermediate player struck the ball with the wrist extended by an average of 10^o from neutral alignment whilst moving towards flexion. After ball impact the wrist moved back towards and further into extension. The novice player was characterised by fluctuations in the wrist flexion/extension angle prior to ball impact with the wrist extended on average by 30^o from neutral alignment at impact. The wrist of the novice palyer moved back towards and further into extension after ball impact, although less than for intermediate and elite players. For the elite player, peak EMG levels for the wrist flexors and extensors were reached consistently 0.05-0.1 seconds prior to ball impact. Wrist flexor EMG levels for the intermediate and novice players peaked on average 0.02 seconds after ball impact and extensor EMG levels peaked at ball impact. For the novice player, both flexor and extensor EMG data exhibited fluctuations consistent with the wrist kinematics data. Previously cited conditions that predispose a novice player to injury were not observed in this study. Given current injury mechanism theories, the data from this study suggests that the susceptibility of a player to tennis elbow injury cannot be established by generic skill level alone. Tennis players need to analysed as individuals.

Keywords: backhand, tennis, elite, intermediate, novice, wrist kinematics, EMG.

1. Introduction

Studies have demonstrated that muscle damage and soreness are greater after exercise that involves eccentric contractions [1,2] and that repetitive wrist movement may predispose an athlete to injury [3]. It is argued that conditions exist for novice players that assist the eccentric contraction of wrist extensor muscles at ball impact during a one-handed tennis backhand groundstroke [4,5]. Additionally, if the stroke is performed with the wrist flexed, the extensor muscle tendons may be over-stretched and exposed to higher loads [4]. Roetert et al. [6] suggest that 40% to 50% of recreational tennis players will be affected by ‘tennis elbow’ injury at some stage characterised by localised pain at the lateral epicondyle of the elbow where the wrist extensor muscle tendons originate from [6]. It is generally acknowledged that elite tennis players do not suffer from this condition, despite their frequency and intensity of play [4]. The prevalence of tennis elbow among the population of recreational tennis players has been attributed to poorly performed one-handed tennis backhand groundstrokes [7,8]. On the basis of wrist kinematics and electromyography (EMG) data, novice players are more likely to rely on wrist motion to perform this stroke [4].

Blackwell and Cole [4] found that elite players struck the tennis ball with their wrists extended by an average of 23^o from neutral alignment; moreover, their wrists were moving further into extension at impact. In contrast, novice players struck the ball with their wrists flexed on average by 13^o whilst moving their

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wrists further into flexion. Riek et al. [9] used experimental results as input to a computer simulation model. In agreement with the trend reported by Blackwell and Cole [4] the advanced group reached a minimum extension angle of 10^{o} approximately 0.1 seconds before impact and then moved their wrists further into extension. The model predicted that the novice group began movement toward wrist flexion from a position of wrist extension well before ball impact and reached a peak wrist flexion angle of approximately 10^{o} around 0.1 seconds before ball impact. Shortly after impact, the wrists of the novice were forced into flexion in agreement with the experimental results of Blackwell and Cole [4], before extending once more.

EMG data have been collected and used as an indicator of forearm muscle activation level [4,10,11,12]. Surface EMG techniques can only be used for the examination of superficial muscles. For the forearm especially, due to the relatively small width of the muscles, their proximity to each other and the large conduction volume, there is difficulty in isolating the EMG signals from specific muscles. However, studies have demonstrated that for wrist movement, the flexors and extensors work together as synergists [12]. Blackwell and Cole [4] found that for the 0.5 seconds prior to ball/racket impact, wrist extensor EMGs showed similar levels of activity for elite and novice performers but that for the 0.5 seconds after ball/racket impact elite players displayed greater EMG levels consistent with wrist extension. High levels of muscular activity in elite players may function to maintain grip stability with the wrist in a position of extension [10]. The computer simulation model of Riek et al. [9] predicted that peak activation of the wrist extensor muscle would occur approximately 0.1 seconds prior to ball impact for a novice player in contrast to the elite player with an extensor muscle activation-time history peaking at ball impact. The low level of muscle activation at ball impact was cited as a contributing factor to repetitive microtrauma leading to injury in novice tennis players.

Various methodologies have been employed by researchers to collect kinematic and EMG data of tennis players and synchronise the two. Giangarra *et al.* [10] post-synchronised data from sixteen-millimeter cameras operating at 200 frames per second with EMG data from indwelling electrodes sampled at 2500 Hz by placing marks on the film and EMG data electronically. Bauer and Murray [11] studied the EMG and racket acceleration data of injured and uninjured tennis players performing volleys. A data logger worn about the player's waist was used to collect and store all sensor data at 1000 Hz. Wire leads from three sets of surface EMG electrodes and the cable from a uni-axial accelerometer mounted on the racket frame were connected to the data logger. Data was synchronised based on ball impact as determined from the accelerometer signal. Chow *et al.* [12] placed a microphone near a ball machine located behind the baseline for the synchronization of all recording systems. The sound from a projected ball activated a synchronisation unit. The output signal from the synchronisation unit was sent to the video (a white square mark appeared on the video images), force platform, and EMG recording systems.

In this study we looked to apply similar methodologies and quantify differences in the magnitudes and timings of wrist flexion/extension angles and forearm flexor and extensor EMG data for three tennis players performing one-handed backhand groundstrokes. Specifically, we aimed to examine how the aforementioned variables may change from an elite to an intermediate and through to a novice standard tennis player and possible implications for injury to a particular skill group.

2. Methods

2.1. Performance data collection

Data from three right-handed, healthy male tennis players with no history of elbow pain were collected: an elite tennis player with a world ranking in doubles (aged 22, mass 75.5 kg, height 1.86 m); an intermediate club level player who participates once or twice a week (aged 19, mass 79.7 kg, height 1.98 m); and a novice tennis player who claimed to play five times a year on average (aged 36, mass 97.8 kg, height 1.90 m). Testing procedures were explained to all players in accordance with approved institution ethical guidelines and informed consent was given. After a thorough warm-up, kinematic and EMG data of the players performing one-handed backhand groundstrokes were collected. All trials were conducted in an indoor gymnasium with a surface deemed by results of a pilot study to be comparable in terms of ball bounce and velocity characteristics to an Astroturf® tennis court.

Kinematic data

The kinematics of the three players performing one-handed backhand groundstrokes were automatically tracked using a Vicon automatic motion tracking system. Twelve infrared strobe cameras sampling at a frequency of 250 Hz were used to calibrate a performance volume of approximately 2.5 m^3 and then track the motion of markers attached to the players and tennis racket as they performed one-handed backhand groundstrokes. For all trials, a Head LM 8 tennis racket frame strung with synthetic gut at 56 lbs of tension was used. Reflective markers, 25 mm in diameter, were placed in pairs on the medial and lateral epicondyles of the elbow and wrist so that the line connecting the two markers went through the joint centres of rotation. Two markers were also placed on the carpal bones below the index and little finger to establish the orientation of the hand relative to the forearm (Fig. 1).

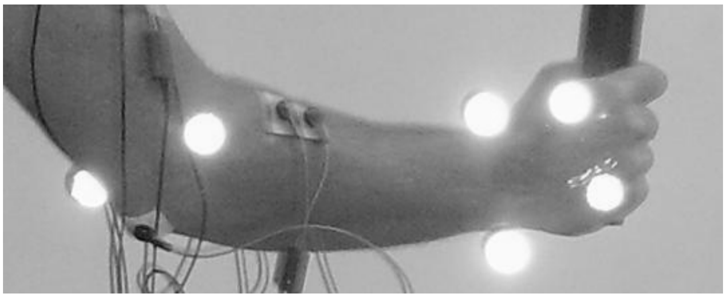

Fig. 1: The reflective marker and EMG electrode placements on the elbow, wrist and hand.

Raw kinematic data from the Vicon motion analysis was fitted using quintic splines [13] to smooth possible errors in the data. The closeness of fit at each point was based on the difference between the raw values and the average value from the two adjacent times [14]. 3D reference frames were specified for the forearm and hand segments and the Euler angles defining the flexion/extension and radial/ulnar deviation angles of the hand relative to the forearm were calculated.

For each player tested, new Pro Penn Titanium tennis balls were fired from a Bola ball cannon and the player was asked to perform one-handed groundstrokes, without intentionally imparting spin, as he would during a baseline rally with no instruction given to the form of the stroke. Two Phantom v4.1 high-speed digital cameras (Vision Research Inc.) operating at 2500 Hz were used to calculate ball velocities and note the location of ball impact on the stringbed. The high-speed cameras were genlocked with the master camera directly behind the tennis player and the slave approximately in line with the longitudinal axis of the tennis racket at the point of ball impact (Fig. 2). The trigger was chosen so that ball impact occurred approximately in the middle of the data capture.

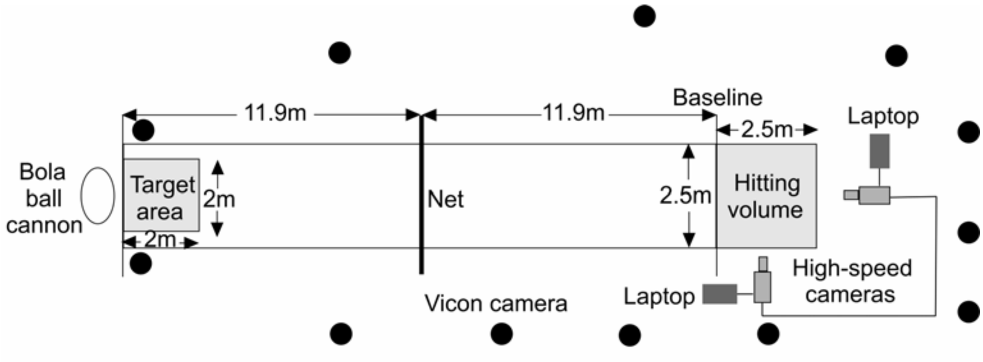

Fig. 2: The equipment set-up for analysing one-handed backhand groundstrokes.

EMG

A Biovision EMG system was used for the analysis of wrist flexor and extensor muscle activity during each trial. Two pairs of surface electrodes were placed over the flexor carpi radialis and extensor carpi radialis brevis (Fig. 1) muscles. If necessary, the player's skin was shaved in the area of electrode placement and the surface of the skin was treated with alcohol to reduce interelectrode resistance before the electrodes were applied with conducting gel. The system wires and amplifiers were taped to the player's skin to minimise any movement and hence reduce noise. The sampling frequency was set to 1000 Hz and an electrical gain of ± 5 V was used. The collected EMG data were full wave rectified and then filtered using a fourth order Butterworth filter with 6 Hz cut-off frequency to obtain linear envelopes. For each player, the resulting envelopes across trials were normalised with respect to the maximum EMG level measured during that session. Flexor and extensor muscles for each player were treated independently.

2.2. Synchronisation of data

Synchronisation of all the equipment used during performance data collection was achieved using a system of triggers and receivers. A wireless trigger was used to send a radio signal to the receiving trigger box and the Vicon data station. An analogue channel was set up in the Vicon software to receive a square pulse to allow post-synchronisation. The trigger box receiving the signal from the wireless button directly triggered the EMG and high-speed camera systems (Fig. 3).

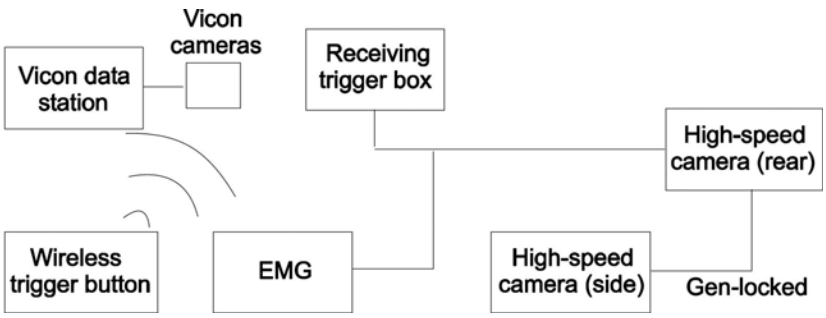

Fig. 3: The synchronisation process for equipment used to collect kinematic and EMG data.

2.3. Data reduction

Players were asked to perform approximately twenty one-handed backhand groundstrokes. At no point did any of the players state that they felt fatigued from the testing protocol. A trial was considered successful if all data was captured correctly and the ball landed in the designated target area. Three successful trials for each player were selected for further analysis. To minimise the effect of racket recoil due to the ball impact and for control across players, trials were only selected where the ball impacted at the geometric stringbed centre. The wrist flexion/extension angles and normalised flexor and extensor EMG time-histories were calculated for a 0.6 second period centred on initial ball impact.

3. Results and Discussion

Wrist flexion/extension angles are shown for three players where flexion was defined as a positive joint movement from neutral alignment (0^o when the hand was flat). Gripping the racket created an extension angle of approximately 20^o. Initial ball impact with the stringbed was at time zero (Fig. 4).

Normalised wrist flexor and extensor EMG-time histories are shown for three players where initial ball impact with the stringbed was at time zero (Fig. 5). The same colour indicates the wrist flexor and extensor muscle groups for the same trial.

All three players in this study maintained wrist extension for the 0.6 second period centred on ball impact (Fig. 4). This suggests that adverse loading as a result of over-stretching the wrist extensor muscle tendons is not likely. The elite player struck the ball with the wrist extended by an average of 10^o whilst moving towards flexion. Immediately after ball impact the wrist moved back towards and further into extension. For one of the three trials, there was a positive wrist angular velocity in the flexion direction immediately after ball impact which has been linked in the past to high eccentric loading of the extensor muscle tendons [4]. This has been proposed as a characteristic of a novice performer prone to injury [4,5]. The intermediate player exhibited similar wrist flexion/extension angle-time histories to the elite player although there was less variation between the three selected trials for the intermediate player. In addition, the largest range of extension angle of 30^o was observed for the intermediate player. It has been suggested that novice players use more wrist motion than more skilled performers [3] and therefore rely more on the wrist extensors as a power source. This was clearly not the case for the three players in this study where, on the basis of wrist flexion/extension angle-time histories, the intermediate player relied most on the wrist extensors to generate power. The novice player was characterised by fluctuations in the wrist flexion/extension angle prior to ball impact with the wrist extended consistently by 30^o at ball impact. The wrist then moved back towards and further into extension immediately after ball impact, in contrast to the results for novice players in a previous study [4], although less than for the intermediate and elite players.

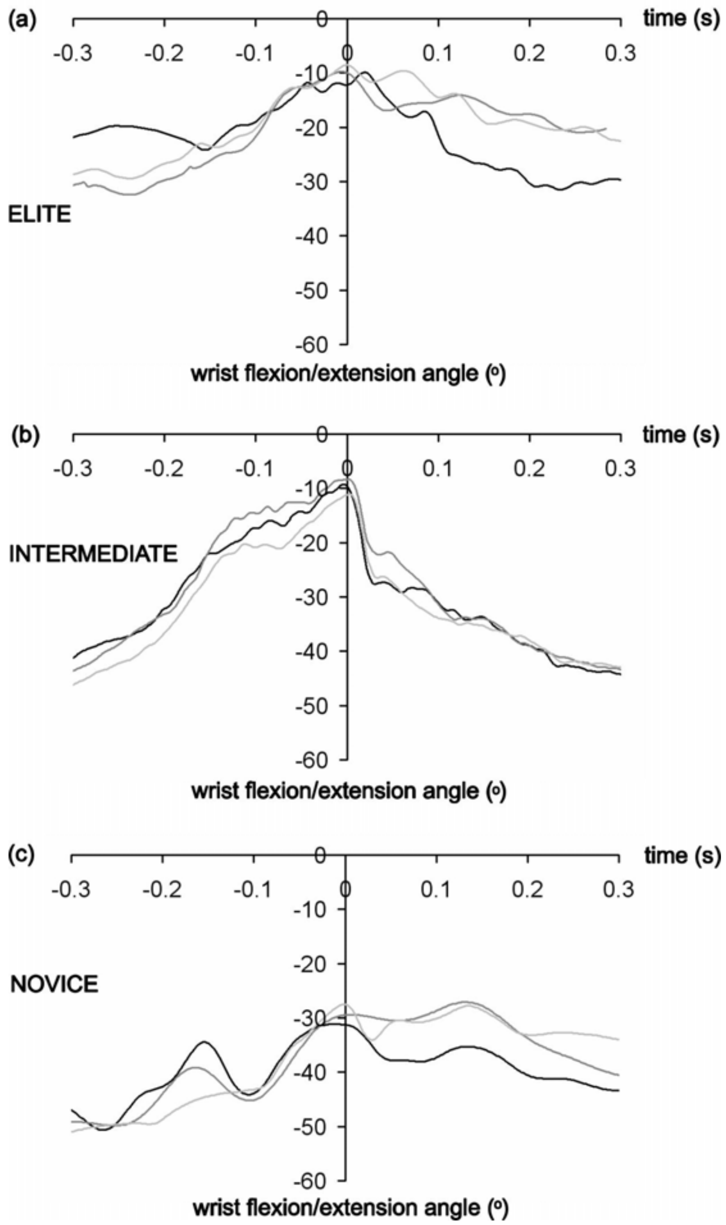

Fig. 4: Wrist flexion/extension angles for three trials by an (a) elite, (b) intermediate and (c) novice standard tennis player performing a one-handed backhand groundstroke.

There are a number of possible reasons why the results from this study, particularly for the novice player differ from that of previous work [e.g. 4], the most obvious being that different players were used. It would appear that it is not possible to classify skill levels by observing the wrist kinematics alone. Thorax, shoulder and elbow joint kinematics are undoubtedly important in tennis since the one-handed backhand groundstroke requires coordination of multiple body parts to orientate the racket correctly for ball impact [6]. In the present study, trials were studied for which the ball impacted only at the geometric stringbed centre. The number of off-centre hits (in brackets) during the performance data collection from approximately twenty trials was greater for the intermediate (6) and again for the novice (10) compared to the elite (3) player. This trend was also noted by Blackwell and Cole [4] although it was not stated where the ball impacted the stringbed for the trials analysed in that study. It is likely that a severe off-centre impact will force the wrist into flexion to some extent. Distinct changes in wrist kinematics between players of different skill levels may occur for off-centre impacts which have been identified as a possible cause of injury [15]. Additionally, in a dynamic sport such as tennis where techniques evolve as players become better conditioned, the thirteen years between studies may also be a contributing factor. All players in this study were athletic, strong and therefore the forearm musculature for all players was perhaps better able to cope with the force from ball impact inducing wrist flexion.

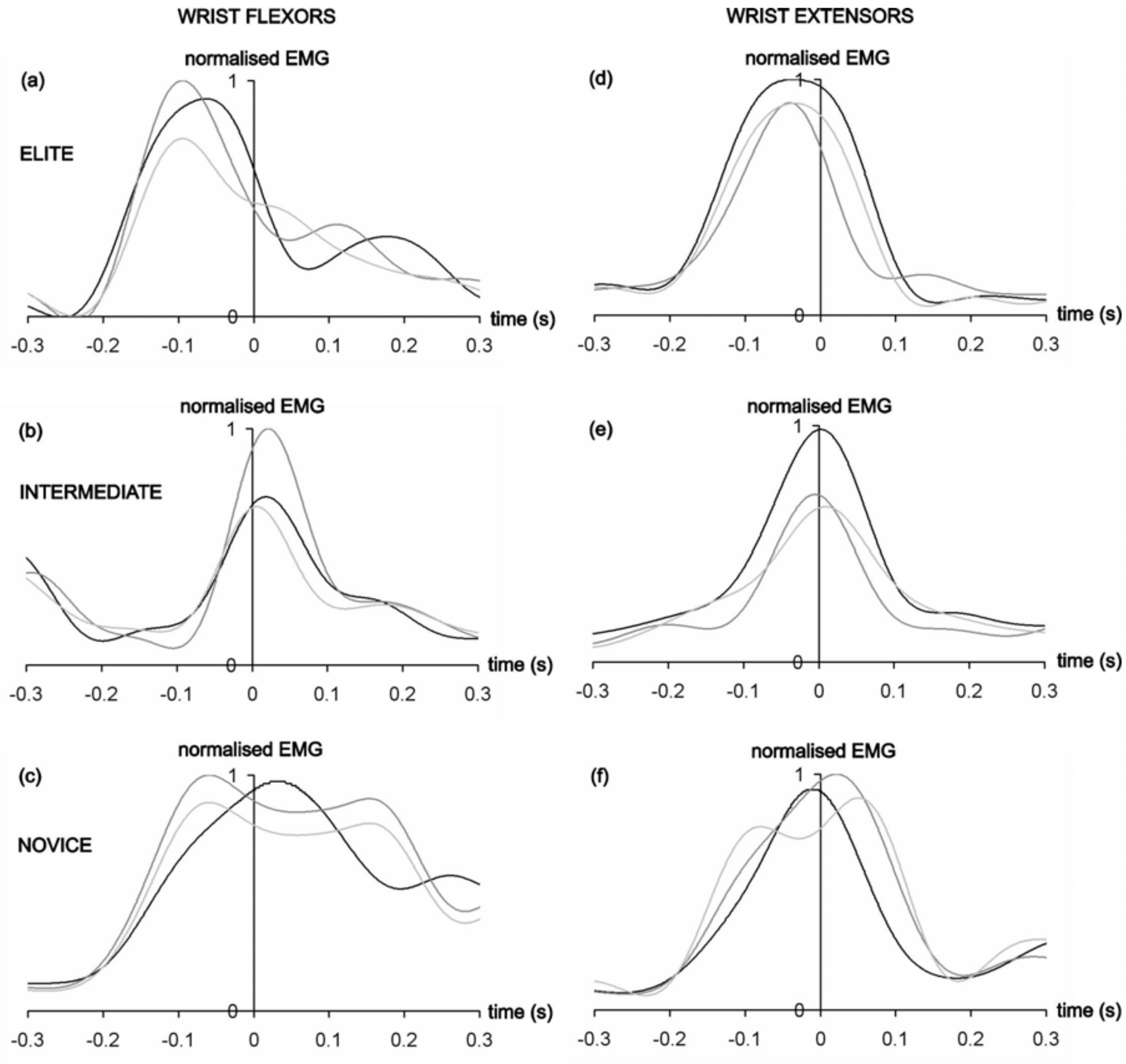

Fig. 5: Normalised wrist flexor /extensor EMG data for three trials by an (a)/(d) elite, (b)/(e) intermediate and (c)/(f) novice standard tennis player performing a one-handed backhand groundstroke.

For all players and trials (Fig. 5) peaks in wrist flexor and extensor EMG were found in the 0.6 second time period centred on ball impact, consistent with increased grip forces during this period. For the elite player, peak EMG levels for the wrist flexors and extensors were reached consistently 0.05-0.1 seconds prior to ball impact. Paradoxically, a study by Bauer [11] found that wrist extensor muscles were activated earlier for injured as opposed to uninjured players when the prevalence of tennis elbow in elite players is reported to be lower [4]. Wrist flexor EMG levels for the intermediate player peaked on average 0.02 seconds after ball impact and extensor EMG levels peaked at ball impact. In terms of normalised peak EMG level, greatest variability was found for the intermediate player. For the novice player, both flexor and extensor EMG-time histories exhibited high but fluctuating levels peaking at ball impact, consistent with the wrist kinematics data. The EMG data in this study showed the opposite trends to those predicted by Riek et al. [9] for elite and novice players. Combined with the wrist kinematics data, it would appear that not all players of a similar skill level exhibit the same forearm muscle strategies when performing one-handed tennis backhand groundstrokes.

4. Limitations and future work

We have assumed that the trials selected for the elite, intermediate and novice standard tennis player were typical one-handed backhand groundstrokes since no instructions were given to the player other than to return the ball into a designated target. Only trials where the ball impacted at the geometric stringbed centre were selected but on the basis of the number of off-centre hits for each skill level, analysing these trials as well in the future would be prudent to examine intra-subject variability. Collecting more data from additional players within each skill group, from females as well as males and over a broader age range would help to increase understanding of how the stroke differs across the range of skill levels. Whilst raising ethical issues, it would be of interest to collect data on injured players within each skill category. Due to its prominence in the literature, this study has focussed on wrist kinematics (specifically flexion/extension). Visually, the strokes performed by the three players appeared markedly different and therefore a quantitative comparison of trunk, shoulder and elbow kinematics could be undertaken in future. The limitations of collecting EMG data using surface electrodes to estimate muscle activation timings are well documented in the literature [16]. Tendon loadings could not be calculated directly from the data collected in this study and therefore any discussion regarding potential injury mechanisms must be viewed as speculative. Non-invasive techniques in the future, such as computer simulation, could advance knowledge as to the influence of player kinematics (technique) on tennis elbow injury.

5. Conclusions

On the basis of results presented in this paper and current injury mechanism theories, it is not possible to characterise a player as more susceptible to injury based on their skill level classification alone. Wrist kinematics showed some similarities across the skill levels with all player's wrists being extended throughout the stroke. In contrast to previous studies, it would appear that the conditions proposed for the novice player to facilitate microtrauma of the wrist extensor muscle tendons were not evident. In fact, only the elite player displayed some of the characteristics suggested symptomatic of a tennis player prone to injury such as decreasing activation of the wrist extensor muscles at ball impact. The susceptibility of a player to tennis elbow injury cannot be established by generic skill level alone and players need to analysed as individuals. Future work should investigate additional factors such as player strength and the wrist kinematic strategies used by different players to cope with off-centre hits. These impacts may place higher demands on the wrist extensor muscle tendons.

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